THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

PENSIERI

An Inquiry into Sketching and Modelling in Design

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ABSTRACT

When proposing ideas for design solutions, designers often make representations, for example sketches and models of different kinds. This thesis seeks to examine what designers do when interacting with different media to externalise their ideas, and the resources they have at their disposal.

In two studies, students and experienced design practitioners were asked to describe their working processes. The first study made use of weekly design diaries of 11 masters students, collected during a seven-week project course. Furthermore, semi-structured interviews were held with 11 practitioners regarding the process of creating their latest award winning products. They discussed what they were able to achieve and how the media and representations they used enabled them to do so.

The findings of these studies highlight (i) the roles of sketching, and physical and digital modelling for ideation in individual designer's work, and (ii) some prominent qualities of media and representations that support designers during these activities, for example the extent to which they are malleable, accurate, or fixed.

By providing a taxonomy for classifying various media and design representations, these findings expand on previous conceptions about sketching and modelling. An increased understanding of how ideas emerge and are materialised in the early phases of a design process, can provide opportunities for facilitating and stimulating the act of creation.

Keywords
Design Activities, Product Representations, Concept Generation, Sketching, Physical and Digital Modelling

PREFACE

The Italian word *"pensieri"* refers to explorations and experiments that Renaissance artists made in their study drawings. These were made possible by advances in printing, and the production of affordable paper (see history of drawings in Buser, n.d.). Representing ideas and thoughts visually did not however emerge in the 15th century. Prior to the printing revolution, monks and scientists realised their work on handmade paper, which was expensive and in limited supply. Historically, other surfaces were used for making representations: stones, cave walls, pottery and seals.

Cave drawings belong to one of the most sophisticated and rich art eras, dating back to 30,000 BCE. Some of the most well-recognised cave drawings were found in France and Spain. Since the discovery of these drawings in the late 1800s, art historians have devised several hypotheses to explain the meaning, function and processes behind the making of cave art. Among other things, these drawings are believed to have been used for aesthetic pleasure, as hunting magic, to facilitate the process of finding food (e.g. a drawing of a sleeping bison would lead to easier hunting), and for spiritual ceremonies and rituals (Cothren and Stokstad, 2011, pp. 8-10). Most recent theories indicate that these drawings portray a large amount of information about the animals' behaviours and were used for educational purposes. The drawings include illustrations of mating, seasonal behaviours, hoof prints and patterns of animal faeces that instructed and prepared novice hunters. Three techniques, used either in isolation or combination, are associated with the making of cave drawings: (i) drawing with fingers or blocks of ochre pigments, (ii) painting with a brush made of hair, and (iii) using hands as stencils, which involved chewing a piece of charcoal to dilute it with saliva, and blowing the mixture onto the surface of the walls or using some sort of a pipe. The latter technique was, for example, used to make an uncoloured hand trace by placing the hand on the wall and blowing pigment directly onto it, to make a vertical line by positioning the hand vertically, or to draw a curve by forming a scoop with the hand and blowing under it to trace the upper edge of the hand. The latter could depict the curvature of an animal's back for example.

The story behind cave drawings resembles designers' activities for representing and communicating their ideas; in the same way as the cave drawings embody knowledge and insights possessed by their creators and represent phenomena that were not in close proximity to the cave walls, designers engage in various activities to represent ideas and solutions that are not immediately present. Moreover, cave drawings were used to construct a model of animal behaviour and to inform and instruct others about the hunting practice before it took place in reality. They

provided the hunters with a virtual environment without threats and dangers, a perfect playground for familiarising themselves with the reality and enactment of hunting without endangering their lives. Many of the activities in the design process are also safe playgrounds where designers can experiment without a worry of failure. In fact, designers rarely become hunters; instead they envision and represent a solution that will be made by others.

Ways of representing and materialising ideas have had a large influence on human development. Many professions involve making representations of some kind. Little, however, is known about these activities. The present work, therefore, seeks to gain insight into the emergence and embodiment of ideas in design practice.

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Maral Babapour
Gothenburg, 5th May 2015

APPENDED PUBLICATIONS

PAPER A

Babapour, M. (2014). Roles of externalisation activities in the design process. *Swedish Design Research Journal, 1*(14), 34-46.

PAPER B

Babapour, M., Rehammar, B., & Rahe, U. (2012). A Comparison of Diary Method Variations for Enlightening Form Generation in the Design Process. *Design and Technology Education: an International Journal, 17*(3), 49-60.

Contribution: Rehammar and Rahe were responsible for planning and data collection. Babapour analysed the data and wrote the paper. The co-authors contributed as reviewers.

PAPER C

Babapour, M., Hjort af Ornäs, V., Rexfelt, O., & Rahe, U. (2014). *Media and Representations in Product Design Education.* Paper presented at the 16th International Conference on Engineering and Product Design Education. Design Education & Human Technology Relations, University of Twente, The Netherlands. 4-5 September 2014.

Contribution: Rahe and another researcher were responsible for planning and data collection. Babapour analysed the material and wrote the paper. The co-authors contributed as reviewers.

PAPER D

Babapour, M., Hjort af Ornäs, V., Rexfelt, O., & Rahe, U. *Roles and qualities of sketching, and physical and digital modelling in design.* Paper submitted to the International Association of Societies of Design Research (IASDR) Conference 2015. INTERPLAY between design, science, technology and the arts.

Contribution: Babapour planned the study, conducted the interviews, analysed the data, and wrote the paper. Rexfelt and Hjort af Ornäs contributed ideas as discussion partners and, together with, Rahe served as reviewers.

ADDITIONAL PUBLICATIONS

Babapour, M., (Submitted). *Reasoning with Shapes in the Embodiment of Design*. Working paper submitted to the *14th NORDCODE Seminar & Workshop,* Jyväskylä*, 19-21 September 2015*.

Babapour, M., (2014). *Externalisation activities and creativity in design process*. Working paper presented at the *13th NORDCODE Seminar & Workshop, Gothenburg, 10-12 September 2014*.

Babapour, M., (2013). Roles of Visualisation Tools in Form Design Process. Working paper presented at the *12th NORDCODE Seminar & Workshop, Trondheim, 18-20 September 2013*.

Babapour, M., & Rahe, U. (2013). Bridging the discrepancy between reflective practice and systematic form generation approaches. In *DS 76: Proceedings of E&PDE 2013, the 15th International Conference on Engineering and Product Design Education, Dublin, Ireland, 5-6 September 2013*.

Babapour, M., & Rahe, U. (2013). *Visualising the design process – an educational approach for the synthesis of design diaries*. Paper presented at the 10th European Academy of Design Conference, Crafting the Future, Gothenburg, *17-19 April 2013*.

Babapour, M., Rahe, U., & Pedgley, O. (2012). *The Influence of Self-reflective Diaries on Students" Design Processes.* Paper presented at the DesignEd Asia Conference, Hong Kong, *4-5 December 2012*.

Rahe, U., Babapour, M., & Rehammar, B. (2012). *Creating novel product form based on formal aesthetics - a method for advanced form design education*. Paper presented at the 14th conference on Engineering & Product Design Education, Artesis University College, Antwerp, 6-7 September 2012.

Babapour, M., Rehammar, B., & Rahe, U. (2012). *A comparison of diary method variation for enlightening form generation in the design process*. Paper presented at the Design Research Society Conference, Chulalongkorn University, Bangkok, 1-4 July 2012.

Rahe, U., Babapour Chafi, M., Warell, A., & Rehammar, B. (2012). *Innovative Form Design-A Formal Aesthetics Design Approach for Creative Form Generation.* Poster presented at the Design Research Society conference 2012, Bangkok, 1-4 July 2012.

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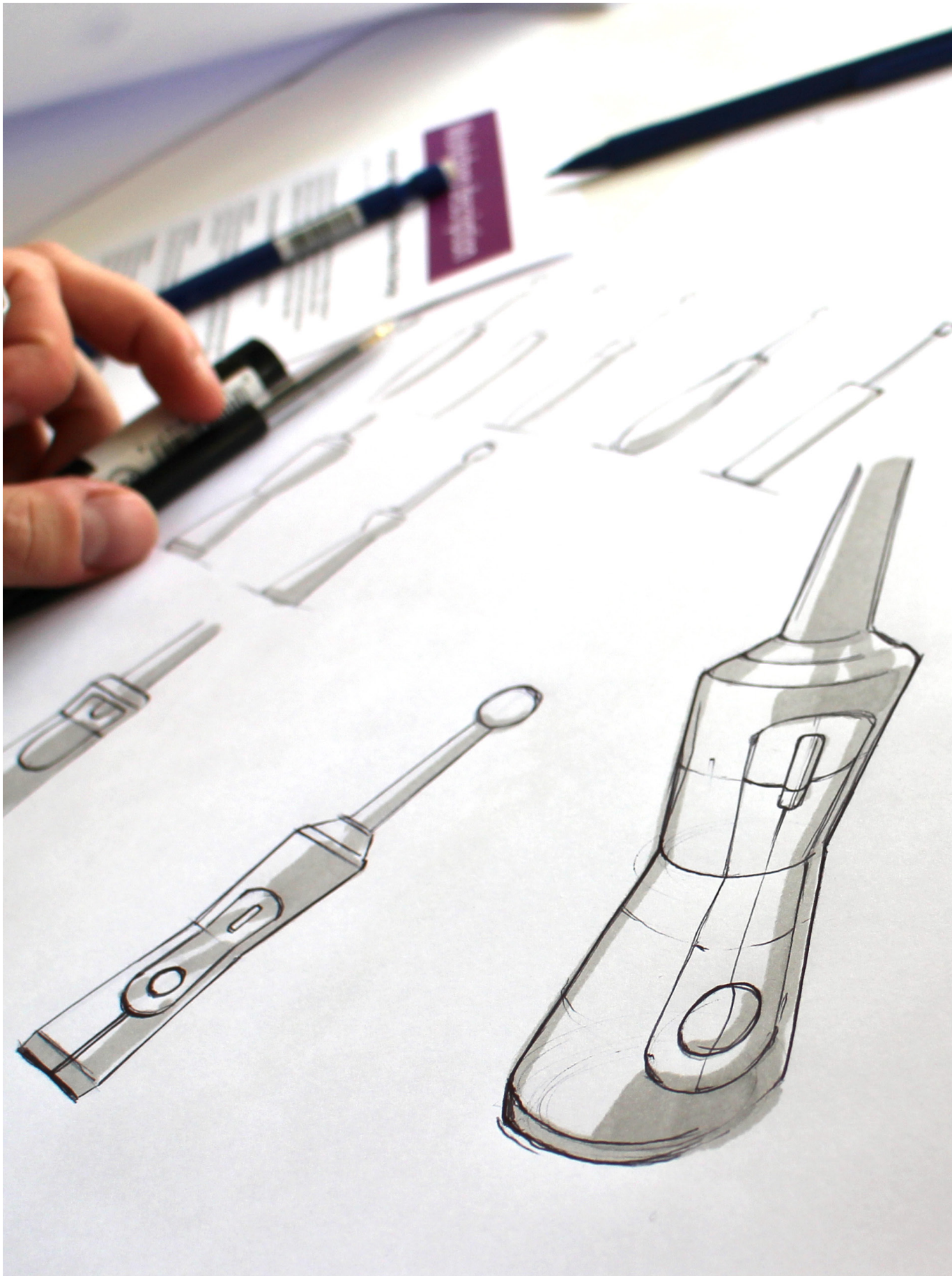

CHAPTER 1

INTRODUCTION

Most acts of creation involve representing an idea. In design, this involves proposing design solutions through sketches and models of different kinds. Design representations reveal some of the thinking of designers and provide visible traces of the emergence and evolution of ideas. The making of representation, here called externalisation activities, has a large array of motivations and goals; some representations are made to gather and assemble information and provide inspiration, some to generate and document ideas, and some to envision future scenarios. A drawing of a table lamp, for example, may represent a vision of a particular lamp that has specific functional, material and aesthetic qualities and hold qualities that inform and inspire the designer, rather than merely depicting an idea for a lamp.

