1 INTRODUCTION

Let's begin this thesis with a small exercise. Imagine you have to perform three simple tasks. At the beginning of task 1, you are asked to "Close your eyes and try to visualize for your 'mind's eye' as many different examples of *chairs* as you can. Give a short description of each example in terms of form, material and color. You are given three minutes for this task. Ready, set, go…". You almost certainly would not have any trouble in coming up with enough examples to fill this time span. The chair you are sitting on, the lounge chairs you have at home, your grandma's rocking-chair, some well-known design chairs etc. Task 2 is a little more complicated. Here you are asked to "Close your eyes and try to visualize for your 'mind's eye' as many different examples of *kitchen chairs* as you can. Give a short description of each example in terms of form, material and color. You are given three minutes for this task. Ready, set, go…" Unless you are an expert on kitchen chairs, the number of examples you could imagine will almost certainly be lower. Now let's go to the last task. Task 3: "Close your eyes and try to visualize for your 'mind's eye' as many different examples of *kitchen chairs, which fit into a modern, Italian-like kitchen, look elegant and stylish but not fragile, are marketed at young professionals, age 25-40, and cost less than $300.* Give a short description of each example in terms of form, material and color. You are given three minutes for this task. Ready, set, go…" So, how many examples do you think you would be able to come up with?

The tasks in this exercise are not intended to test the capabilities of your memory or mental imagery. They are meant to give you an idea of the kind of problems product designers are facing when designing a new product. Even though they can keep their eyes open, are not limited to three minutes and can

use techniques like sketching and modeling to externalize their thoughts and ideas, the design of a new product which corresponds to a design brief, such as the one used in the last task, is a major challenge.

Somehow, however, designers seem to be able to cope with this, because every year, on cocktail napkins, sketchbooks, drawing boards and computer screens in design offices and companies all over the world, thousands of new product ideas are being born. Carefully nurtured by their creators, some of them are raised into full-grown consumer products, being put into a world that is already cluttered with an enormous amount of existing products. To be noticed by consumers as new and attractive players in such a competitive market, these new products should reflect, in their designs, characteristics regarding function, form or use, that make them stand out from their competitors. At the same time, however, to be recognizable as members of their product class, they have to reflect characteristics regarding the same aspects of function, form and use, that make them blend in with their competitors. How do designers integrate these two apparently contradictory sets of characteristics into the design of one, coherent product form? What role does and can the existing body of products play in this process? And if some light can be shed on these issues, how then can these insights be applied in developing new design techniques and design support tools to assist designers in the generation and development of new products?

These, in short, are the main research questions of this thesis. They were addressed using various methods and means, such as literature reviews, contextual interviews and experimental studies as well as user interface design and software prototyping. The perspective throughout this thesis is that of a designer as an active organizer of design knowledge in a design context, who both effectively and affectingly manipulates a form, using various visual representations, into a solution for the design problem at hand. The importance of existing products in this process was identified through two series of interviews with designers. It was then grounded in theory through a review of the literature on concept formation. Assumptions from this theory were then tested in a design experiment. The results from this experiment initiated the development of a visual database of existing products as a design support tool. The organization of this database was then the subject of a second experiment. Finally, the user

interface of the database was designed and a fully functional prototype was built and evaluated in an educational setting.

1.1 The form-creation phase in the product design process

The research was situated in the domain of product design, focusing on the form-creation phase in the product design process. Designing products within a company involves the development of product ideas, which have resulted from a search for new opportunities, taking the company's strength and weaknesses into account, as well as any opportunities and treats coming from the market. Design methodology, which has as its aim the improvement of design practice through the study of principles, practices and procedures of design (Cross, 1984), has provided several models for staging the product design process (Roozenburg and Eekels, 1995; Pahl and Beitz, 1997). Although different in the grouping of activities that form the different stages in the process, they all reflect a development from abstract to concrete, starting with an analysis resulting in specifications, followed by the translation of these specifications into concepts, the materialization of the concepts into designs, and, finally, the detailed elaboration of these designs into complete plans, describing the realization of these designs.

At a certain moment in this product design process a transition takes place from an abstract functional description, which reflects no decisions regarding a material form at all, into a first conceptual structure expressing a materialized idea. Muller identifies this moment as the beginning of the form-creation phase, 'that starts at the moment that any conceptualization about the material form emerges and ends when a definitive design is established' (Muller, 2001). Thus creating the technical or physical principles on which the existence and functioning of the product is based, is not considered as being a part of the form-creation phase.

Form creation in product design thus involves the generation and development of the product's geometrical and material form. In this phase the internal ideas of the designer are externalized, explored interactively and

represented tentatively in a visual form using a variety of media (McKim, 1980). These visualizations can be sketches, collages, renderings, clay models or computer models, representing design alternatives in different stages in the process, while the corresponding medium is paper, clay, foam or computer code. The process is not solely concentrated on determining the material conditions for the fulfillment of the function of the product, but is also aimed at establishing the product's desired semantic qualities in relationship to its intended use. Muller states therefore the objectives of form creation being twofold (pp. 146):

1 The materialization of *the idea* for the potential functioning of a design as it is laid down in a solution principle, creating a *material utility* value that is specific to the product involved.
2 The materialization of *an idea* about the way of fulfilling the function, creating a *social and cultural utility value* that is not only specific to that product, but goes beyond it and is shared with many other products[1].

For example, in the design of a chair the form-creation phase starts from a minimal three-dimensional scheme, a composition of lines without any substance, that represents a schematic depiction of the product class "chairs". This scheme, which reflects the capacity to support a sitting person, is then materialized in a set of physical properties which communicate its material utility value, the function of sitting, to the user. However, the form of the chair not only denotes this 'primary' function, it also refers to a certain image of the way in which, the environment in which, and the ideas through which this primary function can be fulfilled. Thus the physical properties of the chair also communicate its 'secondary' function, which connote its social and cultural utility value, referring to a specific way of sitting as well as the social context in which this ought to take place. This double objective of form-creation reflects the previously observed dualism between unique and shared design characteristics. While creating a product's form, the designer has to constantly evaluate the implications for the socio-cultural value of any changes in the material value, and vice-versa.

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[1] Italicization by Muller.

