Shape Does Matter

designing materials in products

Proefschrift

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“Knowledge is only part of understanding.
Genuine understanding comes from hands-on-experience”
Seymour Papert
[quoted on the lego mindstorms packaging]

Summary

This work addresses a simple but universal problem: how to search and select materials in products.

Imagine you want to buy new curtains for your home. You go to the store and together with the salesperson you browse through books with fabric samples. You might take a few samples home to see how the materials interact with the products you already have. However, how a small sample piece will translate to a large surface such as a curtain is left up to your imagination. Now, suppose you go to a fancy online store that allows you to upload any design you can possibly imagine: patterns, fabrics, textures and colors. The options that you implicitly eliminated by going to a specific store with a carefully selected collection now explode into an unmanageably large solution space.

Product designers face similar challenges when exploring materials in products. Aided by small samples and examples of materials, they try to understand how a material will be experienced in the product they are designing. They encounter visualization problems when trying to assess a sample as applied to their product as well as when designing new materials. Advanced computer support allows designers to visualize materials in products and depict material properties in detail. However, these visualization techniques are designed for demonstrating and specifying, and are not adequately adjusted to support the designer's thinking process in the early stages of the design process, when material choices are made. Whereas selecting materials used to be a manageable task, constrained by manufacturing technology and available materials, advances in both manufacturing technology and material science mean materials are no longer simply selected, but are designed for a specific appearance and performance. This makes the solution space unmanageably large, both in designing the material, and designing the interactions between the material and shape.

In this thesis I investigate how to support designing the appearance of materials in products, specifically how to search for new materials and to explore the interactions between materials and shape. Central in this thesis is a novel design called Skin 2.0. Skin allows designers in the early stages, using their physical models, to experience richness of material visualization found in computer support of the latter design stages. Skin supports the imagination through iterative, highly interactive visualization cycles. It engages designers in trial and error processes, letting them explore new materials as well as the interactions between shape and materials. Skin itself was developed through a series of participative action research cycles. Prototypes of new

tools and techniques were developed with practitioners, and evaluated in relevant, real world design situations. These cycles of research and design led to insights in how to support designer's thinking process, ultimately leading to the following recommendations:

1. **Minimize the time to experience and iterate.** Skin makes trial and error quick and effortless through an interactive representation. This leads to an energizing creative process of generating ideas and interpreting the consequences, and an efficient search through the solution space.
2. **Maximize the opportunity to make serendipitous connections.** New ideas made with Skin are often based on unexpected or unintended uses of existing source materials. In Skin, materials are evaluated in context of the shape to avoid pre-judgment. The rough visualization provides ambiguity.
3. **Make it impossible to detail and beautify designs, without sacrificing attractive results.** Skin prevents detailing and optimizing, makes it's use effective and fast. Nonetheless, the results are still attractive and explicit.
4. **Be group accessible and make sure everyone can express themselves.** The early stages of the design process include many stakeholders, of whom not all have a design background. Skin makes these stakeholders active contributors who can express themselves and search the solution space first hand.

Chapter Five presents the prototype of Skin and in Chapter Six the action research cycles are documented, including the considerations that led to the design. Together these chapters allow designers and researchers to apply and evaluate Skin. Chapter Seven presents workshops with Skin in industry. These workshops show how participants used Skin, and how it radically changed their ideas regarding materials. Within one hour they had sufficiently explored the solution space, through an trial and error process. Within another 30 minutes they had reviewed their concepts, resulting in a few selections to guide the further development of their product.

Samenvatting

Dit proefschrift gaat over een eenvoudig maar universeel probleem, namelijk het zoeken naar en kiezen van materialen.

Stel dat u nieuwe gordijnen wilt kopen voor, bij voorbeeld, uw huiskamer. In de winkel bladert u met een verkoper door de stalenboeken met stoffen. Mogelijk krijgt u een of enkele stalen mee naar huis om te beoordelen hoe deze zullen staan in uw bestaande interieur. Dat lijkt een goede zaak, maar het is verre van eenvoudig om met een relatief klein staal te zien hoe dat zal uitpakken op een groot oppervlak als gordijnen. Maar stel nu dat u de gordijnen gaat bestellen bij een online winkel, waar u elk denkbare kleur, patroon of stof kunt kiezen. Het aantal mogelijkheden die u impliciet gereduceerd had door naar een winkel te gaan met een zorgvuldig gekozen collectie, is nu onhanteerbaar groot geworden.

Product ontwerpers staan voor soortgelijke uitdagingen. Geholpen door kleine stalen en voorbeelden in producten, proberen zij zich voor te stellen of een bepaald materiaal geschikt is voor een te ontwerpen product. Zij komen visualisatie problemen tegen bij het ontwerpen van nieuwe materialen, maar ook bij de interactie tussen materiaal en vorm. Geavanceerde, computer gestuurde, ontwerptechnieken stellen ontwerpers in staat om zeer precies materialen te visualiseren. Deze technieken zijn echter vooral geschikt voor de latere fasen van het ontwerpproces, bij demonstraties en specificaties van voorstellen. De meeste van deze ontwerpprogramma's falen in het ondersteunen van de vroege fasen van het ontwerpproces, de fasen waarin de materialen worden gekozen. Nu was tot voorkort het selecteren van materialen te overzien, de technologie maakte slechts een beperkte keus mogelijk. Door de vooruitgang in materiaalkunde en productietechnologie is het nu mogelijk een bijna onbeperkte veelheid aan materialen te ontwerpen, elk met een eigen, specifieke uitstraling en effect. De oplossingsruimte van het probleem wordt daarmee onhanteerbaar groot, zowel bij het ontwerpen van materiaal alsook bij het bezien van de interacties tussen materiaal en vorm.

In dit proefschrift heb ik onderzocht hoe men ontwerpers kan ondersteunen bij het ontwerpen van materialen. Specifiek bij het zoeken naar nieuwe materialen en bij het bezien van interacties tussen materiaal en vorm. Ik introduceer een nieuwe, innovatieve ontwerptechniek, genaamd Skin 2.0. Skin maakt de rijkdom aan mogelijkheden van de computergestuurde visualisatie, toegankelijk en bruikbaar in de vroege fasen van het ontwerpproces. Op die manier ondersteunt Skin de creativiteit van de ontwerper door middel van iteratieve, expliciete en interactieve visualisaties.

Skin is ontwikkeld in een serie participatieve actie onderzoeken. Samen met ontwerpers zijn hulpmiddelen bedacht en in de praktijk uitgeprobeerd op echte problemen in relevante ontwerp situaties. Zo ontstond inzicht in de vraag hoe het ontwerp proces en het denkproces van ontwerpers het best kan worden ondersteund. Dat heeft geleid tot de volgende aanbevelingen voor het ondersteunen van ontwerpers:

1. Minimaliseer de tijd die nodig is tot een resultaat ontstaat en laat iteraties toe. Een interactief model waarin snel materialen kunnen worden gemaakt en uitgeprobeerd, zorgt voor een energiek proces waarin efficiënt de oplossingruimte kan worden verkend.
2. Geef ruimte aan de factor "toeval". Het evalueren van materialen in de context van het product, bevordert verassend materiaal gebruik en voorkomt vroegtijdig oordelen. Samen met een dubbelzinnige visualisatie stimuleert dat de creativiteit.
3. Voorkom het vroegtijdig van het detailleren van een ontwerp. Het beperken van mogelijkheden zorgt voor een snel en effectief proces. Maar laat de visualisatie er wel van het begin af aan goed uitzien, attractief en expliciet.
4. Zorg dat iedere deelnemer actief de oplossingruimte kan verkennen. Niet iedere deelnemer in een ontwerpteam heeft ontwerp ervaring. Stel ook deze deelnemers instaat actief deel te nemen en zelf dingen uit te proberen.

Het actie onderzoek is vastgelegd in hoofdstuk 6, het prototype in hoofdstuk 5. Alles is zorgvuldig gedocumenteerd, zodat ontwerpers en onderzoekers in staat zijn de ideeën te evalueren en toe te passen. In hoofdstuk 7 worden de workshops met Skin gepresenteerd. Getoond wordt hoe Skin ontwerpers op radicaal nieuwe ideeën bracht en hun zicht op materialen veranderde. In minder dan een uur waren ze in staat om de oplossingsruimte voldoende te verkennen, door een breed scala aan materialen uit te proberen en hun effect te beoordelen. Vervolgens bleken ze in staat om in een half uur hun concepten te evalueren. Op deze wijze werkend konden zij efficiënt hun ontwerpproces voortzetten met een beperkt aantal potentiële oplossingen.

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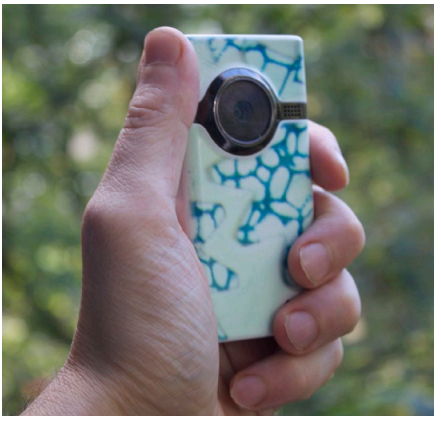
1 Introduction and Overview

1.1. Introduction

When thinking of materials, we think of the materials that have been used by mankind for many years: woods, metals, stone and plastics. For product designers, selecting materials is an essential part of the design of a product, and when choosing materials designers take many aspects into account. Some of these aspects are quantifiable and can be simulated and optimized using computer aided design (CAD) tools, others are qualitative and are not so easily expressed in equations or even in language. How do designers choose materials in products? And how do they design the materials for your next product? We will see some resourceful approaches and show novel techniques using new media to support these approaches.



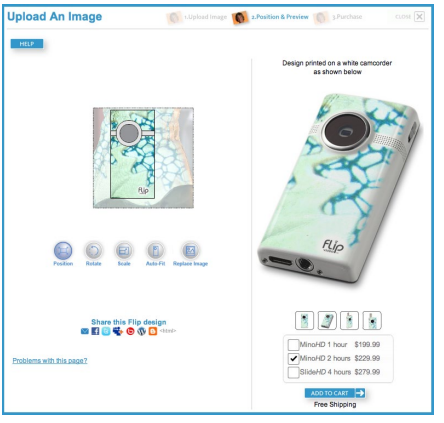


Figure 1.1. *A custom-designed skin for the Flip MinoHD camcorder. Theflip.com provides a web-service to upload and manipulate 2D images to customize their products. On the left, the customized product, in the center the source materials and on the right, a screenshot of the user interface.*

Recently I gained access to a laser cutter. I was amazed at how quickly that tool extended my language when designing shapes. A laser cutter cuts sheet material into detailed shapes with sub-millimeter precision. Using a laser cutter is almost as simple as printing on paper and designs can be made with standard, commonly available 2D vector software typically used to design graphics in documents. Compared to traditional manufacturing techniques, e.g. routing and sawing, the laser cutter is faster, and makes manufacturing of complex shapes easily available. 3D printers are used with similar aims to rapidly produce prototypes in 3D. They provide

unprecedented form freedom. However, on the other hand, manufacturing a quickly sketched shape requires CAD software and necessitates thorough planning of manufacturing details such as wall thickness, driving the design towards details that one might not want to consider for a quick prototype. CAD tools are generally aimed at the later, detailing stages of the design process and offer functionality to support that.