Descriptions of design processes sometimes focus on the problems, sometimes on the solutions, and sometimes on building a bridge between the two. This involves either decomposing problems into pieces, reconstructing them in a new way, and evaluating the consequences of the new arrangements (cf. the analysis, synthesis, evaluation model in Jones, 1992) or proposing a solution and evaluating its consequences with respect to the problem and its pieces (e.g. Schön, 1983). Whether designers start from the whole and work towards the parts or vice versa, they are inevitably required to externalise and give form to their ideas. In other words, "*there can be no design activity without representations*" (Goldschmidt and Porter, 2004). Externalisation activities occur throughout design processes. They involve two opposing modes of creative thinking: (i) the ability to come up with several alternatives for tackling a problem and generate new ideas, i.e. divergent thinking, and (ii) the capacity to narrow down the search for a solution to a better answer, i.e. convergent thinking (Csikszentmihalyi, 1996). These abilities require fluency, for generating a great number of ideas, and flexibility for shifting from one perspective or idea to another.

Although making representations of ideas is something many professions share, this thesis focuses mainly on what goes on in the course of these activities in product design and development processes.

1.1 EXTERNALISATION ACTIVITIES AND PRODUCT REPRESENTATIONS

The term "*externalisation activities*" here refers to all of the activities that involve representing and giving form to an idea in design processes. Different communities and disciplines have divergent views on what constitute product

representations and the process of making them. Figure 1 provides an overview of the definitions, origins and key interpretations of key concepts and terms relating to externalisation activities. These terms are, however, at times blurry, especially since they are used to refer not only to an activity, but also to the media and tools by which the activity is carried out, and/or to the resulting representations. For example, while "sketching" usually refers to the act of externalising ideas by making marks on paper, McKim (1980) uses sketching as a general term to explain the generation of ideas: "*Idea sketching is a way to express visual ideas. [..] Visual ideas can be expressed by acting them, talking about them, writing them down, constructing them directly into a three-dimensional structure, and drawing them*."

EXTERNALISE (VERB)	**EXTERNALISATION (NOUN)**
- to make external or externally manifest - to attribute to causes outside the self Synonyms: express, embody, incorporate, manifest, materialize. First Known Use: 1852	- the action or process of externalizing - the quality or state of being externalized Synonyms: embodiment, manifestation, icon, image, objectification. First Known Use: 1803
REPRESENT (VERB)	**REPRESENTATION (NOUN)**
- to serve as a sign or symbol of - to portray or exhibit Synonyms: define, depict, describe, portray First Known Use: 14th century	- the act or action of representing - the state of being represented - something that stands for something else First Known Use: 15th century
MODEL (VERB)	**MODEL (NOUN)**
- to design (something) - to make a small copy of (something) - to make something by forming or shaping - to plan or form after a pattern - to produce a representation First Known Use: 1625	- a usually small copy of something - a usually miniature representation - structural design - a description or analogy used to help visualize something First Known Use: 1575
SKETCH (VERB)	**SKETCH (NOUN)**
- to make a quick, rough drawing - to describe (something) briefly Synonyms: define, delineate, outline, trace First Known Use: 1694	- a rough drawing representing the chief features of an object or scene and often made as a preliminary study First Known Use: 1668

Figure 1 – An overview of some of the central terms used in this thesis, source: www.merriam-webster.com.

The inconsistent use of terminology also extends to the use of sketching and drawing to denote making marks on paper, or modelling and prototyping for making three-dimensional representations. For the sake of brevity, **sketching** and **modelling** will be used here as collective terms used to denote (i) making marks on paper, and (ii) creating physical or digital representations, respectively.

1.1.1 SKETCHING AND SKETCHES

Sketching typically refers to the process of making marks on paper in order to represent an idea. In visual arts, it refers to making a rough type of drawing that does not require representing accurate likeness and precision; hence, the artist is freed to make mistakes and engage in creative exploration. During the Renaissance period, these types of sketches were called pensieri*, meaning thoughts.

Sketches represent various types of information and are put to use in different ways. According to Pei, Campbell and Evans (2011), sketches may be classified as: (i) rough sketches, which can be personal, shared, persuasive, or meant to be handed over, (ii) the more formal and structured sketches, which can be divided into industrial design sketches (e.g. scenarios, or layout and presentation renderings) and engineering design sketches (e.g. detailed drawings, and technical illustrations). This classification not only highlights how the sketches will be used, it also indicates the type of activities, concerns and purposes that designers may have when sketching.

There are various means and media for making sketches. Ballpoint pens, pencils, and markers (with a variety of colours and nib thicknesses) are commonly used alternatives. However, sketching in computer environments has gained considerable importance in design practice. Since interacting with digital pens resembles sketching on paper (e.g. applying pressure results in darker and thicker lines), they have not been differentiated in this work unless relevant.

1.1.2 MODELLING AND MODELS

Modelling refers to representing ideas using either a tangible or a digital medium. In design disciplines, the process of making tangible models has always had a prominent role in developing and communicating future solutions. "*At the beginning the designers were the model makers, and they were artisans. They made wood shavings. They were half sculptors. They made everything out of clay*" (Wim Gilles, cited in te Duits, van Daalen and Beuningen, 2003)**. At the same time, digital modelling has gained prominence in the past three decades.

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* Pensieri (plural), means thoughts in contemporary Italian.

** Wim Gilles was Netherland's first industrial designer to explain the post World War II design context.

Different types of models are made during a design process. For example, Houde and Hill (1997) categorised models depending on the aspects and dimensions they represent: (i) function and use, (ii) look and feel, (iii) implementation and technical considerations, and (iv) integration of the three previous dimensions. This also means that designers carry out externalisation activities with a host of different questions and purposes in mind.

Tangible concrete media ranges from materials like paper and cardboard to foam and clay . Digital modelling media also vary; some involve surface modelling and others solid modelling; some are for making advanced surfaces that can be used for production, and others for preparing renderings. The advances in Rapid Prototyping Technology and optical scanning in the past decade have also provided opportunities for designers to convert their digital representations into tangible ones and vice versa. The present work differentiates physical modelling from digital modelling to underline the use of tangible or digital media respectively, and highlights the use of specific technologies if needed. This is mainly due to the large difference in how one interacts with the different media; fro example, filing edges and corners of a physical model is significantly different from inputting a radius to modify surface transitions in a digital model.

1.2 ORIGINAL DRIVER BEHIND THE PROJECT

This research was initiated as a part of a project for developing and improving CAD systems. This required gaining insight into the design process, for which design diaries were used in an educational context. An initial review of these diaries indicated that the students' ideas emerged and developed during the course of making design representations. This was the case regardless of the effort they put into framing their problems. In addition, an initial skimming of the literature revealed that the process of making representations is rather uncharted (see Chapter 2, and Paper B for an overview). These observations prompted the research questions addressed in this project.

1.3 AIM AND RESEARCH QUESTIONS

The aim of this work, on a general level, has been to broaden the understanding of designers' activities, and increase the knowledge about the act of creation in design, especially concerning how designers experiences using different tools and media. More specifically, this involves describing, explaining, and clarifying the roles* and characteristics of externalisation activities aiming to give form and matter to designers' proposals for design solutions (i.e. sketching, and physical and digital modelling). Comparing and contrasting the roles that different activities fulfil, facilitates the understanding of the dialectical nature of design and highlights how these activities can influence the design processes and their outcomes. In

* In this thesis, the term "role" signifies the function and usefulness of something in a particular process.

addition, gaining insights into the work that underlies design proposals would enable the development of tools and methods for facilitating design processes.

This inquiry concerns gaining insight into design processes (see basic design research Buchanan, 2001)*, i.e. activities carried out during the working process, and acquiring knowledge about objects of design, i.e. media used and representations made along the way.

The aim of this work is first to understand what designers do during externalisation activities by investigating their interactions with media and representations through their own perspectives. To address this aim, the following research question was posed:

RQ1: What roles do the externalisation activities (sketching, and physical and digital modelling) have for ideation in the individual designer's work?

A second aim has been to highlight and explain how designers perceive differences and similarities among media and representations when coming up with and externalising their ideas.

RQ2: How do media and representations (in externalisation activties) facilitate the emergence and realisation of ideas?

1.4 DELIMITATIONS

This work focuses on the externalisation activities of individuals in design processes. Product design and development take place in a complex socio-technical context, and externalisation activities are carried out in a social setting. Many scholars have investigated how making representations facilitates collaboration, drawing on observations of the conversations that take place between designers and various stakeholders (e.g. Eriksson, 2014). These conversations are accessible facets of design processes. The present study, however, deals with relatively uncharted aspects of making representations and addresses the interaction between individuals and the materials they work with.

Furthermore, externalising activities are not limited to sketching and modelling; verbalisations (e.g. Dong, 2007), and gesturing (e.g. Visser and Maher, 2011) are other examples of these activities that are not addressed here. Apart from externalising ideas, designers engage in various other activities and employ different methods for problem framing, requirement specification and/or communication. These complex processes, however, lie outside the scope of this thesis.

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* Buchanan (2001) categorises design research as basic (explaining the nature of design), applied (finding principles or rules-of-thumb based on an extensive number of cases and studies), and clinical (solving particular individual design cases).

1.5 OUTLINE OF THE THESIS

The thesis is structured as presented in Figure 2.

INTRODUCTION

Chapter 1 presents the reader with background, main concepts and terminologies of the thesis and the addressed research questions.

SKETCHING AND MODELLING IN DESIGN THEORY

Chapter 2 reviews different perspectives on design theory and externalisation activities.

RESEARCH APPROACH

Chapter 3 highlights overall theoretical and methodological considerations.

THE STUDIES

Chapter 4 elaborates on the procedures of each of the studies included in this work.

OUTCOMES

Chapter 5 summarises the appended publications and puts together the results from each study to answer the research questions.

DISCUSSION AND IMPLICATIONS

Chapter 6 discusses the findings and their implications together with reflections on the appropriateness of the methodology. The chapter concludes with some final words and suggestions future work.

Figure 2 - Structure of the thesis.

SKETCHING AND MODELLING IN DESIGN THEORY

Sketching and modelling have been discussed in design theory from various perspectives. Major strands of design theory that underpin different views on the nature of design processes and externalisation activities are reviewed in this chapter.

2.1 DESIGN AS PROBLEM SOLVING

Central developments in design theory and methodology have been rooted in seeing design as problem solving. One of the major objectives of this perspective was to systematise design work and make it "*less circular and more linear*" (Jones, 1992, p. 52). This view set the scene for the design methods movements that took off in the 1960s, which formalised design according to a rationalist doctrine with the same standards as science.

"Problem solving is often described as a search through a vast maze of possibilities, a maze that describes the environment. Successful problem solving involves searching the maze selectively and reducing it to manageable proportions." (Simon, 1996, p. 54)

In one of the early texts that influenced this view, problem solving is defined in terms of reconciling the solutions of the sub-problems with each other, which requires evaluation, judgement and intuition, while the beginning and end of the process are depicted as analytical and executive (Archer, 1963). Various models of design were proposed in this vein, for instance, Jones' (1992) analysis, synthesis, evaluation model, which involved (i) analysing the design problem, and its constraints and criteria to formulate requirements, (ii) decomposing the problem into pieces, solving them separately or in parallel, and putting them together in a new way, and (iii) evaluating the appropriateness of the solutions with the help of requirements formulated to meet the problem criteria and constraints, and testing the solutiins to see whether they conform with these criteria and constraints.