1.2 Computer support in the form-creation phase

The development of computer tools to support design activities has traditionally been driven by advances in the computer industry, resulting in faster systems with a high emphasis on processing power. These qualities have made them extremely suitable for tasks which require extensive number-crunching, such as in evaluative and analytical design development as well as in manufacture, providing their users with some very powerful tools for visualization, engineering analysis and production planning. However, in the domain of architectural and industrial design, their use is still mainly restricted to the later phases of the design process, in which the design ideas have already been well-formed. In the early form-creation phase designers still rely on traditional tools such as felt pens, pencils, markers or cutters. These lack processing capabilities but instead score high from the point of view of the designer as a 'performing artist', who puts high demands on his instruments, concerning flexibility and agility, to perform his act, being the creation of a new design (Lakin, 1989).

Tovey (1989), who studied the use of computer-aided design (CAD) for car styling, concluded that the inherent structure of these systems, which is often derived from the included hardware and input devices, tends to constrain the designer from intuitively exploring product forms. Athavankar (1990) monitored industrial designers during their idea generation, reporting them to often launch into some form of quick representation of ideas, thereby effortlessly switching attention from the whole to the detail, and vice-versa, even with incomplete forms. He argues that it is the ambiguity of those incomplete ideas or forms that leads to further exploration and thus contributes the non-popularity of computers in the conceptual phase on the demands made by them on the thinking style of the designer, particularly for conceiving the physical configuration of a design, and the difficulties they impose on the representation of imprecise, vague or ambiguous ideas, thus interrupting a fluid thought process.

Stappers and Hennessey (1999), who made a comparison between the use of CAD systems and the use of informal media, such as beer mats, for making quick and rough sketches, concluded that the latter triumphs over the former when it comes to ease of use, interaction and flexibility. A beer mat doesn't have

a steep learning curve, doesn't take a long time to start-up, affords direct interaction and doesn't trouble its user with any interfering interface elements, such as windows, menus or buttons. An important flaw of CAD systems according to Stappers and Hennessey, is their inability to support the expressiveness of sketching, allowing no vagueness or ambiguity in their representation thus leading to 'dead' designs. Several authors who studied the role of sketching in design have stated, that it is precisely this ambiguity and expressiveness that provides the designer with the necessary 'food for thought' to keep the design process going (Goldschmidt, 1991; Schenk, 1991; Fish and Scrivener, 1990)

Regarding the use of computers for conceptual modeling, Gribnau (1999) states that the current set-up of computers, with a mouse, a keyboard and a monitor, and their associated interfaces, raises considerable barriers for designers to achieve the same degree of freedom as with traditional modeling materials, such as cardboard or clay. For example, the ability to move freely in 3D space using two hands, offering the designer optimal, expressive control over the actual creation of a form, is currently unsupported by computer systems.

Such enumerations make one wonder if computers can be useful at all in the early stages of design. In this thesis it is argued that they can, since their capacities offer unprecedented possibilities for manipulating, comparing, recording, managing, displaying and sharing design representations. However, to open up these potential possibilities, the development of computer tools for design has to be design-driven rather than technology-driven.

1.3 Research perspective

The research in this thesis originated as part of a larger body of research, the IDEATE project (Hennessey, 1992). Initiated in 1990 at the School of Industrial Design Engineering of the Delft University of Technology, it aimed at exploring computer enhancements for the conceptualizing process in industrial design. Central to the philosophy of the IDEATE project was the development of a thorough and shared understanding of the context of design through studying the methods, techniques and tools of designers in their natural design environments.

Based on this understanding several concepts for new and innovative computer tools were developed.

In 1999 the IDEATE project was embedded in the context of the ID-StudioLab, which is made up of a group of researchers, designers and students in the department of Industrial Design (Hekkert et al., 1999). The ID-StudioLab aims at integrating multidisciplinary knowledge on users, technology, and the product usage context. Since this context is social, cultural as well as technological, the full experience of the user is taken into account, involving perceptual-motor and cognitive skills as well as emotional reactions.

Essential to the lab's research approach is the building of working prototypes that are rich both in design quality and user experience. Some of these prototypes express a product vision, integrating in their design research issues from different perspectives, thus embodying possible solutions for these issues as well as their mutual relationships. Other prototypes with design variables act as test platforms and are tested in realistic settings, in an iterative 'research through design' cycle. Results from user testing leads to design knowledge, which again feeds the further refinement of existing research issues or the identification of new ones. All prototypes should have a high degree of interaction and realism, which implicitly encourages their users to get actively engaged with them, requesting an intense level of active involvement. This involvement is considered essential, because through it both the user and the researcher enrich their understanding of the situation or the product at hand.

1.4 Overview of the thesis

Chapter 2 describes the context of the research and its motives through two series of interviews with designers, identifying a set of considerations for designing a computer environment to support creative ideation. A product vision integrating these considerations into a physical design is described. From this design a number of research directions are deduced, including the central topic of this thesis. The chapter ends by formulating the main research questions and stating their relevance.

In Chapter 3 a framework to describe the role of existing products in the generation and development of new form concepts is constructed through a theoretical exposé on the formation of new ideas. The construct of a product type is introduced as a means to describe and organize existing products in terms of the product-specific design knowledge they represent. By grouping together products on their shared typicality regarding function, form or meaning, product types get formed in which design knowledge is organized on a problem-independent level. This specific character then affords the 'displacement' of this knowledge to new design situations, to identify relations between forms, materials and functions of products, or between forms, materials and socially and culturally determined uses of products.

Chapter 4 brings the theoretical framework of the previous chapter into the realm of an actual design situation. The effects of providing designers with precedent designs as reference material while working on a design task, are studied in a design experiment. In this experiment two ways of organizing the provided precedents, random vs. typological, are compared. The results of the experiment show that the typological organization indeed seems to afford the integration of design knowledge, as well as breaking away by the designers of their pre-conceived ideas regarding the product to be designed. At the end of the chapter the concept of a visual database, containing typologically organized design precedents, is introduced as a possible design support tool.

The organization of such a database is the topic of Chapter 5. By designing an organizing task as a possible procedure to enter precedents into the visual database, a connection between design methodology and interaction design is made. In the task, which involves arranging, grouping and naming products, the organization of design knowledge is thus not pre-determined, but made by designers themselves. Each of the three sub-tasks is discussed in detail, supplemented by general observations and findings from a study in which they were used. In this study two groups of design students performed the task, with one group receiving contextual information in the form of a design brief. Analyzing the results focused mainly on identifying and describing overall patterns, concentrating on global observations and impressions rather than individual characteristics. The results of the study demonstrate the feasibility of a

database which may have a starting set of example products, but is essentially built up, organized and extended by a designer himself.