Similar to the form freedom I gained by having a laser cutter at hand, some manufacturers offer easy-to-use customization tools to modify product appearance beyond selecting color or model type. As these are usually web services, users upload bitmap images and map them onto online model of the product. As shown in Figure 1.1, I "skinned" a Flip Mino in this way. Although theflip.com provides an excellent on-screen 3D preview and tools to manipulate images, unpacking the actual product, which I had never seen in real life, was still a surprise, and having the actual product in my hands made me think of other patterns in context of the shape that made better use of the shape and constraint of the lens, and using it as an element in the graphic. Experiencing a physical object, at the true scale, has qualities that a 2D screen cannot reproduce.

1.2. Relevance

"Colors have a very strong expressive impact on the perceiver". [Arnheim 1974 pg 323] The importance of material in the expressive qualities of products is described by many authors [e.g. Arnheim 1969, Jordan 2002]. The relevance of including colors, graphics and materials in the product design process is obvious: they are important to the appeal of products and provide ways to differentiate and express one's personal style. This need is clearly expressed in fashion [Postrel 2004]. The visual domain of materials also has practical applications in expressing a product's use, to order a product's exposed functionality [Burdek 1996] and to express danger and safety [Norman 2002]. The wooden parts in barbecue utensils are usually safe to handle due to their thermal insulation, whereas the metal parts are more likely to get hot. Metal will bend under load, stone has the tendency to break and an emergency button expresses itself by being solid and red and not fluffy and pink. [Figure 1.2]



Figure 1.2. *A French company designed stylized fire extinguishers that certainly express style, but do they express their function? [http://www.fire-design.fr/]*

" Materials are not just a "given" to be incorporated in the designer's calculation but are part of the design problem" [Doordan 2003]. The interactions between function,

material, manufacturing process and shape are seen as the central problem of materials selection in mechanical design [Ashby 2005]. These interactions are bidirectional: the specification of a shape restricts the choice of material and manufacturing process; but equally, the choice of a manufacturing process limits the materials and shapes that can be used. In product design as opposed to mechanical design, the "aesthetic aspects" of materials must be taken into account and are unlikely to be optimized within a given set of quantifiable constraints. Ashby and Johnson [2003] make the distinction between performance and aesthetic properties of materials. The performance properties are the engineering properties, e.g. modulus of elasticity and creep, and the aesthetics properties are properties such as reflectivity, texture and thermal conductivity. Usually performance properties are linked to aesthetic properties, for example in metals and woods, which is convenient because we know what to expect. However, these so-called "found materials" are being replaced by "engineered materials": materials made to order: a material designed for a specific purpose for a specific application. Plastic is an example of such an engineered material, it takes many shapes from bottles to contain water to the fleece jackets to keep us warm. These advances in material technology dramatically change the way we think of materials in products, not unlike the way 3D printing "freed" designers from the relatively rigid manufacturing constraints of mass production. It allows designers to design aesthetics independent of performance without the "constraint" of a given material. Ultimately, a given material's performance and aesthetics will not be applied to an entire product or part, but designed locally, varying throughout the product [see for instance Bickel et.al]: a "3D printer" that manufactures a product on demand as the nano-replicator envisioned by Neil Stephenson in the novel "Diamond Age" [2000].

1.3. Objective

To make materials part of the design problem, we should be thinking in designing materials, not selecting them, and shape our tools accordingly. Current tools and techniques allow designers to explore specific aspects of the design such as shape, material, or behavior, but not the interactions. Not until the latter stages of the design process, can these interactions can be evaluated and made experiential in physical prototypes. The objective of this thesis is to study tools and techniques that support designers designing materials in products by supporting understanding of these interactions from an early stage.

The main research question is:

- **"How can we support designers designing the appearance of materials in products in the early stages of the design process?"**

In order to answer the main question, the following sub-questions will be answered first:

- **"What is the role of materials in products?"**
- **"What are the tools designers use to explore materials in products?"**

Then, through the design and evaluation of a prototype tool and technique, the main question will be answered.

1.4. Scope

The art and craft of product design is to translate people's needs, wishes and dreams into products. Many authors go to great lengths to try to understand the user's subjective experience when engaged in integrated and dynamic interactions with objects, spaces and services. [Pine & Gilmore 1999, Sleeswijk Visser et al. 2005, Desmet & Hekkert 2007] Their research generally aims to provide designers with insights and advice. Although no author aims to provide recipes for designing "meaning" into products or expressing the "emotion" of materials in qualities such as color, texture and touch, some do attempt to map sensory properties onto "personalities" or other abstractions. Although understanding the subjective experience of products may help the creative process, it doesn't necessarily help in generating or specifying experience. The focus of this thesis is on supporting designers in prototyping the physical manifestation of a product.

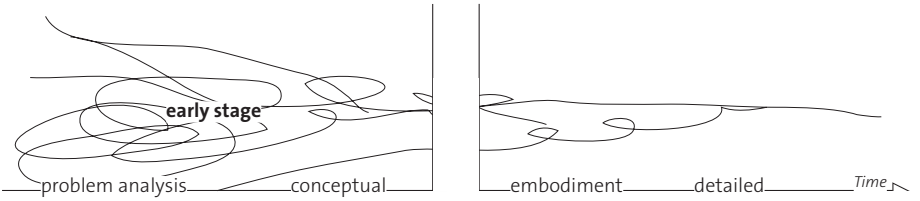


Figure 1.3. *Roozenburg and Eekels [1995] divide the industrial design process into four phases, known as the funnel model. In the problem analysis, user needs are identified, in conceptual design the first ideas are formed which are designed into (physical) products in the embodiment stage. In the stage of detailed design the product is detailed for tests and production.*

The product design process is usually described in multiple phases in which the product becomes more concrete, for instance Roozenburg and Eekels [1995], shown in Figure 1.3. The design of a product is embedded in a larger process of "new product development". New product development (NPD) comprises all the activities that precede the production, distribution and sale of the product [Roozenburg and Eekels 1995] and includes idea generation, finding market needs, and innovation policy. Thus, NPD involves both marketing and engineering. In recent years there have been changes to these early stages [Stappers 2005] under pressure of a decreasing time to market. Increasingly, multidisciplinary teams tackle both the marketing and engineering perspectives and include users in this process. These changes bring new challenges for support tools that must reconsider the roles of marketing and engineering and provide a common ground. As well, they must allow for stakeholders less fluent in the expression of design

aspects. The focus of this thesis is on this early stage of the design process, which I define as being the transition from 1) the fuzzy front end to product design, and 2) from concept to embodiment: the stage at which abstract ideas are transformed into physical objects.

The tools and techniques in this thesis will make use of a mixed physical/virtual modeling approach. I strive to combine the advantages of virtual prototyping of the later stages with the physical prototyping designers use in the early stages to make materials in products experiential. I focus on the "aesthetic aspects" of materials, specifically on the visual appearance.

1.5. Reader's Guide

Shape does Matter is organized [Figure 1.4] around a novel tool and technique called Skin. Skin allows groups of designers to quickly explore materials on their models. If you already know about Skin and are interested in gaining first hand experience, continue to Chapter 5, which explains how to build Skin with standard off-the-shelf components. If you want to assess the benefits of Skin to your company, skip to Chapter 7 to see how practitioners apply Skin to their work process and the results they are getting. The remaining chapters describe the research approach (2); a working model for materials in products (3); and an analysis of design representations in the early stages of design [4]. The development process that led to the design of Skin is described in Chapter 6, which also covers the challenges of how to employ and extend Skin-like systems in other fields.

chapter 1 **Introduction and Overview**
chapter 2 **Approach**
chapter 3 **Materials**
chapter 4 **Tools and Techniques**
chapter 5 **Skin 2.0**
chapter 6 **Using Skin**
chapter 7 **Material Design Workshop**
chapter 8 **Conclusion, Recommendations and Future**

Figure 1.4. *A graphical overview of* ***Shape does Matter****. Chapter 2 explains the research approach "Research through Design". Chapter 3, "Materials" and Chapter 4, "Tools and Techniques", provide the background on materials and how designers design with them. The main part of the text consists of Chapters Five, Six and Seven, which introduce the Skin technique, describe its development process and evaluate the technique. Chapter 8, the conclusion, includes recommendations for the design of tools in the early stages and future research.*

In Chapter Two I outline my "Research through Design" approach. The main approach consists of action research cycles: developing prototypes of tools and techniques and studying their applicability in the field with real designers that solving real world design problems.

In Chapter Three I review the current views in literature on materials in products. That results in a model of materials in products describing materials on two dimensions. The first dimension is the abstract. Abstract ideas about materials are terms such as for example strong or huggable, which can be translated in multiple ways into more concrete material properties such as for instance color, shininess or texture. Whereas abstract descriptions apply to the product considered as a whole, the more concrete the descriptions become, the more they can be addressed to a specific scale. The second is scale relative to the user. Scale ranges from the very small with properties such as surface texture, to the shape of the product or its intended environment.

Chapter Four presents related work on tools and representations used in design practice to model the physical manifestation of the product. First I review the literature on representations, then check these findings with a field study and finally review the prior art in computer support design tools. Chapter Four concludes with a set of considerations identifying what is missing in current approaches, guiding the contextualized action research cycles.

Chapter Five presents the resulting tool and technique Skin in its current state, and together with the accompanying website [http://studiolab.nl/skin] enables practitioners and researchers to evaluate Skin for themselves. Chapter Six describes Skin's development process and addresses the various design decisions made in the process to adapt Skin to the application fields I have touched on. It also provides the information needed to adapt Skin to other fields. In Chapter Seven I evaluate Skin in two workshops in the industry.

In the concluding Chapter Eight I answer the research questions and evaluate the research approach. In addition, I provide recommendations for tools and techniques for the early stages, and for future research.

2 Approach

In this project I look into how support designers in the early stage of the design process, specifically as they design materials for products. Gaining an understanding within the highly dynamic context of multidisciplinary design teams requires an explorative approach. Through action research I intervene in these complex processes using novel solutions, because, similar to complex software systems, the impact and implications cannot be completely designed or tested prior to use [Fischer 2002]. By observing designers use these solutions and with them, reflecting on how these solutions change their work process, I study their needs and wishes for design support. The solutions I develop in this project make use of the prior art in the field of physical computing and new media, combined with techniques that build upon contemporary views in the field of design support for the early stages of the design process. However, prior to this project, neither field had been applied to the designing of materials in products.

My approach to this project is highly influenced by my background in industrial design engineering; I'm a designer of tools and techniques as well as a researcher gaining understanding in the designers' work processes. The method applied in this project, which I will desbribe in this chapter, I refer to as "Research through Design". I use "design" as a verb and argue that the very act of designing will generate the knowledge [Archer 1995] necessary to answer the research question. Both the research and the design are the means as well as the goal [Fallman 2005].