Problem solving models also accompanied various methods to structure each stage of design work. For example, Tjalve (2003) recommended two methods for decomposing design problems into pieces, manipulating their geometries and putting them back together in a new way - either by varying the main elements and their structure or by making various arrangements of functional surfaces.

This involved making rather abstract representations to illustrate the shape and arrangements of parts and the overall structure, regardless of how a problem can be broken down.

EXTERNALISATION ACTIVITIES IN THE PROBLEM-SOLVING PERSPECTIVE

In the very first issue of Design Studies, Archer (1979) defined design as the language of modelling. Representations of space and artefacts in space, how they are created, and how they contribute to problem solving are given a supporting role in the problem-solving perspective (see Figure 3 for an overview). Simon (1996) saw problem solving as a change in representation that makes a solution transparent, a process that begins by retrieving a solution from the repertoire of solutions that one already has. Analysing this perspective, Lie (2011) highlighted how the generation of solutions or sub-solutions is not considered a creative activity, since they are retrieved from the repertoire of solutions that one already possesses; it is rather the art of reconciling the sub-solutions that is regarded as creative. Therefore, the primary task of solving problems and generating solutions takes place in the mind of the designer, and sketching and modelling are considered ways of documenting and externalising solutions retrieved from memory. The emerging documentations (e.g. sketches) are external memory aids that serve "*as a major stimulus for suggesting to the designer what he should attend to next*" (Simon, 1996), and help with evaluating the solutions based on the constraints and variables of the problem (Tjalve, 1979).

"*A key element in the act of designing is the formation of a prescription or model for a finished work in advance of its embodiment.*"(Archer, 1963)

This implies that during the generation of a solution, sketching and modelling serve to externalise the content of a mental image, creating traces and unburdening the working memory. They trigger information retrieval from memory and

In the problem-solving perspective, the use of sketching is intended to externalise the content of a mental image, unburden the working memory and free up space for other tasks in a working process. The resulting representation gains its role in retrospect: as a means to an end, a backup that records a solution to a sub-problem. Once it is created the designer proceeds with solving the remaining sub-problems, and will later come back to the preceding representations in order to combine them with other sub-solutions if needed. Further, externalisation activities enable the carrying out of systematic explorations based on the methods proposed in the problem-solving perspective.

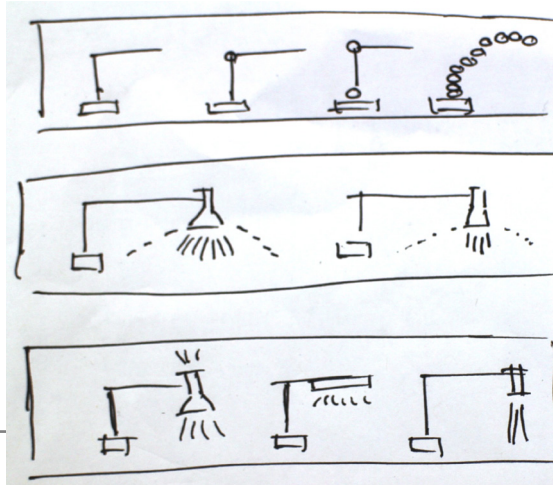


Figure 3 - Extenalisation activities: memory support.

free up space for working out the remaining parts of the design problem. The representations are memory back-ups that can be used for creative reconciliation and evaluation of solutions. Further, they enable the carrying out of systematic explorations. Various efforts have been made to develop and improve computer-modelling programs in order to facilitate this process. These contributions have had a large impact on product design and development in that they assist with the evaluation of the large numbers of solution assemblies.

The problem-solving perspective was based on the assumption that design problems were definable and easily decomposable. However, many design problems are not possible to decompose; they are not fully defined and involve uncertainty, confusing information, and value conflicts between different stakeholders. As a result they have not solution; they only have temporary resolutions (cf. wicked problems in Rittel and Webber, 1973). The methods of the problem-solving perspective did not suffice for finding resolutions to these unique problems. Furthermore, the notion that one general approach for solving problems was viable did not capture the artistry involved in dealing with wicked problems. This view also assumed a dualism between knowing and doing that ignored the tacit mode of knowing-in-action. In reaction to these assumptions, radically new ways emerged of describing how wicked problems are addressed in design practice.

2.2 DESIGN AS PROBLEM SETTING

Taking the notion of wicked problems into consideration, Schön (1983) described how designers approach these problems and navigate between their conflicting values and constraints through problem setting - a process that involves looking at the problem from different angles and setting a frame for the problem situation. In this process, the designer experiments with reframing the problem (what Schön called "*move experiments*"), oscillating between details and reflections on the implications and consequences that each experiment has on the whole. This leads to a questioning of assumptions about the problem situation and gives rise to new insights and reconstructions of the initial framing, which can then be tried again.

"*The designer's moves tend, happily or unhappily, to produce consequences other than those intended. When this happens, the designer may take account of the unintended changes he has made in the situation by forming new appreciations and understandings and by making new moves. He shapes the situation, in accordance with his initial appreciation of it. The situation "talks back," and he responds to the situation's back-talk.*" (Schön, 1983, pp. 78-79)

In this view, "*problem solving is a part of the larger experiment in problem setting*" (Schön, 1983, p. 165). This involves reflection-on-action* which occurs after having engaged in an activity, and reflection-in-action which occurs during the practice where knowing and doing are interwoven components of knowledge generation. Gedenryd (1998) argued that underlying reflection-in-action is a set of cognitive abilities that involve an interaction between mind and world for using and testing knowledge rather than detached reflections. This interactive inquiry** generates practical advantages rather than just mental processes (Goldschmidt, 1991).

The language of designing is a parallel process of sketching and speaking about design in order to teach, learn and communicate. This is carried out in a fluid manner where sketching extends thinking in the moves experiments, and reflection supports making subsequent marks on paper. Schön's dialectical theories on professional artistry were based on a close inspection of conversations between students and supervisors using sketching, where demonstrating, advising, questioning, negotiating and criticising directed the learning experience. He argued that designers' competence, understanding and feel for the material and media are crucial for constructing and manipulating representations that enable rigorous experimentations, and reflection-in-action.

"*A designer makes things. Sometimes he makes the final product; more often, he makes a representation – a plan, a program, or an image – of an artefact to be constructed by others. He works in particular situations, uses particular materials, and employs a distinctive medium and language*." (Schön, 1983, p. 78)

EXTERNALISATION ACTIVITIES IN THE PROBLEM-SETTING PERSPECTIVE

The externalisation activities of the reflective practitioner involve manipulating representations through experiments to explore and test consequences. These are moves by which the practitioner tries to cause a desired change in the situation. The results of each move talks back to the designer who reflects over the consequences, leading to further move experiments.

Sketching is considered central in this view, and scholars have highlighted the different ways it extends designers' cognitive information-processing capacity (see Figure 4 for an overview), and assists designers in considering the consequences of making a particular move (Schön and Wiggins, 1992). Sketches enable designers to operate in a virtual context, a constructed representation of the real world or laboratories for experimenting and testing assumptions and hypotheses (Schön,

* This view is rooted in Dewey's learning by doing, which highlights the role of experimentation in the generation of new knowledge as a result of engaging in various activities (Waks, 2001).

** This view is closely linked to the idea of distributed cognition, where human knowledge and cognition are considered to arise from the coordination between internal and external representations (Hutchins, 1995).

1987). In these labs, designers embody their framings in representations that may include prototypical elements, features, relations, as well as actions and norms used to address the problems (Schön & Wiggins, 1992). In other words, product representations become frames showing the designers' problem setting. These frames allow for expanding the problem space through the emergence of new and unintended interpretations and representations. In other words, designers can see or read more information in their representations than what was initially intended or imagined. These unintended consequences feed directly back into the sketching, through which designers gather further evidences, and advance their understanding of the problem. Some important benefits of sketching according to Schön (1987), are that: (i) it provides a cheap and affordable environment with reduced levels of constraints than in the real world; e.g. interwoven elements in the real world can be separated in drawings; (ii) the speed of drawing can be varied, e.g. slowing down to think or speeding up sequences of events that would take a long time in the real world; and (iii) sketching leaves permanent traces that the designer can return to and review any time.

Drawing on Schön's work, other researchers have further explored sketching and design. According to Ehn (1988), the non-linguistic character of product representations allows for involved practical understanding and experience beyond language (and propositional knowledge), not just detached reflections. He further discussed how these representations bring earlier experiences and reflections to mind, and can be seen "*as reminders and as paradigm cases for [our] reflections on existing and future [computer] artefacts and their use*". Gedenryd (1998) argued that the highly fluid and efficient process of drawing allows for the customisation of properties and work processes. For example, exploratory sketches enable designers to generate ideas (based on their knowledge of the situation) very rapidly without testing them. The sketches are then used to focus on parallel solution approaches

Viewing design as a reflective practice led to externalisation activities being seen in a new light: from a passive storage facility to actively talking back and helping shape designers' understanding of the situation. These activities allow for inquiry through exploration (shifting through alternatives) and analysis (evaluating, and discovering new opportunities). Design representations, in this view, are dynamic; they are pieces of knowledge that not only show what designers know and anticipate, but also what they don't know and can't foresee. The professional experience and tacit knowledge of design practitioners enable them to engage in activities of this kind.

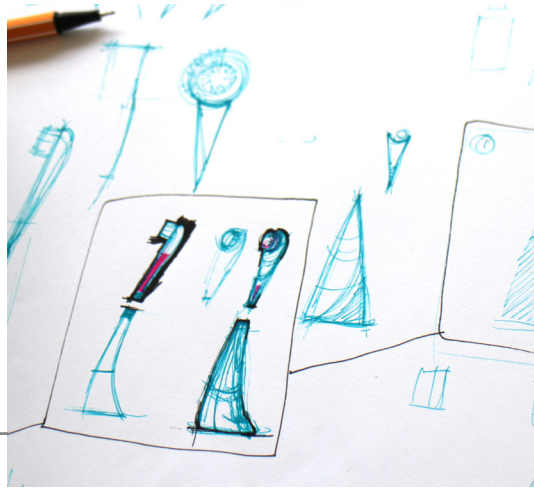


Figure 4 - Extenalisation activities: aid for inquiry.

and possibilities without getting distracted with details. Experimental sketches, on the other hand, are more concrete and used for testing a solution. They may include certain aspects of a design in full detail, while leaving out other aspects. By starting out with exploratory sketches and incrementally approximating to details, the designer will eventually arrive at a satisfactory solution. In this process, thinking and drawing go on hand in hand, and jointly enable the designer to move forward in understanding the problem and approaching it by different means.

The language of designing is not, however, not limited to sketching, though past researchers have mainly focused on sketching. Other forms of externalisation activities yield other qualities than sketching; for example, in clay modelling the backtalk is not only visual but also tactile, and it therefore provides other triggers for reflection-in-action.

It is important to highlight that the dialogue between the designer and the medium may also extend to other stakeholders. In Schön's analysis of the conversation between the tutor and the student, the student is not represented as an active contributor to the situation, but rather as a listener who takes in information and observes the move-experiments that the tutor carries out. The design process, however, is an activity shared among different stakeholders who may be equally involved in interacting with the media. Seeing design as a collaborative practice takes these aspects into consideration.

2.3 DESIGN AS A COLLABORATIVE PRACTICE

Designing and developing new products is a complex task that requires the integration of different skills, viewpoints and values from different disciplines. According to Minneman (1991), the evolution of design solutions depends heavily on negotiation strategies and social interactions among individuals as they strive to establish, maintain and develop a shared understanding.