Chapter 6 then describes the actual design of the proposed visual database. A review of design support systems, which make use of existing products, is first presented, followed by listing a number of design criteria, which guided the development of the user interface of the database. Taking these criteria into account, a new method of interacting with large information structures, called MDS-Interactive, was developed. A number of prototypes were built to demonstrate and evaluate the new method. With a few modifications MDS-Interactive then provided the basis for the visual database, which was named ProductWorld. The design of ProductWorld is presented, followed by an evaluation of its use in an educational setting.

Finally Chapter 7 rounds off the thesis by discussing possible applications and implications of the research results, as well as opportunities for further, more detailed research in the areas of design education, design practice, design methodology and design support systems.

2 A CONTEXTUAL INQUIRY OF THE FORM-CREATION PHASE

In this chapter the topic of the research and the research questions arising from it, are established through two series of interviews with designers at their work place. The reason for conducting these two studies is the previous observation that the current computer tools fall short in supporting designers in the form-creation phase of the product design process. To identify the requirements such tools must fulfill to be successful, a better understanding of the current idea generation and development process, with it's characteristic techniques, tools and physical environment, was needed. This was acquired using the method of Contextual Inquiry, a synthesis of ethnographic, field research, and participatory design techniques that provide designers of computer supported tools with grounded and detailed knowledge of user work as a basis for their designs.

Section 2.1 describes the first study, in which creative professionals from various disciplines other than industrial design, were questioned in their own design studios or offices. The transcripts from these interviews, together with observations, were interpreted into five different categories, to narrow the focus for the second study, which is described in section 2.2. This time only professional industrial designers were interviewed, concentrating more closely on the actual creation of design concepts. Several research projects have sprung from the results of this study, the results of which are briefly presented in section 2.3. Finally, in section 2.4 the potential of precedent designs as a source of design knowledge in the generation and development of new designs is established as the central topic for the rest of this thesis.

2.1 Study 1A: Creative Professionals

The identification of the failure of computer systems in meeting the requirements of the form-creation phase, has led to the notion that to build such systems successfully, a better understanding of the traditional working environment, habits and tools, as well as the cognitive functions involved in conceptual design tasks, is required (Fish and Scrivener, 1990). An increasing number of studies can be found which try to address, from different perspectives, one or more of these aspects (Athavankar, 1990; Ballay, 1987; Christiaans and Dorst, 1992, Goldschmidt, 1991; Ullman et al. 1990; Schenk, 1991).

These studies, however, were almost exclusively carefully designed experiments, usually in a laboratory-like environment, aimed at eliciting very specific and detailed knowledge. How useful these set-ups may be for these specific purposes, they do not provide the necessary information for the building of supportive tools, mainly because of the difficulties in applying the findings from them to the design of real world systems (Wixon et al., 1990). The structure by the designer of his environment, the use of his techniques and skills, the organization and handling of his tools; these form the elements of the context in which new designs are being created and developed. Any computer system has to fit in this context as smoothly as possible if it is to be really embraced by designers. This implies that a thorough understanding of this context has to be established first by deriving the required information from the context itself.

It was decided to first look at the broader spectrum of creative professionals in other domains than industrial design, before limiting ourselves to our group of end-users, being just industrial designers. Thus six interviews were conducted with creative professionals at their personal work environment.

Objectives

The objectives of this first study were:

- To acquire a basic understanding of the context of the form-creation phase in various non-industrial design domains.
- To map the physical environment in which form-creation takes place.

- To identify the methods and techniques used to generate ideas in the form-creation phase.
- To identify the conventional tools used in the form-creation phase, to understand the different characteristics associated with each tool, and any customization of them.

Method

Traditionally, designers obtain their knowledge about future users through methods such as questionnaires, focus groups, and design reviews. While such methods provide designers with useful demographic and opinion data, they rarely provide data that is at a sufficient level of detail or that is adequately grounded in the user's work, thus failing in providing relevant information for a number of necessary elements of product development. Out of dissatisfaction with these traditional, predictive research methods, the method of Contextual Inquiry has been developed (Wixon et al., 1990, Beyer and Holzblatt, 1998), as part of a larger design approach called Contextual Design. It is basically a structured field interviewing method, based on a few core principles that differentiate this method from plain, journalistic interviewing. These principles will now be discussed in light of this study:

- **The principle of context**

  Actually observing and absorbing the whole context in which a new tool or system will be used, is considered essential. The interviews therefore took place at the user's workplace. During the interview, the interviewer or an extra observer tries to record what the user does and says, the interpretation of this, disruptions and workarounds in the user's work, and how the user utilizes different tools to support the work. A video camera was used to tape the interview for later transcription.

- **The principle of partnership**

  The user is seen as a partner in the design. Therefore it is important to recognize the user as an expert of his personal work situation. Interviewing during a contextual inquiry study usually does therefore not include set, broadly worded

questions. Instead, the partnership between the interviewer and interviewee is used to create a dialogue, one where the interviewer can not only determine the user's opinions and experiences, but also his motivations and context.

Beyer and Holzblatt advocate a master/apprentice model, in which the interviewee teaches a skill to the interviewer, by doing the work and talking about it while working. However appropriate this model might be task-oriented domains, such as office work, it was felt that it is not suitable for a more experience-oriented domain as industrial design. Design is not a linear, step-by-step process, that proceeds every time in the same order. It is usually a private activity, demanding a concentrated effort, which can not be performed 'on demand' under the presence of an outsider. We therefore positioned ourselves as researchers with a design background, knowledgeable as well as curious about the characteristics of designing in the form-creation phase.

- **The principle of focus**

  During the interview, the interviewer should be constantly aware of his focus. The focus is a combination of his assumptions, beliefs, and concerns of a particular situation, defining the point of view of the interviewer. All that is seen or heard is filtered through this focus and the return of the inquiry therefore heavily depend on 'keeping focused'. It has to be dynamic and flexible, the interviewer has to be able to expand and shift his focus while doing the inquiry. It should give the interviewer a way to keep the conversation on the essential topics without taking control entirely back from the interviewee. Being clear about one's interests also makes forming a partnership with the interviewee easier. Showing that one has prepared himself thoroughly and already acquired some knowledge on the topics to be discussed, gives a professional impression.

- **The principle of interpretation**

  After gathering the data, meaning has to be assigned to it through interpretation. Design in human-computer interaction is usually teamwork, whereas only one or two person(s) are actually doing the interview. The goal of an interpretation session is therefore to build a shared understanding within the design team of the users and how they work. This is achieved by conducting an open discussion, in

which the interviewer walks through an interview, while the other team members listen, asks questions, make comments etc. The results of such a session, depending on the focus, can be e.g. work models, describing the flow of work and the sequence of tasks; cultural models, describing the relationships between people or physical models, describing the constraints of the physical environment.