2.1. Methodological Framing

Industrial product design is applied, contextualized, and multi-disciplinary, in contrast to fundamental research, which is mono-disciplinary, generalizable and can thus potentially be applied in multiple contexts. Horvath [2007, 2008] distinguishes three approaches falling between fundamental research and design practice, combining design and research: [Figure 2.1.]

Research in a design context is a method wherein an artifact, the design, is used as the stimulus material for an experiment, having the research methodology and objectives of fundamental research. This approach is exemplified by Van Rompay [2005] or Ludden [2008]. In their studies, aspects of consumer products were manipulated in order to gain insight into the contribution of those aspects to how people experience the products. Their research, in the field of psychology, made use of consumer products as stimulus materials in formal experiments.

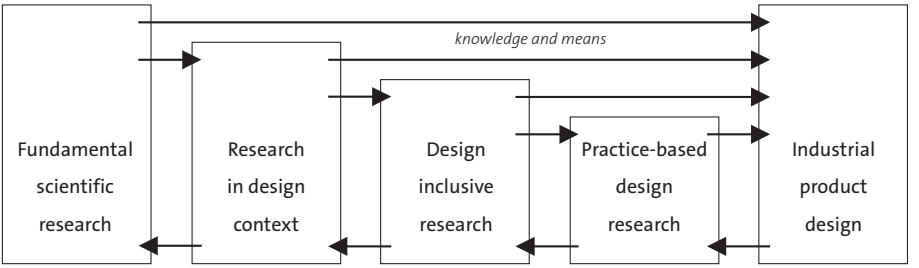


Figure 2.1. *Three approaches to design research between fundemental scientific research and industrial product design: research in design context, design inclusive research and practice based design research. [Horvath 2007]*

The methodology of **Practice-based design research**, on the other end of the spectrum, describes a thoroughly documented design process, following certain guidelines, as for instance provided by the Royal College of Art. This method has its origins in the arts in the UK and Finland and is exemplified by the work of Niedderer [2004] and Mäkelä [2007], both designing physical works of art. The practice-based design research approach takes design as a verb, an activity used to plan and create work with a given objective, and describes the design cycles and the insights thus generated as a research process, not bound by the established methods of fundamental research.

In **Design-inclusive research** Horvath combines the methodologies found in design practice and in fundamental research. He encapsulates a design process within a research process and sees design as the step between theory and proof. Unlike Research in a Design Context, the design process is documented, but it has little interaction with the research project. An example of this method is the Ph.D. work of Frens [2006] on physical interaction. Frens explores various designs for a camera before designing the cameras to be used in his formal proof. When taking design as a noun, in the described methods, the design is used to test a previously conceived idea, and the design must fulfill requirements for both the product context and the research objective.

Even though Horvath gives a compelling overview of how design and research complement each other, the presented approaches do not include the act of designing as an inductive step in the process. In an industrial product design process, the requirements are ill-defined and the question commutes with the solution [Cross 1982]. Designers regularly approach projects as iterative processes, evaluating their initial assumptions and refining their initial goals during various iterations. Accordingly, I frame this project to include multiple iterations. Practice-based-research will be applied to create tools and techniques contextualized for designers and design teams, and design-inclusive research to answer the research question.

2.2. Action Research

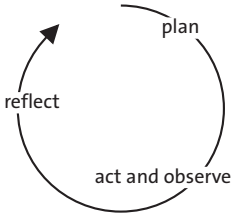


Figure 2.2 *Action research cycles consists of cycles of planning, observing, acting (intervening) and reflecting.*

I will apply participatory action research to study designers in the field. Action research [Lewin 1946] originates from organizational psychology, and is an iterative process involving researchers and practitioners acting together in a particular cycle of activities [Avison 1999]. Action research cycles consist of planning, acting and observing, and reflecting, as shown in Figure 2.2, and provide a qualitative way to study and learn from changes in organizations and communities. In the participatory action research method [Whyte 1989] the participation of practitioners is emphasized, in the definition by Argyris [1999 pg 434]: *"Participatory action research is a form of action research that involves the proposition that causal inferences about the behavior of human beings are more likely to be valid and enactable when the human beings in question participate in building and testing them"*. Participatory action research thus acknowledges the users as experts on their own work process and domain.

In the planning step, the designers' needs for support are collaboratively identified and contextualized prototypes are developed. In the "acting and observing" step the designers use the prototypes in their practice and I observe how it affects their process. In the reflection step we jointly evaluate the impact, leading to additional cycles or to a reframing of the initial ideas. Unlike in traditional action research, developing prototypes is an essential part of these cycles.

Prototypes

A prototype is a model of a "design" that includes some or all of the intended properties of the end product. A prototype functions as an externalization during the design process, evaluating an idea within the constraints of reality. Building prototypes [Kelley & Littman 2001] and experiencing prototypes [Buchenau & Fulton Suri 2000] generates knowledge during various design activities. Prototypes have two main uses in the explorative stages of a design process: developing technology and studying users. Technology prototypes, often using Wizard of Oz techniques to fake technology, provide a look into the future when the technology is not yet available or tools have not yet been built. [Buxton 2007]. Experiencing technology before it is built enables developers to gain insight into its complexity and requirements. Experience prototypes are used to gain insight into the user experience and aim to get input from the user on the context and to explore use requirements. [Buchenau & Fulton Suri 2000] In this project I apply both uses of prototypes.

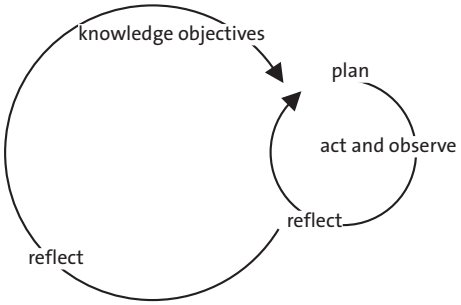


Figure 2.3 *The proposed research approach consists of a double loop. On the right, the small loop consists of an action research cycle and is contextual design directed. The large loop includes the small loop as a case study and is knowledge directed.*

Extracting knowledge from the contextualized action research cycles. Schön and Argyris distinguish a single loop learning cycle from a double loop learning cycle. In a single loop cycle learning is carried out without altering the fundamental nature of the activities, whereas in a double loop learning includes questioning and modifying of existing norms, Figure 2.3.

Fischer [2002] for instance, describes such a cyclic model in the field of software design. In his "Seeding, Evolutionary growth and Reseeding (SER) model [Figure 2.4] an initial design of a software product is given to the users. Over time users adapt the software to their needs and modify and tweak the design in small incremental steps (Evolution), these adjustments could be considered to be single loop learning, and are context specific, users do not necessarily learn from each other or have a shared context. In a "Reseeding" step the design itself is reframed and a new design is "seeded" to the users. The seeding step I consider to be the larger loop that integrates and generalizes the specific knowledge gained from individual uses. Similar to participatory action research, the large loop includes users as active contributors.

I use a double loop process to separate the context-specific knowledge generated in the action research cycles from the reframing of the research objectives and generalizable knowledge. The small loops consists of participatory action research cycles as quasi experiments. The larger loops reframe the research objectives and identify generalizable knowledge.

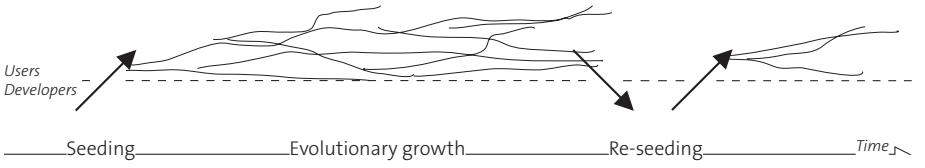


Figure 2.4. *The Seeding, Evolutionary growth, Re-seeing model [Fischer, 2002]. A initial design is "seeded" to it's users, who adapt and modify it during the "evolutionary growth". Then in a "re-seeding" step the design is reframed and a new design is again "seeded" to the users.*

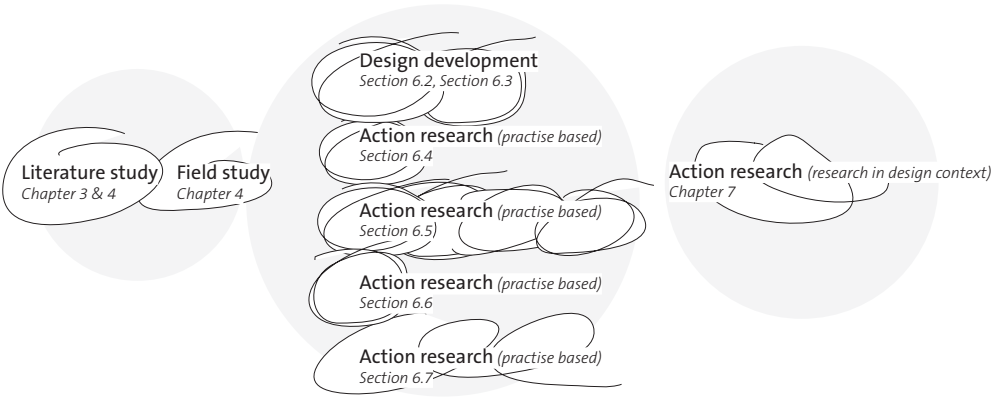


Figure 2.5 *The research setup.*

2.3. Setup

The setup of this research project is as follows [Figure 2.5]. Chapter Three and Four present the prior art in literature, studying materials in products and on representations and tools designers use respectively. A field study in Chapter Four consists of structured interviews; the prior art is checked with respect to materials in products.

In multiple action research cycles [Chapter 6, Figure 2.5] in relevant design situations, insights are acquired using the "Practice Based Research" approach. Finally, in Chapter 7, using the "Design Inclusive Research" method, I evaluate the results in two quasi experiments.

2.4. Quality Criteria

In this section I will explain how I guarantee the quality, through documentation to allow for repeatability.

Aspects that might be taken for granted are noticed more easily when using an unfamiliar tool or technique. The prototyping of tools and techniques and the study of their applications by the users, is based on the established design method of participatory user research [Sleeswijk-Visser et al. 2005, Buchenau & Fulton Suri 2000]. Similar to participatory user research, the designers (my users) are better able to express their needs and wishes in this manner than in interviews or questionnaires. In addition, by studying designers in the field, pre-conceived assumptions are less likely to occur, compared to formal experiments with students. However, in order to study designers in practice, the solutions must be contextualized to the designers' current work processes and their studio. This has implications for the research intent, potentially compromising it. Therefore, I will separate the small, contextualized loops from the larger research-directed loops.

However, these interventions are not formal experiments, lack random and lack a control group. Pre-intervention interviews provide a baseline to measure the effect of the intervention. Each intervention is videotaped, transcribed, interpreted by the participating researchers and documented in Chapters 6 and 7. The approach for interventions is based on the established research method for action research. The number of interventions will provide the evidence to generalize the results beyond the context-specific implications. In addition, the resulting design is evaluated in two parallel quasi-experiments.