Apart from intensive collaborations between various stakeholders within the context of a design firm, design processes can also involve user participation. Participatory design practice* to empower users and reduce the gap between the designer's conception of the problem and the real needs and goals of the users (Lie, 2011). This may take various forms: (i) treating users as sources of information by using methods from the social sciences to gather and understand their views, and engaging in ad-hoc evaluations and analysis of the information gathered in user tests, (ii) borrowing marketing techniques and ethnographic approaches, e.g. in probes to elicit user needs, and (iii) engaging in creative collaboration, e.g. in workshops for design of possible futures (Sanders and Stappers, 2008). In the

* This view evolved from a social and historical movement in the Nordic countries in the 1970s, where labour union policies promoted a democratic development of workplaces and computer systems, by involving users in the development processes (Ehn, 1988).

latter form of participation, users become active stakeholders and bring their own expertise to the design process.

In this view, design expertise "*is distributed among all stakeholders, and […] the design process has an argumentative structure in which one [has] to make up one's mind in favour of, or against, various positions on each issue*" (Ehn, 1988). The sources of ideas in such process, according to Bucciarelli (1988), can be found in the conversations between participants. In this collaborative process of reflection-in-action, designers help the people to share experiences and knowledge, and take part in the decision-making (Sanders and Stappers, 2008). Collaboration between different stakeholders with different perspectives, values and skills is an information-intensive process is organised around design representations (Henderson, 1991).

EXTERNALISATION ACTIVITIES IN THE COLLABORATIVE PRACTICE PERSPECTIVE

Various representations are made in these collaborative processes, either by the individual designer or together with the different stakeholders. In the collaborative practice perspective, researchers have ascribed roles to externalisation activities based on the motivations and purposes behind each activity and its resulting representations (see Figure 5 for a summary). Some have also discussed how these representations can facilitate negotiation in the design team, or can create a shared focus of attention and organise group participation (cf. conscription devices in Henderson, 1991). In addition, they symbolise agreements between the different stakeholders (Bucciarelli, 1988). Other researchers see representations as facilitating interaction between different stakeholders and empowering participants to express their ideas (Sanders and Stappers, 2008).
Design representations inscribe, embed, and contain insights and knowledge from

The collaborative perspective on design practice highlights how externalisation activities and the resulting representations enable different stakeholders to share their values and make their knowledge available to others. This perspective advocates a mediating role for design representations; they facilitate discussions among the different participants and help them organise their teamwork. In this view, a designer's skill in making representations serves to achieve a better understanding of the design problem, not only for the individual designer but also for the other stakeholders in the design process.

Figure 5 - Extenalisation activities: collaborative support for inquiry.

the different team members; they are used in a dialogical way during the process (cf. epistemic objects in Ewenstein and Whyte, 2009). Furthermore, representations may be made to integrate the "*seemingly incompatible types of material, knowledge, and perspectives*" (Gunn, Otto and Smith, 2013) and knit together different pieces of information from various stakeholders to facilitate the reading of alternative meanings and the formation of associations and collaborations across boundaries (Henderson, 1991). In addition, the non-linguistic character of product representations makes it possible to experience them beyond language and propositional knowledge "since they are less abstract and less alienated from practical use situations" (Ehn, 1988). This makes design representations valuable for practical understanding and helps with approximating the ordinary situations of interacting with artefacts.

2.4 SUMMARY AND IMPLICATIONS FOR THE PROJECT

A common thread that emerges from the above inquiry is that sketching and sketches are understood as supporting design processes (see Figure 6 for an overview), while physical and digital modelling, and the ways in which they may aid designers, are less frequently discussed in the reviewed perspectives. Discussions tend to focus on the resulting representations, for instance how they vary in nature and how they may facilitate collaboration. Designers work, however, with different tools, materials and media in making product representations. What they do during these activities and how their ideas come about and grow by using the different media, have not been extensively addressed in the design literature.
A concern regarding the reviewed literature is what of sketching and the design process is captured. For example, Schön's (1983) work was based on a case from a participant observation study that involved reviewing architectural education

DESIGN AS ...

	... problem-solving	... problem-setting	... collaborative practice
Key concepts	Optimisation, Rational Search	Inquiring, Reflective Conversation	User Testing, Collaborative Creativity
Externalisation Activities	Unburdening Working Memory, Systematic Exploration	Move Experimenting	Facilitating, Mediating, Negotiating, Value and Information Exchange
Design representations	Memory Back-Ups, Structured Matrices	Laboratories, Frames	Demonstrators, Knowledge Pieces, Boundary Objects

Figure 6 - Design representations in different theoretical traditions.

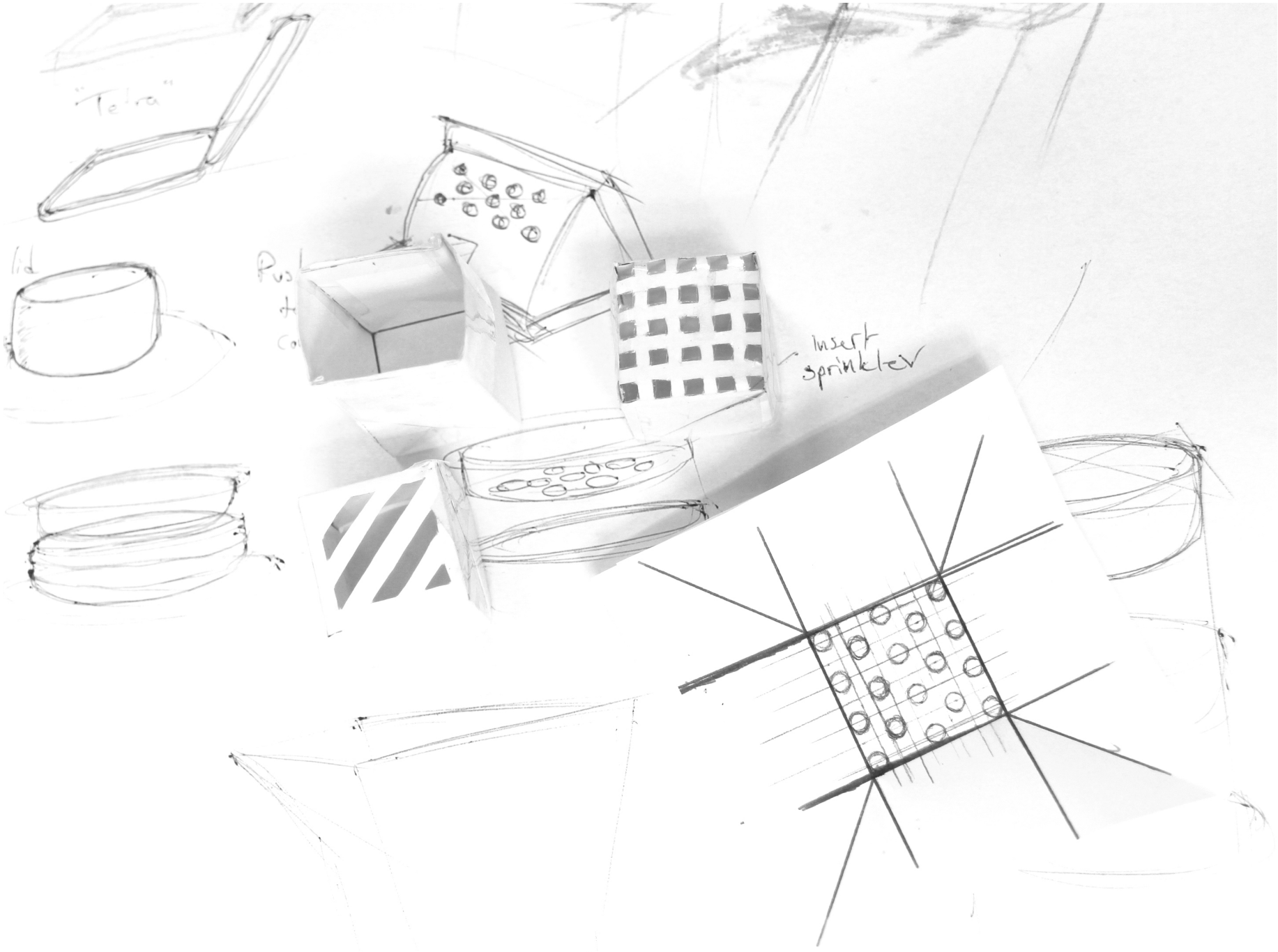
in the late 1970s at several locations in the United States. His thick description of the design process mainly involves analysing a conversation between Petra (a first-year architecture student) and Quist (the studio master)*. The conversation tool place during a review session of the student's design work, where the studio master demonstrates for the student how the work should be done. Furthermore, Schön's descriptions reflect neither the initial nor the final phases of the design work; they capture an episode of the process in which the student's progress is reviewed after a months' work. Various studies have built on Schön's arguments, for example Gedenryd's (1998) discussion of designers' work, which highlighted insights regarding the interactive nature of sketching. This, however, involves scant empirical material, being mainly based on the conversations between Quist and Petra.

Other empirical studies used more or less experimental settings. For instance, in a seminal protocol analysis of a two-hour design exercise with twenty participants, several aspects of design work were investigated (Cross, Christiaans and Dorst, 1996). However, concerns could be raised regarding these studies in terms of (i) the design process being scaled down, and (ii) the conditions under which this work was carried out, for example designers having to think aloud while working.

Designers' experiences of using different media, tools and representations, and the roles these activities have in design work for the individual practitioner, are relatively unknown. Investigating this requires having conversations** with designers rather than constructing situations in which designers are required to think aloud while designing. When sketching, designers do not necessarily think aloud. Most of the time, they are sketching or modelling on their own, after which they share their ideas with others. Therefore, analysing their conversations with different stakeholders does not give a complete understanding of these activities. Furthermore, designers' use of different externalisation activities takes place during the entire course of the design process, and further inquiries into these activities throughout the entire design process are required.

* In another publication, (Schön and Wiggins, 1992) also included a protocol study on an architectural design assignment with 7 designers: 3 young instructors at MIT, 1 instructor from Israel, and 3 practising architects.

** There have been interview studies with designers (especially architects), where the design process is studied on a general level, e.g. the relationship between problems and solutions in the interviews that Lawson (2006) and Darke (1979) carried out.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RESEARCH APPROACH

The author's worldview and its implications for this research are discussed in this chapter. Further, the overall research approach that was taken to address the research questions is presented.

3.1 BACKGROUND AND EMPIRICAL CONTEXT

Researchers' context, background and personal experiences can determine and influence their worldviews (see e.g. Creswell, 2013) and these aspects are therefore addressed here to clarify the research approach taken in this work.

Most of the author's educational background concerned finding solutions for products that accommodate and satisfy the needs of different users. This involved focusing on the users' needs and seeking to understand their subjective interpretations and their experiences of products using various probing methods. These methods are widely used in design practice to acquire knowledge about users' interactions with the products. This knowledge is what designers rely on, and constitutes the theories on which they act. The author acknowledges that these approaches have become her habitual ways of understanding facts and perceiving peoples' different realities, and that she has relied on them during her PhD studies.

The project was initiated in the course of the author's work as a teaching assistant, where she was given the opportunity to investigate students' design processes based on observational data was gathered on a regular basis. The availability of observational data facilitated entering the research setting. This is an opportunistic approach that involves relying on unique circumstances and timely events (cf. opportunistic research in Riemer, 1977). Given the authors' background, it was inevitable to see designers as users of different tools with which they generate a large amount of data, externalise their ideas, and progress towards a solution regardless of the vast differences between the problems they deal with.