Procedure

Based on these four principles, the actual contextual inquiry proceeded according to the following steps:

1 Fixing the focus.

It was decided to look first at the form-creation phase from a broad perspective, rather than focusing immediately on the domain of product design. It was hoped that this would have a positive effect in two ways:

- A better grasp of the common factors underlying the form-creation phase in any design domain would be acquired, which would make a more meaningful interpretation of the data of the second study possible.
- Coming from an industrial design environment ourselves, our own preconceived ideas regarding the context and process of creation form concepts might influence our perspective during the study. By looking first with a broader focus, we hoped we could avoid the effect of being perceptive for only those things which would confirm these ideas. In other words, instead of 'capturing what we expected to capture', we hoped to be surprised with new ideas and perspectives.

2 Identifying of the end-users of the system.

Having set the focus, the domain was limited to those creative professionals, that are involved in creating and developing physical, material forms. Domains, such as literature, poetry or music are therefore not included in this study.

3 Forming a group of users to interview.

The selected group should be reflect the breadth as well as the depth of the end-user group as much as possible. From the local Yellow Pages, six subjects from various creative and craft-oriented backgrounds, were selected. They included a

fashion designer, a potter, a photographer, a jewelry designer, a furniture designer and a sculptor. Diversity was achieved by selecting subjects from various educational backgrounds.

4 Conducting the interviews.

The interviews were conducted by two researchers (Raghu Kolli and the author), one of them acting as the interviewer while the other took notes, made observations and operated the video camera. Each interview started with a short introduction, in which we introduced ourselves and our focus. After this, the rules for the interview were made clear and the actual inquiry was started. Throughout the rest of the interview we used a general outline (Appendix A), which served mainly as a memory-aid. The subjects were urged to recapitulate the form-creation phase by showing and talking about works they had produced. We tried to let them lead the conversation as much as possible, encouraging them to show their jottings, initial sketches, quick mock-ups, favorite tools etc. We also asked them to guide us through their workplace and to demonstrate any special techniques or tools, used by them during form-creation. Each interview took about 60-90 minutes and was recorded on video-tapes, which were transcribed later on. Additional notes were taken to record personal impressions. Finally, the interview was wrapped up with a short summary, containing it's essential elements.

5 Conducting the interpretation session.

First the videos of the interviews were transcribed. Both researchers then divided the transcripts into smaller segments, each comprising a relevant statement, a new topic or an important observation. Whenever there was disagreement between the researchers regarding the place of a segmentation, the situation was discussed and a mutual agreement was made. Finally, all segments were clustered into larger groups, resulting in six areas of interest.

Results

For each of the identified areas of interest, all statements, observations and remarks were interpreted and processed into more general findings.

Background and experience

Remarks and observations providing general information on the subjects' educational careers and working experience.

- All subjects are independent entrepreneurs, except for the photographer, who works in a team with an art director for publication projects.
- The fashion designer has less than two years of experience, while the others are well settled in their profession with five to fifteen years of experience.
- Only the fashion designer graduated from a formal design school. The other subjects started as apprentices or are self-taught.

Projects and clients

Remarks and observations providing information on the kind of projects, the kind and number of clients and the contacts between clients and interviewees.

- All interviewees always work for a client, except for the sculptor who also makes works for his own exhibitions.
- The client, who may either be an individual or an organization, usually has only a vague idea when he approaches the interviewee for a product or project. A better understanding of the client's requirements and wishes is acquired through a face-to-face discussion. Some interviewees emphatically stated that they will not accept a project without such personal contact, which gives them valuable information about the client's personality, style, preferences etc. In some cases samples of previous works are shown so that the client might express his ideas more clearly. If needed, visits are made to the client's place to get a better understanding of possible location constraints.
- Sketches, mock-ups or sample parts are made specifically for intermediate presentation of the concept to the clients. The potter skips this phase, but makes up for it before, by showing extensive examples from her collection or after, by making extra pot so that the client may choose. The quality of the mock-ups depends on the client and the budget involved. The interviewees are cautious against showing too much detail on their sketches or mock-ups. It is preferable that they remain 'rough', but also represent a certain 'firmness' so that the client is not tempted to 'change everything' during the discussion.
- The duration of a project varies from a few days to about six months. On an

average five or six projects are handled simultaneously. Thus, on any given day, the interviewees may be engaged in different kind of activities: meeting a client to discuss a model, idea sketching for an other project, implementation for yet another etc.

- Clients are almost never present during the actual design activity.

Methods and Techniques

Remarks and observations regarding the process of generating and developing form concepts, sources of inspiration, visualization and modeling techniques, reference materials, presentation formats etc.

- The initial ideas seems to form already during the first contact with the client. Some interviewees mentioned 'sleeping on it' for some time, making occasional notes when an idea is triggered. They all get engaged in some form of 'mental notes' or sketching. As the schedule gets closer, more concentrated efforts are made to generate ideas, occasionally through brainstorming or other creative techniques.
- Resources, such as magazines, scrap-books, existing products, shops and television[2], are referred to for inspiration, to trigger ideas or to clarify certain design solutions. Some interviewees maintain an organized scrapbook with their favorite pictures or product samples.
- Ideas are sketched or jotted on any available medium (walls, scraps of paper, sketch books, drawing sheets, notebooks etc.), either to solve a problem of form or detail or simply for later reference. Most sketches are simple, rough and very quickly made, using pencils or ordinary felt pens. Sketching skills have been either obtained through education or self-practice.
- Some interviewees expressed a need to have 'ideas to work with', while others formed their ideas 'while working'. Many ideas are generated that are later never used. The idea generation process fades into the background when one distinctly 'feels' satisfied with an idea, even though certain details of the product are not clear yet.

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[2] At the time of the study, Internet, having not yet begun it's spectacular development, was not influential in the design process.

- Three-dimensional mock-ups are made for the visualization of the overall form or the geometrical configuration of the elements of a product. They may be either scale models or only parts of the product (e.g. a sleeve of a dress). The materials used for them may be the same as that of the final product, but they can also be completely different. While only one mock-up at a time is made for problem-solving purposes, several alternatives are made to be tested or presented simultaneously.
- All subjects document their work in the form of photo-albums, which are usually organized by project. They all like to display their work to visitors.

Tools

Remarks and observations regarding the tools being used, their handling, customization etc.