The resulting design is documented in Chapter 5, allowing peers to repeat the interventions. The considerations that went into the design are documented in Chapter 6. The hardware used in the prototypes is consumer grade, inexpensive and widely available, the software is made available online,

2.5. Conclusion

The approach taken in this thesis is informed by both scientific research and industrial product design. It is research because it strives to generate knowledge that exceeds the context of a single product, yet it is design as the knowledge is generated by designing tools and techniques for specific contexts. Only through designing does the complexity of the research questions unfold. When taking this approach, it is inevitable that the interventions consist of quasi experiments, undertaken in an environment that cannot and should not be controlled. To me, "research through design" therefore has the following characteristics:

1. It is an exploration, into trying to gain understanding in a currently non-existant, novel situation. Through the act of designing new knowledge is generated, and inevitably as with the progress of the design the research questions will evolve.
2. It consists of multiple cycles, as the research questions, design and intervention inspire and drive each other.



Figure 3.1. *Traditional wooden houses in Norway. In Norway traditional wooden houses are often painted red. Not because the Norwegian people particularly like red or associate red with happiness and prosperity as the Chinese do, but because red is cheap to produce from rust and animal blood, both widely available in rural areas. Today if we want to decorate our interior we can choose from palettes containing hundreds of colors and in hardware stores those colors are mixed to order, regardless of the availability of certain pigments. The small color chips as regularly used to select color, however are not very good predictors for the effect of a color on large areas such as walls. Akzo Nobel, a paint manufacturer, discovered that people tend to choose colors that are too dark [Personal communication at the Akzo Nobel factory]. To assist people in their choice, Akzo Nobel developed a sampler package consisting of a small amount of paint, a brush and a large poster. The larger poster, painted in the chosen color and placed on a wall, allows people to better judge the impact on their interior. What makes the sampler package exceptional is that Akzo Nobel also includes paint two tints lighter than the selected color.*

3 Materials

3.1. Introduction

Colors used to be mixed from pigments found in nature. The ancient Greek had no terms for color but described colors in terms of pigments or by referring to known colors on objects, for instance "olive" to describe a specific shade of green. The lack of availability of pigments made some colors more expensive and that was reflected in people's associations. In Western Europe, for instance, blue was associated with power. Nowadays we have almost total control over colors on a continuous scale. All colors can be manufactured and visualized.

Like color, materials are no longer described using traditional materials such as woods, metals or ceramics. As Manzini [1989] puts it: *"a material of invention is no longer a found material; rather, it is calculated and engineered to achieve a specific, desired performance"*. Likewise, as illustrated in Figure 3.2, a material with a desired performance can be given a specific, desired aesthetic that may or may not follow the associations of found materials. In addition, modern fabrication techniques have brought unprecedented freedom and allow building up shape from atoms rather than assembling and transforming prefabricated or found materials. 3D printing techniques are likely to increase form freedom even further. Similar to color, these advances reduce the role of manufacturing technology as a driving factor in product appearance: designers gain the capability to manipulate materials from the smallest details to the large external shape of the product. Consequently, designers do not select materials, but design a material for a product.



Figure 3.2. *A children's tea set by Madieke Fleuren. The tea set appears to be made of a knitted fabric, but is in fact ceramic. Products with a desired performance can be given a specific, desired appearance.*

Unlike colors, the methods to describe the appearance of materials in products involve more than a perceptual mapping of a material's physical properties. For example, "transparency" [Arnheim 1974 pg 253] might be achieved through the use of a translucent material, but also through an open shape made out of sheet material or through a surface knitted out of braid with carbon

and epoxy. A product might express durability through associations with specific manufacturing processes such as sharp edges typically associated with a milled metal. A physical material is not a guarantee for a perceived material in a product.

In this chapter I develop a model for the perceived appearance of materials in products in order to 1) understand the role of a material in relation to a product and 2) to understand the techniques that aim to support designing them.

Definitions

I use Hekkert's definition of **Product Experience** [2006 pg 160]: *"the entire set of affects that is elicited by the interaction between a user and a product, including the degree to which all our senses are gratified (aesthetic experience), the meanings we attach to the product (experience of meaning) and the feelings and emotions that are elicited (emotional experience)"*.

I distinguish three levels in product experience: sensation, perception and the attachment of meaning. With **sensation, sensorial** I refer to *"Stimulation of the sensory organs and the transmission of information about this stimulation through the nervous system."* [Papalia & Olds 1988 pg 77]. **Perception** is the *"way the brain interprets sensations to make them meaningful"* [Papalia & Olds 1988 pg 77]. Descriptive terms in perception are: colored, gloss, hard, loud, soft, rough, smooth.

With respect to the attachment of **meaning**: *"many cognitive processes play a role, such as interpretation, retrieval from memory, and associations. These processes allow us to recognize metaphors, attribute personality or other expressive characteristics, and assess the personal or symbolic significance of products"* [Hekkert 2006 pg 160]. Descriptive terms in meaning are: secure, proud, impressive, introverted, unstable and liberating.

3.2. Experiencing Materials in Products

Materials are often described using classes [e.g. Lefteri 2007] that have been around for a long time: metal, wood, stone, clay. These so called "found materials" have fixed combinations of sensorial and performance properties. For instance "metals are strong and cold", "woods are warm but can break". These classes have associations of function and value that are determined by culture, economical availability and tradition of use. In the current trend of sustainability for instance, bamboo has an environmentally friendly image, since it's a natural material that grows rapidly and is renewable. Diamonds are made artificially rare, are expensive and known for jewelry applications. Associations like these may change over time. Aluminum used to be very expensive to manufacture, more valuable than gold, and used as Napoleons III's tableware [Polmear 2006].

When it became cheaper it was widely used as a lightweight material. Nowadays, aluminum is valued and advertised for its recyclability. Associations not only influence the perceived quality of a product, but are often necessary to express a product's functioning. In barbecue utensils metal is used because it can handle hot temperatures, woods are used for the insulating handles because for their comparatively superior heat capacity and thermal conductivity. A novel material, intended to be used as a handle, could be designed to give it wooden appearance to call up these associations.

"Plastic itself, by its very nature, complicates efforts to think about it. Able to assume many degrees of shape, texture, hardness, density, resilience, or color, the myriad varieties are united only by a word—plastic—that has defied most attempts to promote specific trade names. What do we mean when we talk about plastic?" [Meikle 1995 pg 1867] Plastic products for bathrooms may share aesthetics of ceramic products to express their hygienic performance. Similarly, finishes and veneer techniques have been used for a long time to alter the appearance of a product's material to influence the product's associated value. However, products that appear to be made of one material while they are in fact made from another [Figure 3.3] might result in disappointment, being experienced as being fake [Jordan 2002], or might be intended to elicit surprise through sensorial incongruities [Ludden 2008].



Figure 3.3. *A fake bamboo tube to package mizu-yokan [photo http://pingmag.jp]*

Kitchen products provide examples of innovative material use that break with these associations. Think of ceramic knives, and of the cake-moulds and oven products made out of heat-resistant elastomers. Applications of these materials make sense in terms of performance and usability, however they require a change in people's associations. What in the appearance of these elastomer products conveys that the product is safe to be heated? For new materials, engineered rather than found, new associations might need to be invented. Ashby and Johnson [2009] argue that these associations may also be connected to manufacturing technologies and call it "expression through process". A bolted join between parts for instance suggests a strong and heavy-duty product compared to glue, and tooled metal, which typically features sharp edges and geometric forms due to the manufacturing technology, whereas injection-molded aluminum can have complex organic forms with soft edges. A material like MDF (Medium-Density Fiberboard) consists of wood pulp combined with wax or resin binder, and has little to do with the wood

grown in trees. Yet unlike injection-molded wood, MDF is shaped by the same tools traditionally used for woods. Products made from prefabricated MDF sheets resemble wooden products rather than injection moulded plastics.

It is necessary to distinguish between the physical material, and the perceived material. To make a product appear to be glossy for instance, the material itself could have reflective properties (compare an elastomer to a plastic). Light colored materials appear to be less glossy than their darker counterparts due to the contrast of the highlights. [Hunter 1975]. Surface roughness also influences gloss perception, smooth surfaces appear to be glossier than rough ones. Beveled or rounded shape transitions catch highlights and can emphasize a glossy appearance, as can other curves that cause highlights and reflections. To make a product's appearance glossy a designer can intervene on all these scales. While it is impossible to see shape without seeing material [Bailey 1855, cited in Claessen 1995] it is likewise impossible to see material without shape. A physical material is by no means a guarantee for a perceived material; in order to convey a desired expression in a product; the scales up to shape must be taken into account.

Models for the perceived materials in products are descriptive, not prescriptive, unlike the various standards that exist to measure and specify the performance of materials. Although most sensations can be perceptually mapped using the Weber Fechner law, perception and meaning are less evident, and are usually measured using descriptive words or pictures. Either the product is considered as a whole, without measuring the contributions of its aspects, e.g. in product-emotion measurements, or specific aspects are tested within the context of the product. For instance, to measure the bodily expression of products, a property usually attributed only to people, van Rompay et.al [2005] studied the influence of shape, by creating a number of shape variants. Other studies study aspects in isolation. Rao [1996], for instance, made a descriptive model for identifying textures. Based on a standard set of textures, he identified three significant dimensions (of the many dimensions that make up a texture): repetitive vs non-repetitive; high-contrast and non-directional vs low-contrast and directional; granular, coarse and low-complexity vs non- granular, fine and high-complexity. The vocabulary and abstraction level used in descriptive models, helps understanding and communicating existing products, but might not serve designers when exploring, visualizing or specifying a desired product expression.

3.3. Generating Materials in Products

Selecting colors provides an analogy, as to how it has evolved from a technological ability, e.g. artists had to become skilled at mixing pigments, to mixing red, green and blue in computer tools, and how designers perceive and search for colors.

Early computer support for color choice started with the mixing of red, green and blue components (RGB), a direct mapping of the color generation in a display with additive primaries, such as Cathode Ray Tubes (CRT) displays (which relates to the wavelengths human eyes' receptors respond to). Although design professionals are proficient in using RGB color sliders, the RGB cube as a model to navigate through color space is far from ideal. Apart from the device dependency issues, it is not an intuitive way of selecting or browsing for colors. [Jackson et al. 1994]. *"For instance how would you adjust the red, green and blue values to make a skin look more sun-tanned? and it is not perceptually uniform, meaning that one unit of coordinate distance corresponds to varying perceptual color differences from one region to another in the cube. Colors on adjacent grid points, for example, may look quite different in the white corner but be indistinguishable near black."* [Jackson et al. 1994] The RGB model is in contrast to the so-called perceptual color models, such as for instance proposed the artist Albert Munsel in 1905, that are based on humans' visual responses to color. In the late 80's the first perceptual color models were introduced in computer supported drawing tools. The HSV color model [described in Foley et al. 1995], for instance, describes colors in three dimensions: hue, saturation and value. Current computer supported drawing tools have on-screen palettes to select colors visually rather than by specifying numbers.