3.2 THEORETICAL CONSIDERATIONS

Clarifying the authors' ontological and epistemological assumptions, and methodological approach is essential for interpreting "*the meaning of research questions, the purposiveness of research methodologies, and the quality of research findings*" (Crotty, 1998, p. 17). This involves highlighting one's views on knowledge and the nature of reality and its implications.

The author's basic assumptions regarding knowledge are that it is both constructed and based on the external reality (cf. the pragmatist view cited in Johnson and Onwuegbuzie, 2004). In other words, the author acknowledges the existence of an external world regardless of human's presence and their ability to measure or observe it*. However, what matters to the author is that reality is received, experienced, and interpreted differently by different people: "*individuals seek understanding of the world in which they live and work. Individuals develop subjective meanings of their experiences – meanings directed toward certain objects or things*" (cf. constructivist** epistemology cited in Creswell, 2013, p. 8). This view has the following implication for the present research:

In this thesis, the experimental and scientific investigation involve inquiring into designers' activities, for example what they do, what works, and what helps them find solutions. These activities (including the media and representations they involve) may have multiple roles for designers, as they experience and use them differently. Therefore, this work focuses on acquiring knowledge based on designers' descriptions of their activities and experiences, as well as the roles and meanings that they associate with these activities. The accounts that different individuals give of their experiences "*are varied and multiple, leading the researcher to look for the complexity of views rather than narrowing meanings into a few categories or ideas. The goal of the research is to rely as much as possible on the participants' views of the situation being studies*" (Creswell, 2013, p. 8).

3.3 METHODOLOGICAL CONSIDERATIONS

Methodology is described as "*the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes*" (Crotty, 1998).

Inquiring into the meaning of phenomena from the perspective of a participant has implications for data collection and analysis. The present work seeks to elucidate the meaning of externalisation activities and design representations

* Worldview denotes "a general philosophical orientation about the world and the nature of research that a researcher brings to a study" (Creswell and Clark, 2011, p. 6).

** According to the constructivist worldview (as cited in Lincoln and Guba, 1985), "realities are apprehendable in the form of multiple, intangible, mental constructions, socially and experientially based, local and specific in nature". Crotty (1998) highlights the differences between constructivism and constructionism (terms otherwise often used interchangeably). Constructivism is an individualistic understanding of the constructionist position, describing the individual engaging with the world and making sense of it. Constructionism, on the other hand, does not concentrate on the individual position; its main concern is that individuals are provided with meanings and learn these meanings in the cultures they belong to. The author acknowledges her focus on the individual designer's activities i.e. a constructivist stance. However, she does not reject the role of enculturation in design practice and the meanings that designers are provided with in their educations and at their workplaces.

from the point of view of designers. This implies using qualitative methods that prompt designers to give accounts of their activities.

The overall research approach involves combining multiple forms of qualitative research methods and sources. This approach neutralises the deficiencies of one method, enables the researcher to better interpret the findings, and secures a deeper understanding of the phenomena (cf. triangulation in Thurmond, 2001).

3.4 OVERALL RESEARCH APPROACH

What is presented in this thesis is in part based on reviewing the literature for what others have found. Furthermore, student diaries were available, which presented an opportunity to analyse documented empirical material. However, concerns could be raised regarding this material in terms of (i) the students being novices, and (ii) the conditions under which this work was carried out. Hence, a conscious effort was made to also incorporate insights from the opposite of novices: award-winning expert practitioners who were recruited for the interview study.

The overall approach of this project may be described as an exploratory design with sequential timing. This involved identifying themes that emerged from the literature and further developing them based on the accounts that students and practitioners provided of their activities. Figure 7 provides an overview of the research progress and methodological considerations in different phases of this work.

In addition to the studies included here, throughout the project the author has engaged in various activities to further explore the topic, for example holding workshops and conducting focus groups (see additional publications).

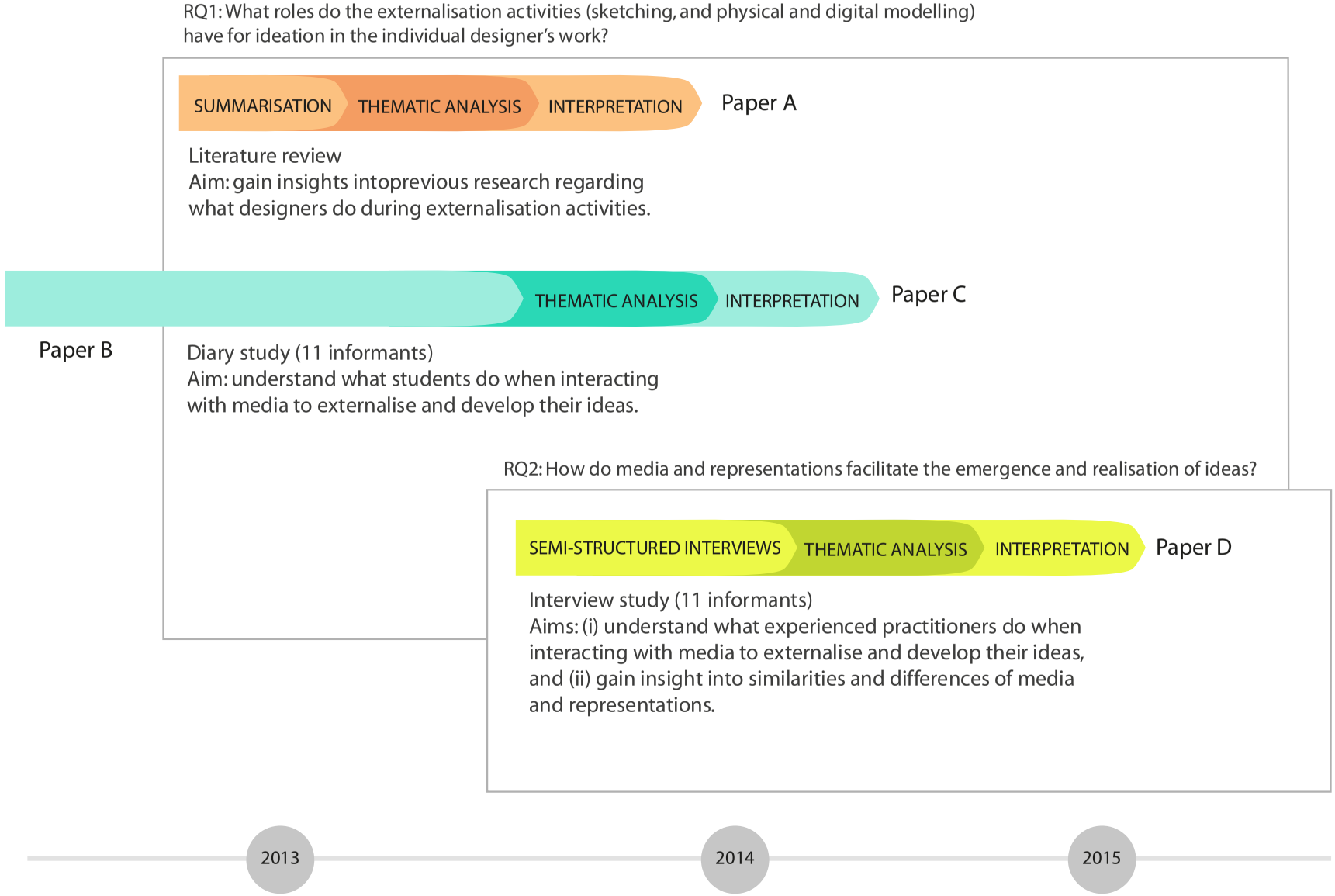

Figure 7 - Overall research approach.

THE STUDIES

The research process involved literature reviews, a diary study and an interview study. The procedure of each study and its methods are described in this chapter.

4.1 LITERATURE REVIEW

Reviewing the literature has been an on-going process throughout this project. There were however some peaks in this activity, one of which formed the basis for the succeeding studies in this thesis, and it is therefore briefly described here.

The primary aim of this review was to get an overview of research concerning externalisation activities and design representations, and to examine their implications for the design process. A skimming of the literature revealed that research on externalisation activities and their roles mostly addressed sketching, while a broader, more holistic and systematic review of physical and digital modelling was lacking. Paper A addresses the insights acquired from this review and describes its methodological considerations in detail.

PROCEDURE

The search for relevant literature was initiated by defining a set of inclusion and exclusion criteria. In accordance with these the review (i) included research regarding sketching, and physical and digital modelling*, (ii) addressed designers' individual processes and not collaborative activities, and (iii) in addition to product design and development discipline, also included architecture, engineering and mechanical design, as well as communication design. The analysis of the reviewed literature followed, according to Hart's recommendations (1998): summarising, extracting, tabulating and mapping key ideas, theories, and interpretations. To establish a frame for categorising roles of design representations, the notion of visual thinking** was considered. Finally, to explain and exemplify the identified roles, observational data that was gathered from an educational context was consulted.

* In total, 45 sources were reviewed, most of which were journal publications. The exceptions were 5 (peer-reviewed) conference papers and seven books that were regarded as professional literature (e.g. design-related books that include anecdotal evidence on externalisation activities). Among theses, 23 publications addressed sketching, ten digital modelling, and seven physical modelling, and the remainder addressed all three. The majority were published in the 2000s, two were published in the 1980s, twelve in the 1990s and five in the 2010s.

** Visual imagery, according to McKim (1980), is defined as an interaction between (i) doing, e.g. sketching (physical aspects), (ii) seeing (sensory aspects), and (iii) thinking (cognitive aspects).

4.2 DIARY STUDY

Prior to this study, design diaries were used as a teaching method in a masters course* on initiating and documenting self-reflections. Paper B elaborates on the methodological considerations regarding the structure and use of diaries as an educational method. The design diaries yielded large amounts of observational data and provided an opportunity to investigate students' design processes. The aim of this inquiry was to compare the empirical material with the literature review. This involved investigating whether the roles identified in the review were manifested in the diary entries, and enabled comparing and contrasting the different activities. The results from this inquiry are presented in Paper C.

PROCEDURE

The accumulated observational data in diaries from the study year 2011-2012, with a total of 11 participants, were considered for content analysis. These diaries were gathered on a weekly basis over a total of seven weeks. They comprised of students' self-reflections on their design processes, the underlying motivations behind their activities, and visual journals showing their weekly progress.

A thematic analysis was made involving a top-down approach in three stages: (i) identifying, categorising, and clustering diary entries that reflected the roles identified in the literature, (ii) identifying sub-categories to complement the literature review, and (iii) tabulating the findings for cross-comparison to explore the potential influences of the identified roles. In an additional step, the findings were also quantified to assess the prevalence of identified themes (as recommended by Miles and Huberman, 1994) enable comparison between the different activities.

4.3 INTERVIEW STUDY

In order to acquire a deeper understanding of externalisation activities and their roles, experienced practitioners were interviewed. The primary aim was to further investigate how the roles identified in the earlier literature review were manifested among practitioners who have fluency in different externalisation activities and are outside the educational context addressed in the diary study. The rationales and motivations behind designers' interactions with media and representations were explored to understand the qualities that designers associate with media and representations in their design processes. The insights from this study are presented in Paper D.

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* Since 2011, the author has been a teaching assistant in a masters course called Advanced Form Design (7.5 ECTS) offered as an elective course in the Industrial Design Engineering programme at Chalmers University of Technology. The course requires the students to look for approaches that can lead to a creative and experimental, yet structured, generation of formal product solutions. Through an explorative process moving abstract form generation to a concrete product design development, the students work in groups on a project to develop creative form ideas and solutions for a dinnerware product with a high level of novelty, aesthetic detail, and functionality.