- Of the available tools, very few are actually used in the form-creation phase. They are invariably simple and inexpensive, such as pencils, felt pens, knifes, scissors, scrappers etc., and do not require any specific 'handling' skills. Tools used during training or education are not necessarily used in professional practice.
- Interviewees expressed a preference for certain types of tools, such as a felt pen of a specific brand, because it has a special feel to it when it is in contact with paper or because it is comfortable to handle.
- Some subjects make their own tools for very special tasks, e.g. the potter, who makes her own grinders for scraping clay.

Work environment

Remarks and observations regarding the organization of the physical environment.

- None of the subjects, except for the fashion designer who works at her home, have any chairs for visitors. While sketching is performed while sitting down for short intervals, other activities, such as modeling or making collages, are being done while standing or moving around.
- The work place usually has more tables then desks. They are cluttered with materials, tools, products and all kinds of other things, almost never neatly organized. A creative and comfortable atmosphere is created with displays of samples, products, earlier sketches, mock-ups etc.

- Walls, windows and even ceilings are used to display finished work, work in progress, inspiring images, posters, cardboard models etc. Thus the physical environment becomes an extension of the actual design space, with the designer always being surrounded with visual stimuli.

Ideal/Computerized environment

Remarks and observations regarding ideas for an ideal of computerized working environment.

- In general the subjects felt the inherent need to have physical contact with the material they are working on, just seeing them on a computer screen is insufficient for them.
- One subject mentioned that a computer could provide pictures of environments or 'backgrounds' for products as an aid for their presentation. Another subject suggested that a computer could provide a wide choice of existing designs, which then can be modified to suit the given requirements.

Conclusions

The basic objective of this study was to acquire a basic understanding of the context of the form-creation phase in various non-industrial design domains, which would enable us to have a clear and concentrated focus when conduction a similar study in the domain of industrial design. The clustering into six areas of interest and, subsequently, the remarks and observations in each area, guided us in setting up a much more detailed questionnaire before the second study, as well as 'staying on track' during the actual interviews. The results of this first study also provided valuable input in translating the findings from both studies into actual research implications, as will be described in section 2.3.

Regarding the use of video, it was observed that some of our subjects did not feel really comfortable when being filmed, the time allotted for each interview being too short to let the subjects become familiar with the situation. Also, although the video tapes provide a rich source of material, analyzing them is a time-consuming process. Therefore it was decided for the next study to use a tape-recorder, which is less obtrusive, to record the conversations, and a photo camera, to capture any interesting scenes.

After the interpretation session it was also felt that, besides a textual analysis of the transcripts, a more visual analysis of the data and presentation of the results was needed. Therefore in the next study the results of the textual analysis were supplemented with appropriate pictures taken during the interviews.

2.2 Study 1B: Industrial Design Professionals

Based on the experiences of study 1A, the second study was conducted. Again the method of Contextual Inquiry was used, however with a more concentrated focus. It was limited to the actual creation and development of a geometrical and materialized form in the product design process. Topics that were addressed were sketching and modeling practices and tools, idea generation habits, presentation techniques, the use of computers for form-creation, and the organization of the physical work environment (Appendix B). Eight practicing industrial designers with at least two years of experience, from different educational background and working at both small and large design offices in the Netherlands, were interviewed.

Objectives

The objectives of this second study were:

- To acquire a thorough understanding of the context of the form-creation phase in the industrial design domain.
- To develop a set of design considerations for the development of computer environments or -tools, to support the industrial designer in the form-creation phase.
- To identify new research topics or directions.

Method and procedure

Basically the same procedure was followed as in the previous study. A recent work was taken as a base for the discussion, asking the subjects to show related sketches, models, product samples, photo's, materials etc. Again the position of design researchers was taken, knowledgeable of the basic factors, but curious to find out more.

Results and conclusions

Interpretation followed the same procedure as in the first study, with the exception that this time the data was evaluated on its merits to provide input for the design of a computer environment to support conceptualizing. Clustering the statements, observations and photographs thus resulted in a set of seven considerations for designing such an environment (Kolli and Pasman, 1993). Each of these considerations is now discussed, supported with visuals gathered during the interviews. Possible implications for the design of computer tools are also presented.

1 Support the Rapid and Rough Capturing of Ideas.

All activities characteristic of the form-creation phase, are based on the quick, rough and flexible externalization and manipulation of simple shapes and images. Sketches are created rapidly, without going into much detailing or evaluation. Rough models, made of materials which just happened to be at hand, are made to test our certain spatial arrangements or to explore certain forms by tactile feel.

Figure 2.1 Quick sketches are made to visualize certain shapes, textures, materials or curves.

Figure 2.2 Simple mock-ups out of foam are quickly created to explore features that are difficult to evaluate in two dimensions, such as volume proportions.

Figure 2.3 Pieces of cardboard are combined into very simple mock-ups to get a feeling for spatial arrangements.

Computer tools, developed to support the designer while conceptualizing, should try to facilitate this rapid and rough process of capturing ideas by constraining the designer as less as possible with technical limitations, interface restrictions or performing constraints, which interfere with the constant flow of his creative thoughts. They should respond as quickly and transparent as possible, affording the same flexibility and speed which was observed in the current physical environment.

2 Afford a Personalized Environment.

The subjects all work in an information-rich and highly individual-oriented environment, which is expressed in the way they organize their workplaces. Models, material samples, parts of products and other interesting objects are being put on the desktop, arranged in an apparently unorganized manner. Clippings from newspapers or magazines are collected and stored or, together with old sketches, jottings and doodles, hung on the walls. The ways in which the subjects described their favorite pens, papers, materials or tools, suggests a kind of 'designer-tool intimacy' that has been developed through extensive and intensive use.

Figure 2.4 Designers have chosen a set of preferred tools and have developed their skills in exploiting the particular strengths of these tools.

Figure 2.5 The interior arrangements of the design studio's varied considerably; designers use this to create their own working atmosphere, style etc.

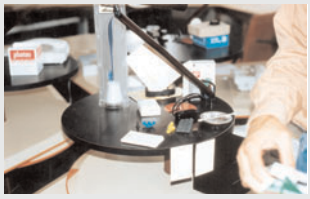

Figure 2.6 In their immediate vicinity many designers surround themselves with inspiring visuals, product samples or other collected objects.