Computer support for materials is still highly application-dependent, not perceptually uniform, and provides a low level interface with the underlying algorithms rather than being an intuitive way of designing material appearance. [Kerr & Pellacini 2010]. Obviously, models to choose materials need more dimensions than the models for color and include properties such as gloss, transparency, and roughness. Each of these properties can be described and visualized

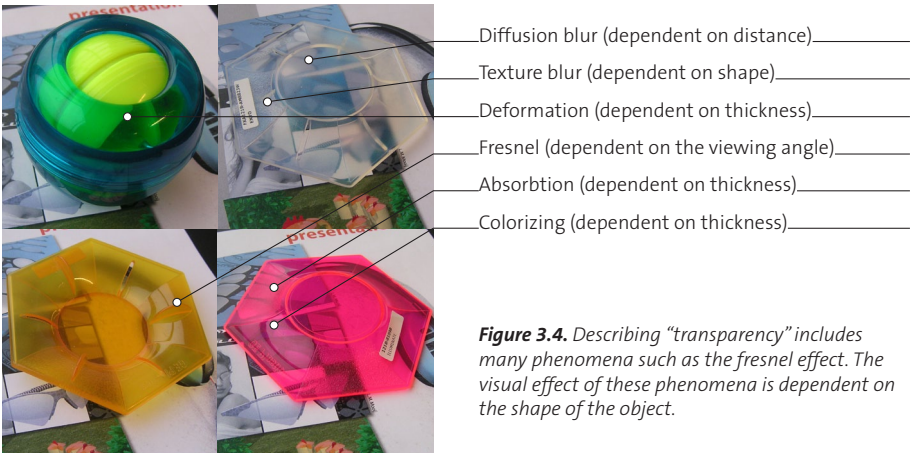


Figure 3.4. *Describing "transparency" includes many phenomena such as the fresnel effect. The visual effect of these phenomena is dependent on the shape of the object.*

meticulously in current computer graphics visualizations, as shown for transparency in Figure 3.4. Advances towards perceptual mappings of these properties are being made, for instance Pellacini et al. [2000] mapped the appearance of gloss onto two governing variables that he offers to users in a slider interface. Yet, similar to the CIE color system, his system is calibrated

on spheres having opaque surfaces without texture and provides less help when designing the material in a product, that involves surface and shape manipulations as well. Generally, computer aided design software has independent interfaces for materials, details and shape [Saakes 2006b]. Consequently, to visualize one perceived property of a material in a product, adjustments have to be made across several independent interfaces.

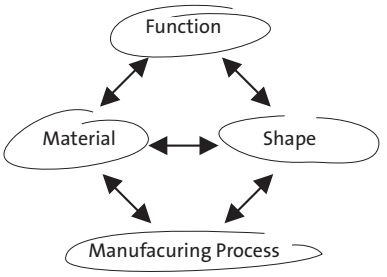


Figure 3.5. *Ashby's model of material selection in mechanical engineering visualizes the interactions between shape, material, manufacturing processes and function.*

The interactions between function, material, process and shape are seen as the central problem of materials selection in mechanical design [Ashby 2005]. Ashby developed a model to support material selection in mechanical engineering. In Figure 3.5, the relations between material, manufacturing process and shape are drawn. Here material is defined as: "the matter from which things are made". In this matter-centric definition all aspects of the product's embodiment are considered to be material. Shape is both the external and internal (e.g. honeycombs) geometry of a product. To achieve the shape, the material is subjected to processes that are called manufacturing processes, such as forging, casting, machining, welding. The interactions in the Figure 3.5 are two-way. The specification of a shape restricts the choice of material and process; but equally, the choice of a manufacturing process limits the materials and shapes that can be used. Likewise, given a function, existing solutions with similar functions may give rise to ideas for suitable materials and manufacturing solutions for an existing product might inspire solutions for a new product. Ashby's model is intended as a generative technique, to be used with an accompanying database of material properties, manufacturing techniques and applications. Poelman [2005] sees this process of matching potentialities and functionalities as the key process of technology diffusion in the industrial design process.

Similar techniques exist in designerly methods that aim to support designers in understanding the role of materials in products and to aim to provide tools to discuss the material aspects. Sonneveld [2007] for instance, created the tactile experience guide, a mind map technique to map a tactile experience of a product. Likewise, The MoM (meaning of materials) tool [Karana 2009] for designers and the MiP (Materials in Products tool) [van Kesteren 2008] describe aspects of materials in relationship with shape and product. Both are intended for discussions between designers and their clients and potentially users. However, they do not allow to explore and identify the translation from perceived to physical materials.

3.4. A Model for Perceived Materials in Products

A model for understanding perceived material appearance should a) take shape and manufacturing process into account, but also b) the role they play in perceiving and experiencing the product. I identify two dimensions in thinking about the expressive qualities of materials relevant to product design. The first dimension is the translation of abstract expressions into the physical representation of the product. The abstract dimension covers "function" in a broader sense and distinguishes between ingredients, perceptions and meaning. The second dimension spans the scales from atoms to parts.

Meaning to Ingredients: the Abstraction Dimension

When designers design product appearance they express meaning through manipulation of the product's physical manifestation, which in turn is experienced by users. The processes of designing and experiencing are depicted in Figure 3.6, and go from meaning, then perception, to ingredients (physical manifestation) and back again. The ingredients layer consists of the physical properties: reflection described in bi-directional reflection functions and length measured in meters. The perception layer describes how people perceive the physical properties ("glossy", "light", "heavy", "rough", "smooth", "sharp", "repetitive") and the meaning layer includes the expression of the product in terms such as "proud", "restless", " distant", "friendly". Whereas in the perception layer the contributions of individual aspects can be addressed, such as color, or weight, within the meaning layer the product is considered as a whole.

The descriptive models presented in Section 3.2 are mapped as going up from ingredients to perception or meaning. The generative techniques for color and gloss, presented in Section 3.3, go down in the model, from perception to ingredients.

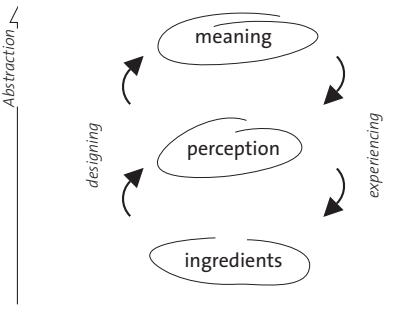


Figure 3.6. *The abstract dimension describes the relationship between product expression (meaning) and the product's physical manifestation (ingredients). People perceive the product through its physical manifestation and attribute meaning to it. When designing, designers manipulate ingredients to achieve a desired expression.*

From Atoms to Parts: the Scale Dimension

The appearance of materials in products can have multiple aspects from the raw granulate, to details, up to parts, therefore the second dimension refines the ingredients layer with the notion of scale, Figure 3.7. To the left we find the atoms and molecules, and the structures that form metals; while to the right, we find parts, products up to the relationship of multiple products or the relations of a product with its environment. Ashby's Figure [3.6] of material, manufacturing process and shape is mapped on scale, wherein the manufacturing process is considered to show

up in details, such as joining. Unlike Ashby's definition of shape, here internal shape is here considered to be part of the manufacturing technology or material. The importance of this figure is that it shows a continuous range, transitioning from materials seen as alloys and microshapes such as honeycombs.

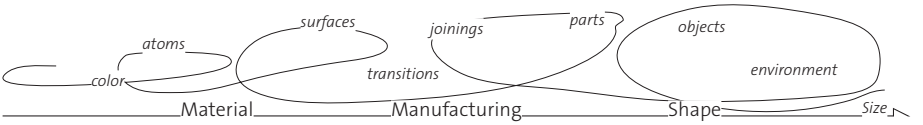


***Figure 3.7**. The scale dimension describes aspects that influence product expression on a continuous scale from small to large.*

Unlike the existing models, manufacturing technology is considered an expressive quality, and the product is either manufactured using a certain technology or its aesthetic design can adapt the distinctive elements of that manufacturing technology to provide the desired associations.

In the scale dimension, the distance from the observer must be considered. A patterned appears to be a smooth color when observed from a distance. Whereas designers tend to inspect products closely, products like chandeliers are experienced from a distance; where the influence of the small scale might be of less importance. The separate interfaces of computer aided design, and 3D visualization software in general, can be mapped as distinct areas in this dimension. A material editor typically allows setting on the small (left), a texture editor allows creating and positioning textures and patterns (middle) and the geometry editor allows manipulations on the larger scales.

The Matter: Magnitude, Meaning Model

When combining both the dimension of scale and dimension of abstraction, a new model is formed which I call the Matter, Magnitude Meaning (MMM) model, see Figure 3.8. On the horizontal axis we find the scale from small (atoms) to large (parts). The vertical axis depicts the layers of abstraction. At the bottom we find the physical aspects that are measurable with quantitative means, the perception layer describes how we perceive the product in qualitative properties. The meaning layer is applied to the product as a whole.

3.5. Examples

In the following examples I show how to describe products using the MMM model and give an example of materials visualizing using computer aided design.

Describing Products

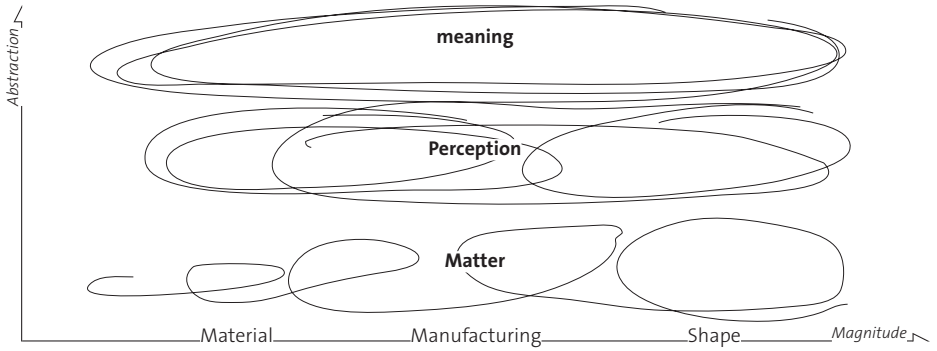


Figure 3.8. *The Matter: Magnitude, Meaning (MMM) model for the appearance of materials in products consists of two dimensions: abstraction (vertical) and scale (horizontal).*

In 2005 Lenovo acquired the personal computer division of IBM and extended their laptop products, previously aimed at businesses (Thinkpads), with consumer orientated netbooks (Ideapads). Thinkpads feature a distinct matt black business-look with sharp or beveled edges and a boxy shape. The Ideapad netbooks shares the boxy external shape, largely determined by the screen and keyboard, but all other aspects are distinctly opposite: round and glossy [Figure 3.9 bottom]

Fisher Price todlers toy products are made from high quality plastic, heavily rounded and consist of non-integrated shapes with vivid colors and relief decorations. The HILTI powertools share the high quality, vividly colored plastic and non-integrated shapes with Fisher Price's baby products. However, in contrast to Fisher Price, the shapes are sharper and instead of relief decoration have shape details such as plate fins [Figure 3.9 top]. The newer generation HILTI products share the integrated shapes of many of the consumer power tools. Still, the integrated, rounded hot air guns to remove paint are distinct from hot air guns to dry hair. Paint removers typically have an exposed metal head (metal can get hotter than plastic) and their shininess places hair dryers in a bathroom environment rather than the toolshed.