PROCEDURE

A total of 11 semi-structured in-depth interviews were conducted with senior representatives of Swedish design organisations that had received a Reddot Design Award* during 2012-2013. The informants were asked to bring design representations that were made during the process of designing the award-winning products. These were used to facilitate communication and served as a basis for reviewing their design processes and eliciting unique comments regarding their activities (cf. photo elicitation interviews in Clark-Ibáñez, 2004).

The analytical effort involved transcribing the interviews, a top-down analysis based on the earlier literature review, and a bottom-up analysis that involved the coding, memoing and identification of new themes and sub-themes (cf. theory-led and data-led analysis approaches in Howitt (2013).

4.4 COMPILATION OF FINDINGS

Throughout the course of the research, the findings regarding RQ1 have been refined. RQ2 however was mainly addressed in the interview study. These findings from the different studies are compiled together and presented in Chapter 5.2.

* The Reddot Design Award is a an internationally recognised design competition (Source: red-dot.org).

OUTCOMES

5.1 SUMMARY OF PAPERS

Central outcomes were published in four papers, and are briefly presented here.

5.1.1 PAPER A: ROLES OF EXTERNALISATION ACTIVITIES IN THE DESIGN PROCESS

Paper A provides an overview of definitions and terminologies with regard to externalisation activities - i.e. sketching, and physical and digital modelling - and presents a review of design research literature dealing with these activities, and their roles in design processes. Three categories were identified to describe the roles of these activities in the design process: (i) physical roles, ways in which engaging in externalisation activities supports, facilitates or enables the making or manipulating of something; (ii) sensory roles, how carrying out these activities facilitates the seeing, touching, feeling, or hearing of something with respect to the artefact; (iii) cognitive roles, how engaging in these activities supports, facilitates, or enables thinking and/or gaining knowledge about something.

This paper highlights that the roles identified in the literature mostly concern sketching. Moreover, sketching is considered to facilitate idea generation in design processes, while digital modelling is seen as a threat to creativity. This gave rise to a need to investigate the manifestations of the identified roles in design processes considering not only sketching, but also physical and digital modelling.

5.1.2 PAPER B: A COMPARISON OF DIARY METHOD VARIATIONS

Paper B deals with the methodological considerations related to use of diaries and journals in design education. It recommends a variant of the diary method that facilitates reflections among students and enables the gathering of data on their design processes. In addition, collecting diaries on a regular basis enables different activities to be investigated throughout the design process.

5.1.3 PAPER C: MEDIA AND REPRESENTATIONS IN PRODUCT DESIGN EDUCATION

Paper C aims to examine what students do in their design processes and seeks manifestations of different roles* in the design diaries of students. The results show that sketching and physical and digital modelling were used in similar ways. In other words, most of the roles that were associated with sketching (in Paper

* These roles were identified in the literature review (Paper A).

A) also applied to physical and digital modelling. Further, several sub-categories were identified for some of the roles. These involved the different aspects that the students dealt with, for example verbal and visual data, perspectives, components, dimensions and proportions, functionality and use situations. Other modifications regarding the identified roles were combining categories that were conceptually interwoven: fragmentation and integration, as well as embodiment of ideas and generation of ideas.

Several themes emerged from the results: (i) the conversations between the designers and media are not limited to sketching, but extend to physical and digital models as well; (ii) immediacy regarding feedbacks and engagement were dependent on the students' skill and fluency in using media; those who were skilled in using a medium found it more immediate than the alternatives; (iii) media and representations may hinder the process by imposing certain solutions and repertoires, resisting change, and presenting information that students found inconsistent with their mental images.

5.1.4 PAPER D: ROLES AND QUALITIES OF SKETCHING, AND PHYSICAL AND DIGITAL MODELLING

Paper D explores what experienced practitioners do during their design processes, specifically regarding externalisation activities, and the resources at their disposal for pursuing new ideas. Instances of the previously identified roles were notable in designers' accounts of their activities and processes. These were however categorised in terms of: making (physical roles); perceiving (sensory roles); and thinking (cognitive roles)*.

In addition, a taxonomy was developed to describe some prominent qualities of the media and representations that support designers during these activities. This addressed qualities such as the extent to which they are malleable, accurate, or fixed. By providing a terminology for classifying media and design representations, these help with understanding some parts of the design process.

The findings in this paper also highlight that fluency in manipulating media and representations has a large effect on the extent to which the potential qualities of media and representations are realised.

* These changes were made to further clarify the concepts. In addition, the new terminology is in line with McKim's (1980) categories of visual imagery: drawing, seeing, imagining.

5.2 ANSWERS TO RESEARCH QUESTIONS

Findings from the the different studies are put together in this section in order to answer the research questions.

5.2.1 ROLES OF MEDIA AND REPRESENTATIONS IN EXTERNALISATION ACTIVITIES

During externalisation activities, designers attend to different types of information, they sketch and/or model ideas from scratch, they make modifications and variations of their ideas, they decompose problems, they perceive different types of information, they unburden their working memory, they attend to specific aspects of the problem, and they interpret, evaluate, and learn. These are enabled and facilitated designers' use of different media and their making of representations in the course of externalisation activities.

RQ1: What roles do the externalisation activities (sketching, and physical and digital modelling) have for ideation in the individual designer's work?

This work highlights three categories of roles for media and representations in externalisation activities (see Figure 8 for an overview). These roles were first identified from the literature review, while the diary study and the interview study sought to explore their manifestations in design work.

IN MAKING

Roles related to making something address ways in which media support, facilitate, or enable the embodying, realising, and/or materialising of ideas during externalisation activities (see Figure 9 for an overview).

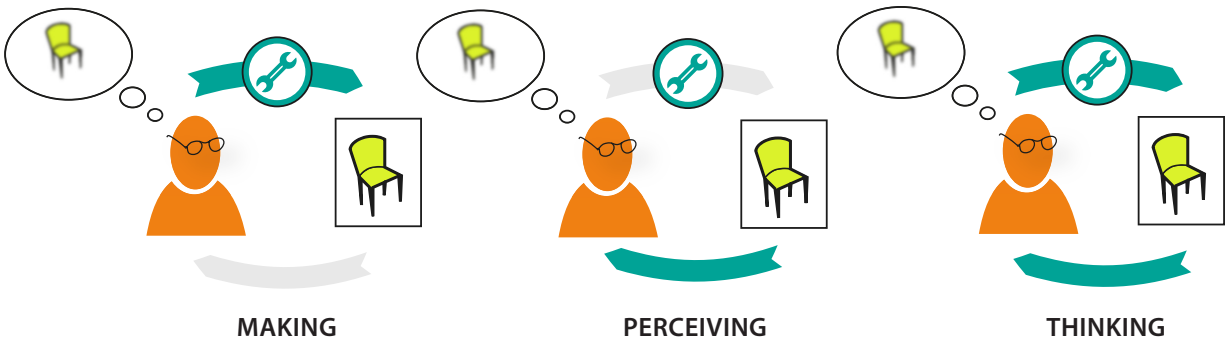


Figure 8 - Roles of media and representations related to making, perceving, and thinking.

MEDIA ...

... FACILITATE GENERATION OF ALTERNATIVES.

Exploring and realising ideas were accomplished either through working with various fundamentally different alternatives, i.e. radical transformations, or through making small changes to one idea, i.e. incremental transformations.

... ALLOW PROBLEM FRAGMENTATION & INTEGRATION.

Making representations involved fragmenting different aspects of the artefacts, e.g. functions, views, or isolated visual and spatial properties, and re-integrating them when needed.

... TRIGGER CERTAIN SHAPE REPERTOIRES.

The way surfaces were made and manipulated was considered to be steered by the media .

... ENABLE DIRECT AND IMMEDIATE ENGAGEMENT.

Manipulating visual and geometric properties of products, making changes regarding spatial properties (e.g. dimensions or location), and working with proportions were considered direct and immediate in some media.

Figure 9 - Roles of media, in making, based on the informants' reflections on their activities.

REPRESENTATIONS …

... DISPLAY VISUO-SPATIAL PROPERTIES.

The visuo-spatial information conveyed through representations involved e.g. shape, dimensions, composition, and organisational and proportional associations between different components.

... CONVEY TANGIBLE PROPERTIES.

To experience the tangible aspects of artefacts and physically trying out a solution was considered invaluable, especially with products that require physical interactions, e.g. handheld objects or things that require balancing one's weight or carrying something.

Figure 10 - Roles of representations, in perceiving, based on the informants' reflections on their design activities.

IN PERCEIVING

Roles related to perceiving something are related to the representations, and how they assisst designers by conveying information and providing stimuli regarding different aspects of an artefact (see Figure 10 for an overview).

IN THINKING

Roles related to thinking something concern the media, representations and externalisation activity as a whole. These roles address ways in which engaging in externalisation activities support, facilitate, or enable the process of thinking and/or gaining knowledge about something (see Figure 11 for an overview).

MEDIA AND REPRESENTATIONS …

... PROVIDE AN EXTERNAL MEMORY SPACE.

The possibility to capture ideas and "move on" was considered essential for remembering one's thoughts clearly. Bringing together various representations in larger displays enabled monitoring not only a single idea, but also a spectrum of thoughts.

... ALLOW FOR SELECTIVE ATTENTION.

The different aspects in focus were exemplified: specific visuo-spatial properties, a specific view, or a function or a component of the product.

... FACILITATE VISUAL THINKING AND IMAGERY.

Imagining consequences of manipulations was facilitated by making a representation and using it as a resource to rely on in subsequent transformations.

... ENABLE LEARNING THROUGH HIGHLIGHTING PROBLEMS.

By posing questions, trying out an idea and eliminating its errors, making representations facilitated learning about a problem or a potential solution.

... FACILITATE INTERPRETATION, EVALUATION & VERIFICATION OF IDEAS.

Making representations was considered a "catalyst" that helped in interpreting and evaluating different aspects of ideas.

... TRIGGER EMERGENCE OF NEW IDEAS.

New and unexpected solutions emerged during externalisation activities. Sometimes they were considered to be entirely due to the specific activity and unlikely to have been reached at otherwise.

Figure 11 - Roles of media and representations, in thinking, based on the informants' reflections on their design activities.

5.2.2 QUALITIES OF MEDIA AND REPRESENTATIONS IN EXTERNALISATION ACTIVITIES

The second aim of this work has been to highlight and explain how designers perceive differences and similarities between various media and representations in relation to coming up with and externalising their ideas.

RQ2: How do media and representations (in externalisation activities) facilitate emergence and embodiment of ideas?

Drawing on designers' accounts of their activities in the interview study (see Paper D), a taxonomy was developed to describe some inherent qualities and characteristics of media and representations in externalisation activities. This encompasses nine qualities, five regarding media and four regarding representations, each of which presents a bi-polar scale (see Figures 12-13).

PLASTICITY OF MATERIAL

MALLEABLE ◆ RIGID

Some media provide malleability and flexibility for making different variations while others are found to be relatively rigid and stale.

IMMEDIACY OF FEEDBACK

INSTANT ◆ DELAYED

Some media provide the possibility to represent ideas in a fast and brief manner. While some offer immediate feedback on visual properties e.g. shape and size of the artefact, others provide feedback on proportion in relation to the environment and the use situation.

DIRECTNESS OF INTERACTION

DIRECT ◆ REMOTE

The directness to the representations (e.g. pen & paper sketching or physical modelling) are preferred to the indirect interaction with models in digital media, especially since they require inputting what is being drawn e.g. whether it is a point, a straight line, a curve, or a surface.

EASE OF USE

EASY ◆ DIFFICULT

Sketching is thought to be intuitive, though difficult to use at times depending on the situation; e.g. some ideas may be easier to visualise through sketching, others through physical or digital modelling.