A supportive computer environment should therefore allow the same kind of individuality and lack of organization, by permitting the user to arrange the tools, displays, materials or devices in his own personal way instead of framing the designer into one, fixed arrangement. This calls for an approach opposite from 'putting everything into one, dedicated system'. Such an approach is advocated by Xerox Parc in their concept of 'ubiquitous computing' (Weiser, 1991), which takes into account the human world, by integrating computers into everyday-life products, making them invisible as such to the users.

3 Use Rich Information Resources

Design is a visual task. This is not only expressed in the many visual depictions designers make throughout the design process, but also in the visual character of the information gathered in the form-creation phase, as represented in the form

of photographs, product catalogues, glossy magazines, videos, slides etc. All subjects reported the collection of these kind of visual references to be a major activity. They browse through design magazines, go through their collection of photographs, slides or old sketches, watch MTV or visit museums, shops and exhibitions. Appealing images are cut out and put into a special folder or pinned on the walls, thus becoming a striking element in the work environment of the designer. Various collected images and notes are combined into a collage or 'atmospheric' picture, to visualize the context of the future product, serving as a source for new ideas as well as a means for evaluating them.

Especially references to existing products, in the form of images, models or commercial samples , are actively sought for and used in the form-creation phase. All designers reported to study competitive or similar products, in design magazines and books, shops or museums, to get an impression of the existing solution space, to identify current or historical trends or to acquire knowledge on constructive details or production techniques. Being solutions to similar or adjacent design problems, these precedent designs embody design knowledge, e.g. on spatial structures or color preferences, which the designer seems to transfer to his own, unique design situation.

All this calls for an 'image-intensive' computer environment, which will allow the designer to easily store, retrieve, manipulate and display a large collection of graphic, audio, video and 3D images. The techniques underlying such an environment will have to be rooted in a careful understanding of the different ways in which these images are handled now and the various roles they play in the design process. This issue become even more important if the fact is

Figure 2.7 Appealing images are cut out and put into a special folder or binder for later browsing or reference.

Figure 2.8 Designers keep a rich set of visual resources, invitingly and conveniently arranged for quick reference.

Figure 2.9 Existing products, here organized by product class, are important sources of inspiration and knowledge.

considered that currently large collections of design references in the form of sketches, drawings, photographs or video's are becoming available through the Internet.

4 *Enable a High Level of Communicability.*

Although essentially the actual design task is done by the individual designer, there is a considerable need to communicate ideas, thoughts and views to others throughout the form-creation phase. A number of meetings are held with the client to clarify the initially vague project requirements or to discuss possible concepts. During these meetings the designer presents his sketches, slides, models or other representations of his work to the client. When working in a team, sketches of generated ideas are shown to other team members for comments, group meetings are held to brainstorm on new ideas, with everyone sketching on one common paper or in their private sketchbooks.

Figure 2.10 Presentations to clients or other designers, using slide projectors or beamers, are milestones in the design process

Figure 2.11 Collages or mood boards are composed to convey the product's atmosphere

Figure 2.12 Cardboard displays involving human figures are created to communicate the scale of a design.

A computer environment should facilitate these acts of communication by offering possibilities for collaborative work e.g. through the use of multi-layered marking on created images, or by providing ways for quick presentation of work to other team members.

5 *Support Individualistic Styles.*

Throughout their years of education and practice each subject has developed his personal 'design style', which is expressed in their sketching and presentation habits, their affinity for certain tools and techniques, their preferences for certain shapes and materials etc. This style makes their work stand out form others and

designers are therefore very keen on preserving it. Some of our subjects expressed the fear that by using a computer they would lose this 'personal touch', because they would be limited by what the computer offers them. This fear has turned out to be true today as many designers readily accept the limitations of their computer software and adapt to them…rather than the other way around.

Figure 2.13 Various types of depictions, using different perspectives, in color or black & white are placed on the same sheet of paper.

Figure 2.14 A personal visualization style makes a designer's presentations distinct from others.

Figure 2.15 Computer tools offer only very limited possibilities for creating expressiveness, making their results look 'dead'

This put high demands on computer tools, which should support design activities without intruding on the idiosyncrasies and characteristics of an individual's style of working. This calls for a tool that offers possibilities for adaptation and personalization of it's qualities by the designer. A sketching device, for instance, should allow the same continuous and immediate control that a designer has developed with a pencil on a piece of paper, instead of offering him only a limited number of options, like four possible line thicknesses.

6 *Afford a Smooth Shifting of Activities.*

While conceptualizing the designer will regularly shift his attention to different activities on more than one level, sometimes without the designer being actually aware of it. Since our subjects handled multiple projects, usually three to four, it often happens that, while sketching ideas for a certain project, ideas for another product come spontaneously into mind, which are quickly captured on the current sheet of paper. When an idea can not be sufficiently explored through sketching, the switch to making a cardboard model can sometimes be made. This changing of activities also involves movement: reaching out to grab a piece of paper,

Figure 2.16 A large desktop affords sufficient space to smoothly shift between sketching, modeling, organizing and evaluating.

Figure 2.17 Foam models, drawings and product samples or parts are in the focus of attention simultaneously.

Figure 2.18 The computer environment leaves no space for any other activities.

moving one tool to replace it with another, changing from a sitting to a standing position or going to a different place in the room.

A computerized environment should afford the same kind of flexibility of changing activities and body positions, e.g. by offering multiple, dedicated devices, each designed for a specific task. This would offer the user the possibility to easily exchange one tool for another, or to view representations of different activities at the same time. This in contrast to the current situation were changing an activity means switching to a different application, resulting in the vanishing of former work into the background. A computer tool should therefore mix in with the other elements of the work environment as smoothly as possible, without clearly presenting itself as an obtrusive technical device.

7 *Support Motor Skills*

An interesting observation from both studies was that almost all design activities are done using two hands, the non-dominant hand being used for positioning and orientation while the tool used for generating or modifying the design, is held in the dominant hand. An other striking fact was that a number of activities, such as collage making or modeling, were performed standing-up, using tables, easels or walls. Probably this position gives designers with a better overview and physical freedom, to easily compare or dynamically arrange design materials. It allows designers to work on a larger, often horizontal, surface and provides the ability to easily move from one part of a project to another or from project to project within the studio.

Figure 2.19 Many activities, such as drawing, require the use of both hands. Computer tools, however, just make use of one finger to operate them.

Figure 2.20 An other distinct feature of design is that a considerable amount of work is done standing up.

Figure 2.21 Tools are arranged conveniently, showing their variety and applicability at a single glance.

Present computer-set-ups, which use a single pointing device, usually a mouse, are unequipped to support two-handedness. Also, designing them as a stand-up devices might afford a higher level of interaction than the stationary, sit-down formats.