Generating Products

In the elective "Computer Visualization for Designers" at Industrial Design Engineering in Delft, graduate students render presentational visualizations of a product with 3D software. The final assignment consists of rendering an existing product in a new context, changing only the surface appearance of the product's material to make the fit. The rationale of the assignment evolved out of early computer visualizations of products that omitted any sense of context. Using existing media, such as advertisements and photographs, as a background greatly enhanced the quality of their visualizations. This assignment turns out to be extremely difficult to get right, but with surprising results as shown in Figure 3.10. The difficulty lies in finding a "material" that fits the object's shape as well as the context provided by the background. Students can manipulate the smaller scales through textures and material properties.

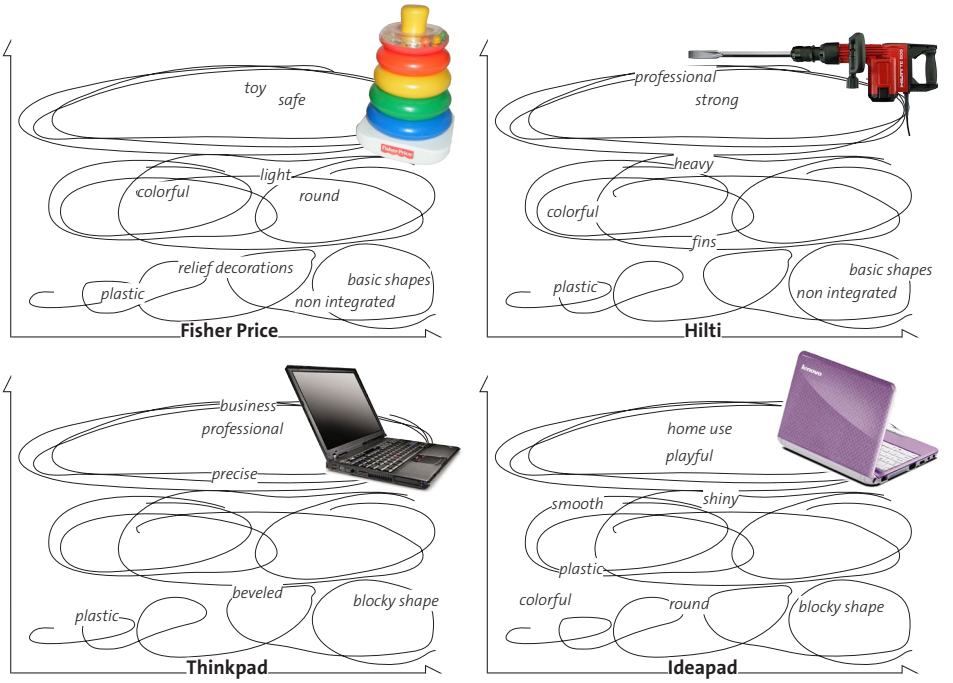


Figure 3.9. *Examples of contemporary products described on the ingredient, perception and meaning levels. The Lenovo Thinkpad is a business laptop computer whose color and sharp shapes serve to differentiate it from the Lenovo Ideapad, targeted at home users. Although the Ideapad has the same boxy shape as the Thinkpad, the rounded edges and bright colors are in clear contrast. The colors, blocky shapes, rounding and bright color make the Hilti hammer drill comparable to the Fisher Price Rock a Stack toy. However, the number of colors and the plate fins distinguish the professional masonry tool from a toddler's toy.*

3.6. Discussion

We perceive a material through its sensory properties. These properties span the five senses of sight, hearing, touch, taste and smell. The sensorial properties map to physical and chemical properties in materials in a qualitative way. Expressions and emotions both belong to the affective domain, but cannot be considered as two sides of the same phenomenon [Fulton Suri 2003]: an object may express cheerfulness, but our emotional response might be irritation if cheerfulness does not seem the right attitude for that context. Likewise, an object may be experienced as distant, but our emotional response may be positive because we do not want an intimate interaction with it [Sonneveld 2007].

It is the designer's job to design the expression of a product in such a way that users can understand it and use it safely (ergonomics) and that users appreciate using it (experience). Designers have various means to design expression or meaning into the physical product manifestation that include both material and shape manipulations through manufacturing technology. Therefore, a material in a product cannot be described in the major classes but must



Figure 3.10. *The Panasonic "Toot-A-Loop" radio r-72. Right top: photos of the original radio, the other visualizations are rendered by Erik Fuente Aira and Massimiliano Marass for the elective course "Computer Visualization for Designers".*

be described in an application, for example “sheet metal” or “bent sheet metal” not just “metal” [Figure 3.11]. Accordingly, techniques that aim to support designers in exploring and selecting materials in products need to include aspects that traditionally are not seen as materials.

Existing models that aim to clarify the relationship between product expression and the physical manifestation are generally descriptive rather than generative and include either the product as a single entity or focus on either shape material, not both. The interpretation and interactions of manipulations are left to the designer. Future techniques should 1) support designers manipulating aspects on various scales and experiencing the interactions, and 2) should address the way designers think, similar to the rich palettes used when choosing colors.

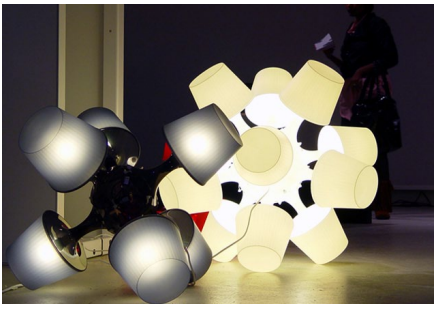


Figure 3.11. *These big lamps are made out of IKEA Lampan lamps. Here the question is, what do you consider to be the material ? Is it the plastic of the lamps, or is it the small lamps forming the larger one? [photo A. van Bezooyen]*

The MMM model presented in Section 3.4 aims to provide insight into this problem, describing materials in products on two dimensions. The basic idea is that material attributes must be described in the context of the product and the model must therefore takes the product’s shape into account. The first dimension is the abstract to concrete dimension. Abstract thoughts on product expression are terms, for example strong, huggable, feminine that can be translated into more concrete material properties as for instance color, shininess and texture but also into shape. Whereas abstract descriptions apply to the product considered as a whole, the more concrete the descriptions become, the more they can be addressed to a specific scale. The second dimension is therefore the scale and maps to the ingredients that make up a product. The model invites designers to be aware of all scales and levels of meaning and suggests that these scales and levels interact. One challenge is to support design not only within each level, but across the levels, so that the interactions become manageable.

In the next chapter I will take a look at the tools that designers use to design materials in products.



Figure 4.1 *Ceramic artists spend weeks modeling statues out of grey clay before they are glazed. Glaze consists of white or dull-colored powders that transform into vivid colors only after being fired in a kiln. The final appearance of the ceramic artwork is often completely different from the way it looks during the various stages of the design process. Firing glazed tiles, as shown on the right, is the only way to experience the glaze recipe.*

4 Tools and Techniques

4.1. Introduction

Designers use and produce a large variety of physical and digital artifacts to represent ideas and concept designs during the design process. These external representations range from inspirational collections of visual materials, to quick sketches, to working prototypes. Some of these representations are detailed and precise, whilst other are rough and fragmentary. Some representations are detailed on aspects, others provide an overview.

Sketches, i.e., rapid, incomplete, and ambiguous externalizations are recognized as key tools to support design thinking by individuals [Fish and Scrivener 1990], and groups [van der Lugt 2005]. Schön [1992] describes the interaction with external representations as a conversation between the designer (architect) and the sketch, in which thoughts are externalized into sketches, and the sketches are reinterpreted into new thoughts. Thinking and sketching are not separate processes: Design thinking occurs through interaction with the medium. Cardboard and foam models can be regarded as 3D sketches [Buxton, 2007; Djajadiningrat et al 2000], which appeal to the human perceptual and motor skills [Hummels 2000], and support intuitive understanding of complex geometrical and physical relationships [Piper 2002].

Although the aforementioned techniques support representation of shape and dynamic behavior, they provide less help with the exploration of materials in products. In this chapter I look into the tools and techniques designers use in the early stages of the design process, to understand how they design materials in products. I first review [Section 4.2] theories on design representations and relate representations to design activities, tools and techniques. Then by means of field interviews in Section 4.3, I relate the theory to the industrial design practice. In Section 4.4 I review the prior art in computer supported design tools. Then, in Section 4.4, I conclude with a set of consideration that aim to guide the development of new tools [Section 4.5], and in Section 4.6 I identify the challenges for supporting material exploration in the early stage.

Definitions

I use **model** as a physical representation of an object.

I define "**representation"** as a description, portrayal or model of the intended physical manifestation of the design.

Tool is a device or implement used to carry out an particular function.

Technique is a way of carrying out a particular task. A pen is a tool to make a drawing. Drawing (verb) can be a technique to visualize an idea. A drawing (noun) can be a tool to communicate a design.

4.2. Design Representations

A single sketch can have multiple uses during the design process, in generating new ideas and communicating ideas to others. Van der Lugt [2001] categorizes sketches by their use in the design process: thinking sketches, talking sketches, storing sketches and prescriptive sketches. The first three he found in Ferguson [1994] and the last in Ullman [1990]. Thinking sketches are sketches that individual designers make to focus and guide their nonverbal thinking process. Talking sketches are sketches to support group discussions, to communicate ideas in a group and to provide *"a common graphical setting for an idea to be debated"* [Ferguson 1994 pg 97]. Buxton [2007] refers to this function as the "social function of sketching". Storing sketches archive design ideas and as van der Lugt puts it: *"to revisit previously conceived ideas during creative group sessions"*. Prescriptive sketches communicate decisions to persons who are not part of the design process. Ferguson describes the prescriptive sketch as *"to direct the drafter in making a finished drawing"*. According to McGown & Green [1998 pg. 436 cited in Van Der Lugt 2001 pg. 40] the prescriptive sketch is *"...used almost exclusively within the latter detailing (pre-manufacture) phases of the design"*. Sketches are used as a technique to support the individual and groups ideation processes, and as a tool to communicate designs.

Similar categorizations exist for physical prototypes and other design representations. Fulton Suri makes the distinction between the designers' "insider tools" for inventing and learning and "tools for communication" of an idea to be shared with others [Fulton Suri 2003]. In defining "others" she describes people who are less familiar with the designer's representation or the context that gave rise to the idea, and are in need of a more explicit form of representation. Likewise, Hummels [2000] distinguishes generating and demonstrating activities. Under "demonstrating" Hummels includes activities ranging from "communicating" to "convincing and selling ideas to an audience". Both discuss a wide variety of models. The representation itself is not the final goal, it either facilitates the thinking process or allows interaction with the future product.