RESOURCE EFFICIENCY

CONVENIENT ◆ INCONVENIENT

Convenience is related to time and resources required in a specific context e.g. clay modelling might be more convenient for making organic forms, digital modelling for working with patterns and repetitions.

Figure 12 - Qualities of media derived from the informants' reflections on their design activities.

ICONICITY IN REPRESENTATIONS

SYMBOLIC RESEMBLANCE ◆ VISUO-SPATIAL ACCURACY

Some representations are accurate in showing spatial qualities, while others are precise in conveying visual properties of artefacts. Inspecting representations with visuo-spatial accuracy and resemblance to the envisioned physical reality was considered important especially when evaluating one's ideas, while the symbolic nature of sketches led to their generally being considered unreliable.

FIXEDNESS OF REPRESENTATIONS

FREE ◆ LOCKED

The possibility to rotate the representations in order to see the artefact from different points of view was considered valuable in physical and digital models.

RICHNESS AND PRECISION

VAGUE ◆ CLEAR

Digital models were considered to approximate reality due to the rich visual information they provide. This was however sometimes seen as a disadvantage when working with a preliminary idea. The vagueness and imperfection of sketches were regarded as facilitating a freed flow of idea generation.

TRACEABILITY OF PRECEDENTS

PERMANENT ◆ TRANSIENT

Some representations provide permanent and persistent traces of ideas. The ability to trace precedent ideas was however considered limited in some media. For example, in physical and digital modelling, typically the interim representations disappear if the designer does not save them while working. As a result, the digital or the physical model only represents the latest changes and traces, preventing designers from tracing the evolution of their ideas.

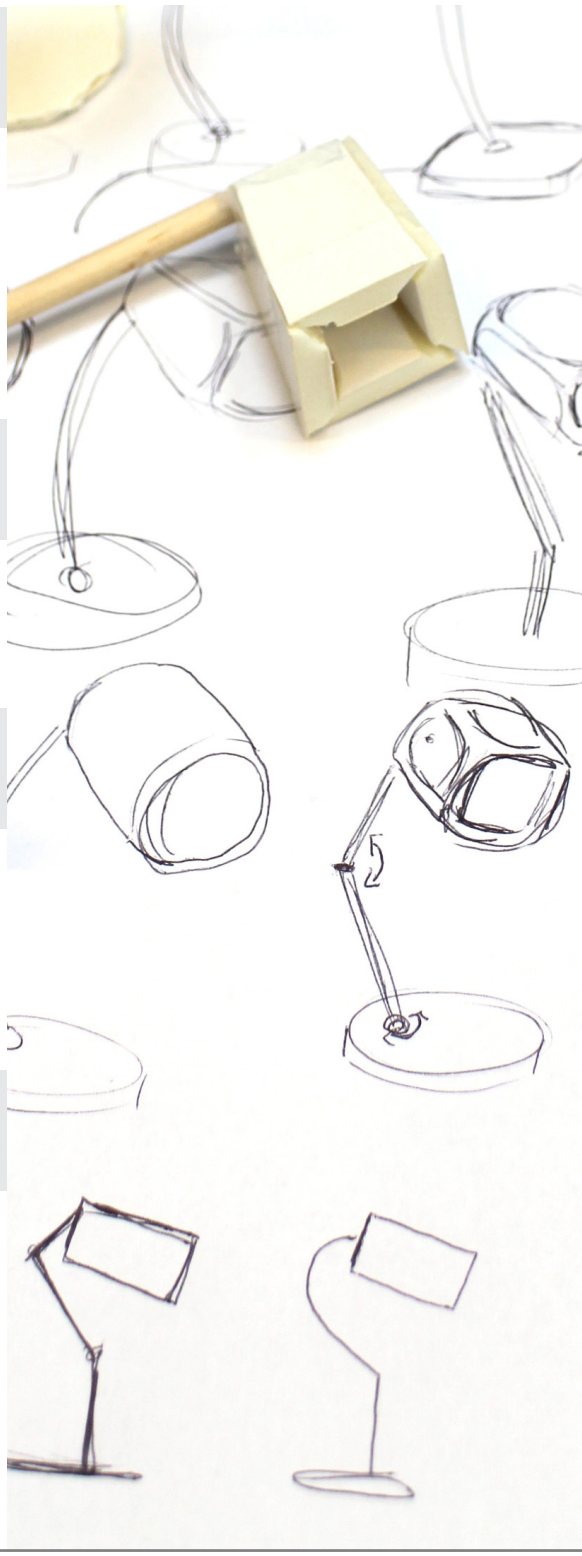
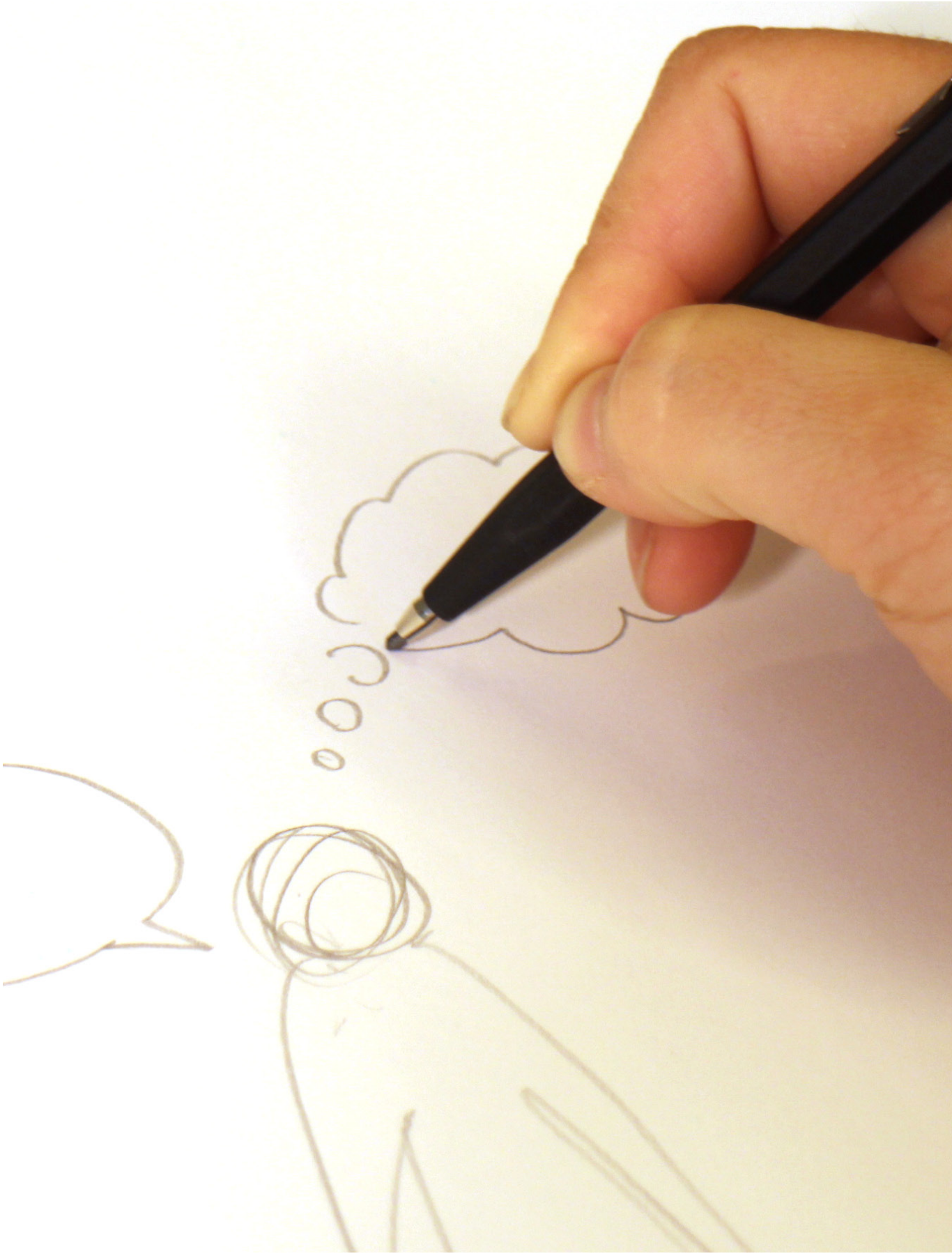


Figure 12 - Qualities of media derived from the informants' reflections on their design activities.



DISCUSSION AND IMPLICATIONS

The findings from the interviews and diaries are compared and contrasted with the literature in this chapter. More specifically, the discussion concerns roles and qualities of media and representations in externalisation activities, as well as the significance of designers' fluency and skill in using the different media and representations. Further, the implications and contributions of these findings are highlighted, as are reflections on the appropriateness of the research approach and the methodological considerations. These reflections conclude with some final words and ideas for further work.

6.1 WHAT DESIGNERS DO DURING EXTERNALISATION ACTIVITIES

Emergence and realisation of solutions occur during sketching, physical and digital modelling. Media and representations have a number of different roles that in a design process. Some of these roles are commonly discussed in the literature, for example how sketching facilitates generating alternatives and seeing and interpreting things, as well as helps to unburden ones' working memory. Some roles, however, have been given little attention in the literature, for example how externalisation activities trigger certain form repertoires and operations. Papers C and D provide examples of each of these roles.

The present work has provided a broad overview of the roles that media and representations may have in the act of creation. In addition, these roles were categorised in relation to what they enable the designer to achieve, for example roles regarding (i) how media enable the making of something, (ii) what information that representations convey, thereby enabling the designer to perceive something, and (iii) in what ways media and representations support designers' thinking. This conception is in line with Schön's view on how designers engage in a conversation with their sketches and how during this conversation they interpret and evaluate their ideas. What designers converse with during this dialogue, according to Schön (1983), are the ideas documented in representations. The present work however extends this view by considering the designers' conversations with the media and the representations.

The above classification simplifies externalisation activities, however. This simplification was made to facilitate understanding these acts of creation, which otherwise are complex in nature. It is therefore important to consider that the

identified categories are not necessarily independent constructs; they are likely to be overlapping, parallel or intertwined during externalisation activities*.

The findings highlight that the various roles frequently discussed in relation to sketching in the literature also apply to physical and digital modelling. In other words, the informants here seemed to be making the same use of digital and physical models as they would of hand-drawn sketches. Some scholars, however, raised concerns about digital modelling for this stage of the design process (e.g. Verstijnen, van Leeuwen, Goldschmidt et al., 1998, Lawson and Loke, 1997). The same view is held regarding physical modelling due to the time it may require, although very few studies have investigated the role of quick and rough physical modelling in ideation (see e.g. Brereton and McGarry, 2000). What follows is a brief discussion of some of the identified roles with respect to the different externalisation activities:

The choice of medium as well as the designers' fluency in working with the medium determines if and to what extent making radical transformations are possible. Both the diary entries and interviews highlight how the informants make radical transformations during sketching, and physical and digital modelling. The literature, however, considers it more or less inconvenient when making digital models (e.g. Bilda and Demirkan, 2003).

Different properties of an artefact are captured in - and conveyed through - the different representations investigated in the present research. Fragmentation enables designers to selectively attend to and think about limited parts of a task, which is only mentioned regarding sketches (e.g. Fish, 2004).

The findings suggest that all of the activities considered here facilitate visual thinking (considering that the whole process revolves around visual thinking and imagery). This contrasts with the conclusions drawn by Verstijnen et al. (1998) regarding how digital modelling may hinder visual thinking (more specifically combining and restructuring of patterns). The informants in this work described their processes of combining and restructuring different components of an artefact when making digital models. It is important to treat this comparison with caution, however, Verstejnin et al. (1998) had an experimental set-up where they investigated the sketching process, and based on this they drew conclusions regarding digital modelling; the present work draws on designers' accounts of what they did during different activities, and these accounts address different aspects of visual thinking.