2.3 Research implications

The next step in the research involved integrating these considerations into the design of a concept computer tool, to support designers in the form-creation process. The purpose of this concept was to present an integrated, design-driven vision of possible implications the identified considerations might have on the design of these kind of tools. Rather than being a detailed and worked-out proposal, ready to become implemented, the concept should act as a tentative object of both analysis and synthesis. The former being a catalyst for the identification and concentration of possible new research projects and topics, thus directing the course of the IDEATE project. The latter being an integrated framework, in which the design considerations have been translated and integrated into physical or virtual design properties.

IDEATOR, a support tool for conceptualizing

First the set of design considerations was evaluated on it's consequences for the design of a tool, supporting sketching in the form-creation phase. Additional information on the dynamic and organizational aspects of sketching was acquired through analysis of video recordings of sketching sessions, as well as through

examination of several sketch books maintained by designers. From this a list of requirements for the design of the tool was drawn up (Kolli, Stuyver and Hennessey, 1993). Several design concepts were then created and evaluated in group discussions on their relative merits regarding the list of requirements. The final concept, called IDEATOR, is a desktop computer-based tool with built-in audio and video features, consisting of three components (Stuyver and Hennessey, 1995):

- The Pad, an A3-size flat-panel color display, overlaid with a transparent digitizer.
- The Paw, a flat tool connected to the Pad, containing control buttons for functions like page browsing, playback, copy, paste etc.
- Pens, with which images can be directly sketched on the display surface, deriving saturation, line thickness and shape from their rotation, tilt, place and pressure parameters.

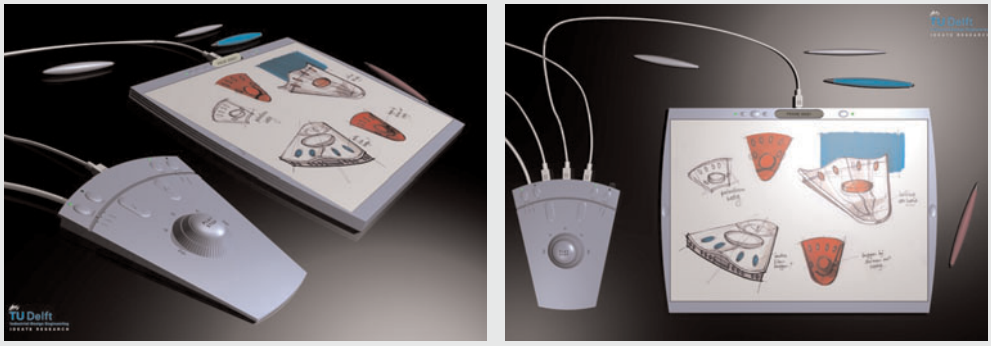

Figure 2.22 The IDEATOR, a design support tool for conceptualizing.

Functionalities of the IDEATOR included, among other things, the dynamic reconstruction of sketches and the ability to make collages, record sounds and annotate videos. To make the interaction with the tool quick and intuitive, affording the rough and rapid capturing of design ideas as natural as possible, it was decided to keep the sketching area of the Pad completely free from any interfering interface elements, such as buttons, menu's, windows etc. Instead, these were assigned to physical buttons or sliders on the Paw, where they can be controlled using the non-dominant hand or by voice, thus providing the ability for two-handed interaction. In the design of IDEATOR, three different perspectives can be distinguished:

1 A cognitive perspective,

e.g. in it's ability to reconstruct sketches stroke-by-stroke, accompanied with possibly made voice annotations. Thus the 'train of thought' of the designer while making the sketch can be traced back and picked up any given time, allowing for a dynamic (re)constructing of the made design decisions.

2 A perceptual-motor perspective,

e.g. in it's operation with both hands. While the dominant hand is doing the actual sketching or manipulating of the images, the non-dominant hand is rotating the Pad or resting on the Paw to operate the control buttons.

3 A methodological perspective,

e.g. in it's capacity to record and play-back a concept history. Small thumbnail versions of all sketches related to a concept can be shown in chronological or structural schemes. Key decisions in the form of voice annotations can be attached to these schemes, creating rich and complementary representations of the design process.

Spin-off projects

These three perspectives have subsequently initiated a number of research projects within the IDEATE-project. In each project one or more aspects of design in the form-creation phase is studied, using one of the three perspectives as it's main focus. Each project will now be briefly discussed, to illustrate the context in which the research of this thesis has taken place.

Sketches of Creative Discovery

From a cognitive perspective, a psychological study into discovery in visual imagery, and the augmentation of externalization through sketching, was conducted by Ilse Verstijnen (1997). Central to her research was the argumentation that the processes of analysis, involving a reinterpretation of existing conceptions of an image, and synthesis, involving a transformation of existing structural images into new ones, would impose different cognitive loads on imagery, thus resulting in different effect of paper-and-pencil support.

Synthesis tasks, that can be easily performed in imagery, would consequently benefit less from support through sketching than analytical tasks. In a series of experiments this hypothesis was further conceived and tested.

Regarding the use of computer support tools, Verstijnen concluded that these ought not to disturb synthetic processing, which is easy and fast in imagery, if they are to support creative processes. However, facilitating analytical processing, such as the reconstruction of sketches in the IDEATOR, would augment the supportive role of paper and pencil.

Two-handed interaction in computer supported 3D conceptual modeling

From the interviews it became clear that designers prefer the traditional materials such as cardboard, foam, clay, etc. above the computer, when it comes to the quick generation, comparison and evaluation of spatial, 3-dimensional forms. Starting from a perceptual-motor perspective, it was felt that a combination of spatial interaction (whereby the hands can move freely in 3D) and two-handed operation (whereby both hands can simultaneously interact with the computer model) would possibly lead to a more direct and intuitive way of geometric modeling, mimicking the maneuvers of designers in the physical world. To explore this combination, alternative interaction devices and new interface techniques were developed by Maarten Gribnau (1999).

Figure 2.23 Two-handed interaction using the Frog input devices.

With the Frog interaction devices and the ID8Model application developed in the project, two rounds of experiments were conducted. The results indicated that both 3D interaction and two-handed operation were easy to learn. Working with two hands proved to be faster than working single-handedly, giving the designer more control over the modeling task. In addition, with bi-manual operation, the workload can be distributed over two hands.