Based on van der Lugt's classification of sketches, I identify four activities in which representations play a role, shown in Figure 4.2. I extend the "prescribing sketch" to a more general demonstrating activity: to show, share, explain and sell ideas; not necessarily restricted to the latter stages of the process. I distinguish between insider tools, e.g. the thinking and talking sketches, and

outsider tools, e.g. the storing and demonstrating of representations to communicate within the larger group of stakeholders. Whereas the fidelity of a sketch or prototype can be low when used as a technique with insiders, to communicate with outsiders and be used as a tool, explicit representations are needed.

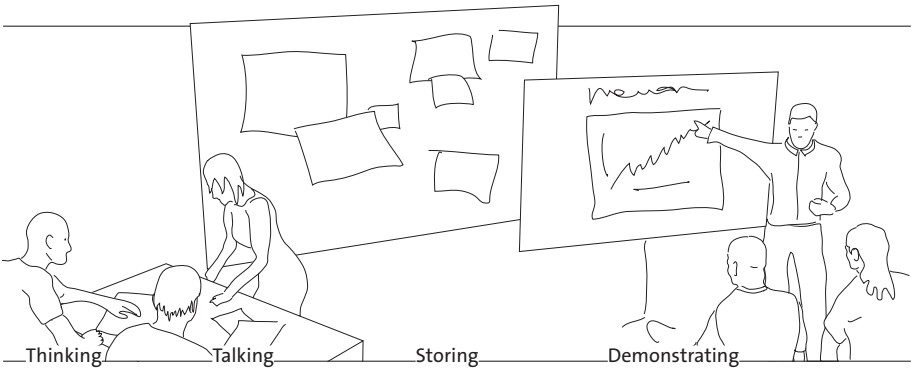


Figure 4.2. *During "thinking" and "talking" activities representations are used for communication within a design team. During the "storing" and "demonstrating" activities representations are used to communicate design decisions to the larger group of involved people such as clients and management.*

The fidelity of design representations range from abstract ideas, quickly drawn diagrams on cocktail napkins [Gross 1994], to concrete 3D models such as beautiful sight models presenting concept cars. The various activities for which designers use these representations have their own specific fidelity requirements. Demonstrating designs to the larger group of involved stakeholders will require more explicit representation to convey an idea than a designer needs for his/her internal thought process. According to Fish & Scrivener [1990] sketches are unique representations, having a special set of attributes that help the human mind in translating descriptive propositional information into depictive information. [Figure 4.3, Fish and Scrivener 1990] This will in turn give rise to new descriptive information, which will in turn lead to a new depiction. This is what Goldschmidt [1991] calls "seeing that" and "seeing as", and Schön [1992] calls the conversational cycle. Fish & Scrivener [Fish & Scrivener 1990] identify three attributes of sketches that contribute to this description-to-depiction translation process: 1) Sketches use abbreviated two-dimensional sign systems to represent three-dimensional visual experiences. 2) Sketches contain selective and fragmentary information. 3) Sketches contain deliberate or accidental indeterminacies that are important to their function.

Different from sketches, physical prototypes are traditionally considered the more concrete representations [Fish & Scrivener 1990], the sight models or pre-production models, built in the later stages of embodiment design. However, many authors [Binder 1999, Djajadiningrat et.al 2000, Brereton 2000 & 2004, Kelley & Littman 2001] report the advantages and use of physical prototyping in the early stages: *"We pitch presentations in stages, show the rough sketch, the cheap*

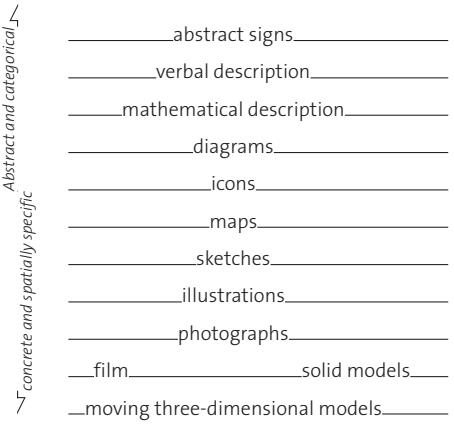


Figure 4.3. *Fish & Scrivener [1990] categorized representations from abstract to concrete, where models are seen as concrete and spatially specific.*

foam model, to right the course before it's too late" Kelley and Littman [2001 pg 113] talking about the design practice at IDEO and *"it's easy to reject a dry report or a flat drawing. But models often surprise, making it easier to change your mind and accept new ideas--or make hard choices, such as forgoing costly and complex features"* [Kelley & Littman 2001 pg. 111] *"The fluid process of sketching and the ambiguity of the sketched representation have analogues in physical prototyping. Because physical objects can be interpreted in multiple ways depending upon their context of use, they too are ambiguous and facilitate context-dependent interpretation as do sketch elements."* [Brereton 2000 pg 223]. Binder [1999] uses basic foam models to invite his users to act out interactions on location. Not only are these prototypes as disposable and quickly made as sketches [Buxton 2007] but they also share the attributes Fish and Scrivener ascribe to sketches supporting the description-to-depiction translation process.

Hummels considers physical prototypes experiential representations as opposed to distant representations. *"An experiential technique allows the creator to experience the story as the main character"* [Hummels 2000 pg. 2.6]. Therefore the prototype needn't necessarily convey a concrete and spatially specific representation. [Hummels 2000] Buchenau [2000] coined the term "experience prototyping" where prototyping aims to let the designer think of the design problem in terms of designing an integrated experience, rather than one or more specific artifacts. Buchenau argues that to meet this requirement the designer: *"needs to focus on 'exploring by doing' and actively experiencing the sometimes subtle differences between various design solutions."* [2000 pg 432] These experiential prototypes are inherently interactive, it is about the activity, the gestures and the playacting. The prototypes both facilitate and invite this.

Table 4.1. *Six dimensions that are relevant to describe the role of representations in the design process.*

Activity	Thinking	Talking	Storing	Demonstrating
Audience	Insiders			Outsiders
Use	Technique		Tool	
Fidelity	Low, high on aspects			High
Quantity	Many		Few	
Lifetime	Transient		Durable	

Brereton [2004] calls these "transient representations" *"produced in the act of designing but never captured"* as opposed to durable representations that endure and can be kept and referred to. For instance, in the "interaction relabeling technique" [djajadiningrat et al. 2000] the mechanical interactions of unrelated ready-made objects are mapped to possible interactions of an electronic device to be designed. Using a ready-made object widens the designer's view of possible interactions as a creative technique.

In this section I touched upon a number of qualities when describing representations. I identify six dimensions relevant to the use of representations in the design process: [Table 4.1] the activity the representation supports, the target audience, the fidelity, use, quantity and lifespan. During the thinking and talking activities fidelity is low, and the representation is used as a technique to support the thinking process, while in the demonstrating activities the fidelity is high and the representation is used as a tool to demonstrate the design to a larger audience. In the next section I review representations designers use, relevant to materials in products and include ready-mades (collecting), mood boards (collaging), drawings (drawing) and physical prototypes (modeling).



Figure 4.4. *Designers tend to keep collections of materials for inspiration. Product designer Joanna Boothman at work at NPK Industrial Design (pictured) surrounds herself with colorful samples and examples.*

Representations Designers Use

The activity of **collecting** is seen as a design technique: *"to organize visual material and find new insights in the order that comes from that"*. [Keller et al. 2006] Designers tend to keep collections of ready-made materials for inspiration: images, sample products and technical solutions. Sample products may be bought for inspiration in a specific project, or collected because of a more general interest. These collections are often personal and displayed in the designer's workspace [Pasman 2003] as shown in [Figure 4.4]. Nowadays, digital photo collections and online resources extend the physical collections. [Keller et al. 2006] Apart from personal collections, various commercial collections with large quantities of materials are available. [e.g. Poelman 2005, Zijstra 2005, Beylerian 2005]; these libraries act as brokers between manufacturers and designers. Companies such as GE-Plastics have design centers around the world with large sample collections of their materials. These centers allow designers to browse through materials [Postrel 2004]. Some of these libraries offer subscriptions to regularly updated small sets of inspiring samples.

Physical samples are the real thing and are high fidelity representations. They can be felt, probed for strength, and also exhibit many visual aspects that cannot easily be verbalized or be drawn. Although browsing through these materials is seen as a inspiring activity, the fact that samples are "discrete" and cannot be manipulated (e.g. change color, gloss or shape) limits their use. Although the samples contain details typically found in plastic products, a material specialist from GE explained to me that her clients encounter difficulties selecting the material for larger objects when using the small samples. [personal communication at the GE Plastics competence centre in Bergen op Zoom, nl]



Figure 4.5. *Two collages made by students at Industrial Design Engineering used as a non-verbal way to explore sensory expression in a design project.*

Collaging is creating abstract images that convey a "feeling", composed out of rich visual materials from various sources. Mood boards, such as the example shown in Figure 4.5, are collages that function as a non-verbal way to express an abstract idea or a specific atmosphere [Muller 2001]. The act of making of a mood board is a design technique, used in the design process for two purposes: as a metaphorical expression [Garner & McDonagh-Philip et al. 2001; Sleeswijk et al. 2006] made by users in generative sessions, and by designers as an abstract sensory expression [Muller 2001] of an experience, an atmosphere or mood. For materials we are interested in the latter, Muller's description: "Designers form new ideas while glancing through magazines and collections and intuitively selecting images and composing them together" [2001]. Mood boards make effective use of the graphics readily found to represent product expression in a non-verbal way. Whereas mood board making is taught at design schools as a "thinking" technique [Muller 2001, Garner & McDonagh-Philip 2002], in Dutch design practice Keller [2006] observed that designers used mood boards as a talking, but foremost as a demonstrating activity to communicate ideas to clients, and only made mood boards if the clients asked for them.



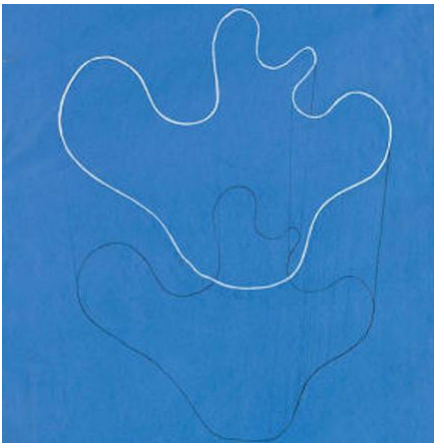


Figure 4.6. *Two drawings that convey material expression through a specific drawing style. Left, with rough strokes and large construction details (the bolts) Ron Arad accentuated the metal and force required to make his "well tempered chair". On the right, Alvar Aaltos sketched his classic Savoy vase with a few thin lines to emphasize its fragility and transparency.*

Drawing is the predominant technique that designers use to visualize ideas, to clarify thoughts, to communicate and present. I use drawing as a two-dimensional representation of a product or aspect thereof. A drawing can be made by hand, or computer assisted, possibly making use of 3D models. The variety in drawings is immense, ranging from quick sketches to presentation drawings [Buxton 2007, Eissen & Steur 2007] and a drawing's intent spans all activities. Designers create large quantities of drawings, often organized in sketchbooks. Digital drawing tools are tools that mimic aspects of painting, sketching or collaging. There are tools such as Painter and Sketchbookpro that aim to mimic painting with paint and pens as closely as possible. Other tools such as 2D vector software, such as Illustrator, allow drawings to be parametrically constructed out of elements. A third type of tool, 3D visualization software, renders photorealistic images from Computer Aided Design drawings.