In summary, the findings support previous work regarding the roles of sketching and show how these roles are also applied to physical and digital modelling.

* For further elaborations on the nature of interactive imagery, see McKim (1980).

6.2 SIMILARITIES AND DIFFERENCES IN MEDIA

The taxonomy/typology presented in Paper D describes some prominent qualities of media based on the informants' rationales for their activities. This taxonomy consists of five qualities for the media, each of which presents a bi-polar scale. Some of these qualities have been frequently discussed in the literature:

Plasticity of material and media was considered crucial for varying alternatives. Some have discussed that how sketching enables shifting from one idea to another (e.g. Goldschmidt, 1991), others how digital media with a high level of complexity bring about resistance to making changes (e.g. Robertson, Walther and Radcliffe, 2007).

Ease of use, immediacy of feedback, and directness of interaction in media may be compared with usability guidelines. Immediacy is related to the system's visibility, and directness to how the system matches the real world, if one were to use the usability lingo. Regarding sketching, e.g. Schütze, Sachse and Römer (2003), among others, have discussed the value of immediate feedback in sketching.

Convenience was discussed during the interviews in relation to time, resources and the relevance with respect to the problem at hand. Various sources have mentioned that the ubiquity of pens and paper makes sketching an unbeatably convenient medium. The findings here, however, provide examples of certain contexts in which other media are regarded as more convenient (e.g. when working on a skin for an electronic device, digital modelling is more convenient, while for a harness, physical models were found more convenient). Apart from the context, different designers can find different media more or less convenient as a matter of personal preference.

6.3 SIMILARITIES AND DIFFERENCES IN REPRESENTATIONS

The taxonomy/typology presented in Paper D describes four qualities of representations, each of which presents a bi-polar scale. Among these qualities precision is frequently discussed in the literature, others not:

Iconicity concerns whether representations are abstract or spatially accurate. According to the interviewees, the more that representations are spatially accurate, the more reliable they may be as a basis for making choices between the different ideas. Iconicity in representations has rarely been discussed in design literature. As product signs, they however are described as the relationship between a physical form to what it refers to in a product (see semantic functions in Monö, 1997).

Fixedness of representations concerns the extent to which a representation is either fixed and resists being moved in space, or allows the designer to easily view it from different directions and perspectives. This is seldom mentioned in the literature.

By conveying information regarding different viewpoints, representations that can be rotated in space have the potential to serve as additional references for the designer and can inspire and inform the subsequent steps.

Precision was associated with the level of detail and richness in representations. The informants, however, had contradictory views regarding precision; digital models were considered valuable for their precision and accuracy, but this lack of ambiguity was also considered a disadvantage in representing preliminary ideas. Ambiguity in sketches is considered to facilitate idea generation (e.g. Fish, 2004), and encourages the designers to shift their focus, thereby generating more alternatives (as cited in Purcell and Gero, 1998).

Traceability of precedents concerns whether representations allow access to all the interim ideas during the course of development. In physical and digital models, all the interim ideas are hidden and disappeared behind the final model, especially if there is no design history. Permanent traces of interim ideas may lead to having multiple reference point, each of which can inspire, inform, and trigger more ideas. This relates to another usability guideline, namely "recognition rather than recall". Sketches have been considered valuable for the "hard traces" they provide (Goldschmidt, 2003). Such traces are, however, less permanent in physical and digital models.

6.4 FLUENCY IN MANIPULATING MEDIA

Personal experiences and preferences have a great significance in the act of creation; e.g. while clay modelling suggests ultimate malleability, it may not be perceived as malleable if the designer lacks the required skills for manipulating clay or simply does not prefer working with clay. Reflecting on their choice of a medium, the informants mentioned how comfortable they were with using it. Further, they repeatedly commented on their "*remarkably good*" skills regarding externalisation activities; some saw themselves fluent in sketching, while the others found digital modelling their "*tools of trade*". Possessing sufficient technical skill to manipulate material and medium is considered a prerequisite for visual creation (Koestler, 1964), which is sometimes described as an ability to use divergent and convergent thinking that is common among creative individuals (e.g. Csikszentmihalyi, 1996). In his analysis of sketching, Schön (1983) found the expert more fluent in interacting with the media than the novice. Similarly, the findings here indicate how being fluent in a medium provides one with a *maximum grip*[*] in relation to it, while falling short in another medium implies having a weak grip. For example, if one has excellent digital modelling skills but is poor at sketching, one will find

* "*Maximum grip*" is a notion that describes the tendency towards getting an optimal sense of a situation (see Dreyfus and Dreyfus, 2004). Here it is understood as referring to the designer's tendency not only to make optimal use of a medium but also to extend the possibilities it affords and use it as if it had the same qualities as another medium.

digital models more malleable and easy to use than sketching. A specific surface-modelling program may be experienced as easy to use by a skilled practitioner, but difficult to use for those who lack fluency in it.

6.5 CONTRIBUTIONS AND IMPLICATIONS

In summary, comparing externalisation activities based on the interviewees' own accounts of their design processes ahs led to (i) identifying what they do when they engage in making representations, and (ii) discerning a taxonomy/typology for describing the qualities of media and representations.

Some of the qualities mentioned above influence the realisation of the identified roles; for example, malleability, immediacy and directness in media enable the making of radical transformations and changes, and therefore support divergent thinking when generating a large variety of ideas. Furthermore, a representation that includes permanent traces of interim ideas, and that is not fixed on the background, creates synergies by offering, in the form of preceding representations, multiple points of reference for use in the creation of ideas. Spatial accuracy and precision were among the qualities that informants found invaluable for making the right decisions when choosing among different ideas, and supported them in convergent modes of the creative process.

On a macro level, the findings of this study help in understanding the act of creation in design processes. The systematic overview of the different roles that sketching and physical and digital modelling may have in a design process has provided a more nuanced understanding of these activities than previous conceptions of them.

Further, the taxonomy of qualities in media and representations not only provides terminology for discussing the different aspects of the design process, it also helps with comparing these media and representations, and enables reflections on one's skills. This helps make sense of designers' otherwise complex interactions with the media and material of their practice, and provides insights into design activities.

6.6 REFLECTIONS ON THE RESEARCH APPROACH

The studies underlying this work were designed to address the research questions and fulfil the aim of gaining a better understanding of the creative process of designing. Inquiring into these processes is most meaningful if they are captured from the perspective of those practising them. This would involve studying designers' descriptions, accounts and narratives of their activities. A qualitative approach was taken for this purpose, several aspects of which will be discussed in this section. Criteria for evaluating the quality of this approach include confirmability, dependability, credibility, and transferability (Miles and Huberman, 1994).

What follows is a discussion of how these criteria are taken into consideration in this thesis.

Confirmability concerns issues of objectivity and relative neutrality in one's work. This thesis - together with the appended papers - provides detailed descriptions of the research process and its origin and context. Further, exhibits of the original data are provided to support the findings. The author has also explicitly acknowledged her potential biases in the section Background and Empirical Context, especially that she views designers as users of certain tools and seeks to understand externalisation activities from their perspective. At various stages, interim results of the work were presented at peer-reviewed conferences. During the analysis phase, the author has had recurrent discussions regarding the findings with her peers and colleagues. Further, efforts were made to make the data available for reanalysis*.

Dependability relates to the consistency of the research process and whether due consideration has been given to its different phases. The focus of this work, and the research questions posed, address the individual designers' interaction with media and representations, and not the collaborative and communicative aspects of the process. Other roles and qualities would have been identified if the data collection and analysis were modified for addressing the latter aspects. Understanding the practitioners' perspective on their activities has led to identifying the different qualities of the media and representations they use, which would have been more difficult to uncover if any other approach was taken. The author acknowledges that the roles and qualities identified in this work are not exhaustive; the informants in this work considered them relevant. Further work may lead to the identification of additional roles and qualities for the different phenomena studied in this thesis.

In analysing the material, the author initially sought to quantify the extent to which each role was mentioned in the data from diaries (see Paper B). An initial quantification of the interview data indicated similarities among the different activities, which may have been due to having informants that were not equally fluent in all of the media. To exemplify, radical transformations were mentioned ten times with regard to sketching by one informant, and roughly an equal number of times with regard to digital modelling by another informant. This approach did not contribute more detail to the findings and was therefore not further pursued.

Credibility concerns whether or not the findings make sense. The findings from the diary study and the interview study are in line with each other. In each study, there were variations with respect to skills and preferences among the participants; some were highly skilled in sketching, some in digital modelling, and some in physical modelling.

* The data from the diary study has been made available to colleagues for reanalysis and additional work, and there is an ambition to do so with the interview data.

Regarding the data collection methods, several issues should be clarified. In both diaries and interviews, the data collection took place some time after the informants' activities; in comparison with the interviews, the diaries involved less delay, resulting in more accurate and reliable recollection of the process. The benefits of using diary methods with shorter logging delays are discussed in Paper B. In the interview study, the designers' own representations were used to facilitate recollection of their activities.

The interview method had a considerable advantage over the diary method; while the semi-structured set-up of the interviews allowed for follow-up questions, which led to various clarifications and exemplifications; the diary method did not allow for posing follow-up questions, especially since the data was analysed some time after the data collection. This was one of several reasons behind the choice of method for the following study.

Whether the findings were in accordance with or in contrast to the literature was discussed earlier in this chapter. Further, some of the informants confirmed that the conclusion drawn from the interview study were in line with their views.

Transferability concerns the extent to which conclusions of a study are applicable to other contexts. The findings of this study were based on different design processes. While the diaries investigated the design processes of students' all of whom were working on the same assignment, the interviews addressed practitioners' design processes, with each interview focusing on the work with a specific product. Considering the wide range of products and processes studies, the findings from this thesis may be applied to any other design process.

6.7 FUTURE WORK AND FINAL REMARKS

The overview of the roles and taxonomy of qualities of media and representations contribute to understanding otherwise complex and uncharted facets of the act of creation in design. They also provide a terminology for discussing the different aspects of the process, and enable comparing various media and representations. They may also be used for self-reflection during the design process.

Further inquiries based on the proposed taxonomy to broaden the understanding of externalisation activities would be beneficial. This could be done, for example by conducting questionnaire studies with a larger sample of experienced design practitioners to enable a more careful comparison of different media.

Apart from the identified roles and qualities of different media and representations, it is important to highlight the interplay between different activities. This involves making one type of representation and using it as a reference for transitioning to a subsequent activity; for example making a digital model as a rough estimate of

proportions and surface boundaries and using it as an underlay for sketching, or as a reference for making a physical model. Through transitioning, it is possible to integrate different qualities of media or a representation, for example in working with vague representations on a detailed and precise background. This enables oscillation between divergent and convergent modes of creation, and is a topic in need of further attention.

The processes studied in this work took place in a social setting where the designer works together with a team of design experts as well as many other stakeholders, such as users, group members, examiners, and supervisors in the diary study, and clients, users, and manufacturers in the interview study. These different stakeholders may have influenced or steered the process in different ways. For instance, one of the informants who did not feel comfortable using digital modelling had a close collaboration with a colleague who was fluent with the medium. A common denominator among the informants has been that they strived to convince one or several stakeholders of the value of their work. These insights from the design processes indicate the possible existence of additional roles and qualities of media and representations through which interactions with other stakeholders took place. This is another aspect that needs further investigation. It may be fruitful to inquire into the relevance of the qualities identified in this thesis with respect to collaboration between the different stakeholders.

Finally, many professions involve making representations, and will continue to do so. It is therefore worth making efforts to facilitate the emergence and embodiment of ideas in other practices than design.

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