TIME: Three-dimensional Input, Modification and Evaluation

An other project incorporating two-handed interaction, involved the development of a concept for a sketching device, which would support simple and intuitive generation, manipulation and evaluation of three-dimensional computerized objects (Gribnau and Pasman, 1996). The device, named TIME, consists of three pieces of hardware:

Figure 2.24 Time, a two-handed sketching device

- The tablet, which is the main input for sketch data. It displays a dedicated user interface and includes trackpads for manipulating camera settings.
- The watch, which is used for positioning the sketch plane, evaluating the model and placing of the cameras. It is to be held in the non-dominant hand and has three buttons.
- The pen, which is used for sketching and manipulating on both the tablet and the watch.

There are two graphical user interfaces, one of the watch and one on the tablet. The interface on the watch is used to set the mode of the watch to object mode, camera mode or light mode. The interface on the tablet is used to interact with the file system, the libraries of pre-defined contours, shapes or objects, as well as for selecting different editing functions.

ideas: a designer's sketching tool

Part of the IDEATOR was further developed into a number of concepts and ideas for a digital sketchbook (Hoeben, 2001). These were then implemented in a

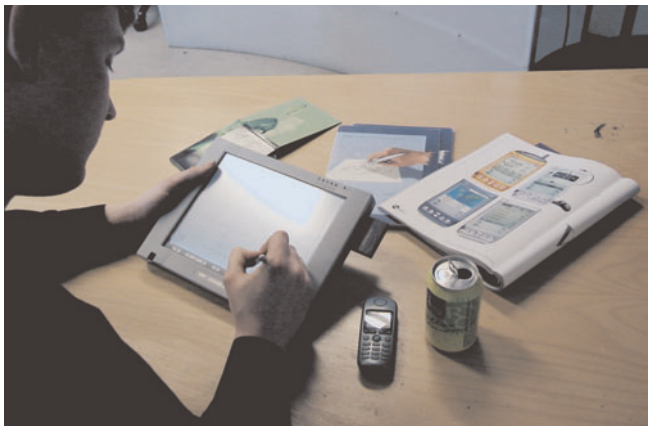

Figure 2.25
ideas: a designer's sketching tool

hardware prototype, which is running on a Fujitsu Stylistic 3400 Pen Computer. Roughly stated, this is a laptop machine without the keyboard and with a touch screen. While the hardware still has limitations, it allows quick implementation and evaluation of new design ideas.

A new interface technique for flicking through page-based documents, using image thumbnails and electronic dog-ears, has been added to aid the user in navigating through large collections of visual documents, such as sketches, images, collages etc. (Hoeben, 2000). Currently Aldo Hoeben, who is both conducting this research and working as a professional designer, is using the sketchbook as his primary means for taking notes and making design sketches.

2.4 The role of precedents in design

Together the results of the two series of interviews clearly indicated the importance of existing products as a source of knowledge and inspiration in the form-creation phase of the product design process. Almost all of the interviewees in both studies reported that they studied existing products or works before or during the generation and development of new ideas. They browse through magazines, visit shops or museums, go through their own private scrapbooks or archives, buy products to disassemble them etc. Nice and inspiring products or previous works are put on display in their design studio's or being used as materials for collages or mood boards. Being solutions to design problems, existing designs provide a designer with important frames of reference in the

generation and development of new product forms. Reflecting certain elements of convention, which have been developed in a society in the relation between function, form and use of a product, these precedents embody design knowledge which can be used by the designer in new design situations (Pasman and Muller, 1995a,1995b).

However, because of the unique and specific character of these situations in an ill-structured problem domain such as design, the designer can not simply 'copy' such knowledge from existing designs and 'paste' it into the design task at hand. Thus successful transfer of design knowledge from precedents would require some form of active adaptation by the designer. How, then, does this adaptation process proceed and in what way should a computer support system be organized in order to augment it?

Goal of the research

The main objective of this research is thus to acquire more knowledge and a better understanding on the role of existing products in the form-creation phase of the product design process. The research will combine a methodological perspective with both a cognitive and a technological perspective. While the first combination will be applied to highlight or adjust existing design methods or –techniques, the latter will be used in the development of new computer supported environments or tools.

The main research questions, that will be dealt with in this thesis, are the following:

1 *What role do existing product forms play in the generation and development of new product forms in the form-creation phase of the product design process?*

2 *How can this role be influenced by means of new design techniques?*

3 *How can these techniques be supported by means of a design support tool?*

These questions will be addressed using a range of different research methods and techniques, such as design experiments, product classification- and assessment tasks and interaction prototyping. The results will be beneficial for

both design methodologist, concerned with the study of designers, design methods and –techniques, and interaction designers, concerned with the development of new, innovative and interactive computer techniques and -applications.

Scientific and social relevance

From a design methodological perspective, the use of existing products is most apparent in design education. Examples of well-known designs, recent as well as historic, good as well as bad, are being studied as references to design solutions regarding such diverse aspects as the choice and use of materials, the technical details of their constructions, or the reflection of socio-cultural values and styles. In contrast with traditional academic disciplines, such as mathematics or physics, students are not directed to general principles or theories, but to a collection of possible outcomes, to which they have to add similar results with novel features. Akin (1997) has thus described design precedents as 'expeditious ways of creating a realistic design situation'. They would, on the one hand, protect designers for reinventing the wheel by providing realistic and satisfactory design solutions for the task at hand. On the other hand, they would provide jumping-off points for the development of new and innovative concepts. To design a product that stretches the existing solution space, one must be first aware of its boundaries.

From an interaction design perspective the relevance of the research lies in its potential value for the development of design support systems that facilitate the use of large bodies of information. At the time the two series of interviews were conducted, the Internet was just starting it's unprecedented advance as an information resource, providing designers with a wealth of material to consult while designing. On the one hand this opened up unlimited possibilities for designers to collect or study existing products without leaving their chair. On the other hand, however, the immense magnitude and complexity of the Internet might have the effect that it's users can't see the forest for the trees anymore, thus being unable to make use of its possible value. Thus the need for simple yet innovative organizing-, navigating- and browsing tools for building up, searching and exploring large collections of information has become more apparent in

recent years. It is therefore expected that the results of this research will be applicable to other domains than just design.

In the next chapter…

a framework to describe the role of existing products in the generation and development of new form concepts will be constructed through a theoretical exposé on the formation of new concepts. The construct of a product type is introduced as a means to describe and organize existing products in terms of the product-specific design knowledge they represent. By grouping together products on their shared typicality regarding function, form or meaning, product types get formed, in which design knowledge is organized on a problem-independent level. This specific character then affords the 'displacement' of this knowledge to new design situations.