Quick sketches mainly focus on conveying shape, construction or dynamics. Materials can be depicted to a certain extent; for instance by exaggerating contrast to indicate gloss or exaggerating manufacturing details, as shown on the left in Figure 4.6. Also the drawing style itself and the type of tool can covey expressions such as fragility and glass as shown on the right in Figure 4.6. Presentation renderings of finished concepts, shown in Figure 4.7, "demonstrate" the product to the untrained eye. Presentation drawings often contain mixes of traditional hand renderings, computer assistance with a tablet as input device, and photos depicting specific material elements such as fabrics or woven polyester structures. Computer renderings are made with computer visualization tools and are usually 3D scenes rendered using a virtual camera.



Figure 4.7. *A number of representations made by Pieter Diepenmaat during the design of a game controller, including improvised prototypes, prototypes for demonstrations, sketches and a photorealistic rendering of the end result.*

As described earlier, **modeling** [Figure 4.7] is versatile, similar to drawing: from the use of improvised objects as props in a playacting sessions to sight models in the automotive industry that are, at first sight, indistinguishable from real cars. Whereas models for the early stages can be made quickly from paper, foam or clay, refined models require the effort of (3D) construction drawings and the tools or services to construct, laser-cut or 3D print. Models are an effective instrument for the talking and demonstrating activities in multidisciplinary teams.

4.3. A Glimpse in Practice

Now that I have discussed the theory of design representations and discussed a few typical representations designers use, I will substantiate the theoretical findings in practice, using a field study.

Background

In 1990, the school of Industrial Design Engineering at Delft University of Technology started a research project intended to explore computer enhancements for the conceptualizing process in industrial design, the IDEATE project [Hennessey 1990]. The project's goal was to gain a thorough understanding of design methods, techniques and tools designers use, through the study of designers in their natural environment. The resulting designer support tools and techniques use digital tools to augment the current practice rather than a technology push in which tools require users to completely replace their techniques. In 1992 Kolli, Pasman and Hennessey [Kolli et al. 1993] studied the design practice in order to find requirements for computer tools to support designers in the early stages. They studied designers in their workspace and studied the context of use, in particular the relationship between tools and the work environment. Their study resulted in seven considerations for the design of computer support for the early stages of design:

- **Support rapid and rough capturing of ideas.** Externalizations characteristic for the early stages are quick, rough and flexible. Computer support should facilitate unconstraint capturing of ideas.
- **Afford a personalized environment.** Designers have a individual-orientated environment. A computer support should be unobtrusive and allow the user to arrange tools and (inspirational) materials in his/her own personal way.
- **Use rich information resources**. Designers make many visual depictions and gather information in a wide variety of rich visual materials. Support a highly visual environment to capture, organize and retrieve information from various sources.
- **Enable high level of communicability**. Although design tasks are done by individuals, there is a considerable need to communicate ideas, thoughts and views. Computer support should facilitate collaboration between team-members and clients.
- **Support individualistic styles.** Personal style, developed over the years, expressed in sketching and presentation habits and tool/technique choice, makes a designer stand out from others. Computer support should allow a personal touch in design representations.
- **Afford smooth shifting of activities.** Designers shift attention to different activities and often work on multiple projects concurrently. Switching media, media should be editable by a variety of tools.
- **Support motor skills.** Many of the designers' activities involve working with two hands, standing up and using large (horizontal) surfaces.

These considerations are clearly a reaction to the early computer aided design and computer drawing tools with spartan, rigidly structured interfaces. The computer support for handling visual media has improved dramatically and the support in motor skills is emerging with the multi-touch [Han 2005] and gestural interfaces. Keller [2005] repeated the Kolli study with a focus on collections of visual materials that designers use for inspiration. Whereas in the 1992 study computer support other than for engineering purposes was rarely found, Keller's 2002 study showed the large impact of online available digital media on the design practice. Keller identified the designers' need to connect the physical with digital domains, born out of the observation that they keep separate collections of physical and digital source materials. Furthermore he argued that serendipitous, unexpected discoveries, important for creativity, were less likely to occur when using the current digital tools for handling source material collections.

For his master's thesis, Jesse van Dijk [2003], interviewed designers at two industrial design agencies (n|p|k, pilots and springtime) and one architectural firm (Benthem Crouwel) regarding their computer use in communicating designs to clients. Van Dijk found that nearly all visualizations used to communicate designs to clients were done using 3D rendering tools, sometimes heavily modified with Photoshop. Whereas Van Dijk focused on the "demonstrating" activity, and the Keller study focused on the use of visual materials as a source for inspiration, I felt that I needed an additional look into practice to study the tools and techniques designers use to explore materials in products.

Method

The participants were recruited from three companies, working in different product domains (furniture, consumer electronics and interior design and commodity design). Unlike the 1993 and the 2002 studies, I included an in-house development team and a design/manufacturing company, thought to have different relationships with clients and manufacturers than design firms. The companies varied in size and nature (a one man design / manufacturing firm, an agency with over 100 employees and a large multinational).

The visits started with a semi-structured interview to provide insights into the work processes, clients and background of the participants. Then a few cases were discussed. I focused on the activities (thinking, talking, storing and demonstrating) and the abstraction level, all in regards to the material aspect. The interviews were transcribed, analyzed and reported back to the interviewees for accuracy. In contrast to the earlier studies I choose to use retrospective case studies [Yin 2003] over contextual inquiries. [Holtzblatt 1996]. Contextual inquiry is an ethnographic method to study a work process through a situated interview while the interviewees are in context doing their tasks. The method was designed to allow members of design teams, without a background in ethnography or user studies, to gain a first hand experience of the use of software tools. The interviewees are considered to be experts on their own work process and they are





Figure 4.8. *The office for Jochem Galema's (JG) company, Contour Industrial Design Solutions, is located in a refurbished shipyard. It is packed with the chairs he has designed over the years, serving as durable representations of his work. On the left is one of the numerous examples of JG's work. This prototype was built to test a moving construction. Experiencing the prototype made JG change the design to make use of separate cushions instead of upholstery.*

observed while working, and occasionally questioned about their doings. The goal is to understand how and why something is done. Obviously, a design process spans a large period of time and consists of many activities, typically including meetings with various stakeholders. In order to perform a contextual inquiry within a reasonable time, it can only provide a snapshot of the activities during the visit. Therefore the inquiry into the design process is approached as a retrospective case study performed on a current or recently finished design project. The produced documents, drawings and models act as props to elicit the story and having these and other materials at hand in the workplace uncovers the tacit knowledge that is not easily brought out in traditional interviews [Sanders & Williams 2001].

Contour Industrial Design Solutions.

Jochem Galama (JG), a graduate of Industrial Design Engineering Delft, has over 10 years of experience as a product designer. During his studies he did a year-long internships at furniture companies and he has been designing furniture, mostly chairs, ever since. JG's company, Contour Industrial Design Solutions, is a one-man design/manufacturing firm located in a refurbished shipyard in the north of Amsterdam. His workspace, as shown in Figure 4.8, is packed with chairs he designed over the years. When it comes to furniture, JG takes a pro-active approach, pitching concepts to manufacturers, and then, if accepted, detailing his concepts into products. Usually JG gets paid in royalties. Recently however, he has become a manufacturer himself, and has been having designs produced in China. Besides furniture, JG designs various products from packaging to graphics for mountain bikes. On some projects he collaborates with Wina Smeenk (WS). She is also a graduate of Industrial Design Engineering Delft, and previously worked in bike design at Giant Bikes. During my visit we talked mostly about chairs with one exception: the styling of a new mountain-bike brand.





Figure 4.9. *JG always starts sketching in his sketchbook (left), which he carries everywhere. JG's portfolio book (right) consists of client presentations, mostly 3D renderings made using Rhino 3D software.*

JG always starts by sketching in his personal sketchbook (A5 format) [Figure 4.9] *"all my ideas are in the sketchbook. I sketch everywhere, at night, when watching television. Strangely enough I never get ideas in the office"*. Promising ideas are put directly into his 3D software (Rhino 3D) and rendered for use in presentations, see Figure 4.9. Sometimes he makes a nicer sketch on A3 paper instead of using rhino. Both types of renderings he presents to clients and manufacturers. *"Advantage of a sketch is that it leaves things open, so the manufacturer can see things that are not in the design. The render is often treated as a 'finished product'."* In this stage he doesn't detail the design or think too much about construction details. If his clients accept a design he usually goes back to his sketchbook before detailing the design in Rhino.

JG seldom makes models. Sometimes he outsources model making to test certain constructions as depicted in Figure 4.8. He showed a crude model made of construction steel, normally used in reinforced concrete, painted black: *"this model I had made to test how to attach the leather. The material of the model is the cheapest you can get, and when it's black it is not so noticeable, it draws the attention to the leather."* For another project he had sent his Autocad files directly to the manufacturer in China, and within eight days he had photos of prototypes of 12 products. He jokes: *"So different from the Netherlands where you send drawings and after three months they call you explaining 'what you have drawn cannot be done' "*. He showed a prototype of a chair made from steel tubes that he had also outsourced. *"they didn't do it right"* he said as he showed me his drawings in comparison. *"so now I send them the measurements of the individual tubes... it is not so easy"*.

Generally his clients decide on materials, colors and fabrics, although he does give them advice. He showed a chair that has a white fabric on the outside and a black seat. *"I like this contrast, but the manufacturer never showed it to his clients. Now 10 years later we do a outdoor chair with this color scheme"*. Manufacturers have their own collection and suppliers of fabrics, they also tend to be conservative according to JG, they often have strong opinions based on personal preference or what is common in the market without doing much market research.

Apart from the fabrics there are not so many options in the tubing of his chairs. Colored tubes are generally considered to be cheap, so most designs are done in either white, black or in RAL 9006, a grey that resembles aluminum. JG has color guides of Pantone colors (for print) and RAL colors (for paint). To express quality, parts are usually chromed, either glossy or matte. However for chroming, the welding and details have to be very neat and clean, which is expensive.

JG speaks with great enthusiasm about materials, the qualities of woods, and how he found this company in China that makes inexpensive but beautiful rough galvanized steel frames. "*they also manufacture the signposts for the region, so their product is durable.*" He makes extensive use of example products to specify materials and finish. He showed a wooden chair he had manufactured in India: *"The manufacturer in India asked me what kind of wood and finish, then I had to look for examples, because I lack the necessary vocabulary." "During my studies I learned too little regarding materials, while in practice they are very important for the appeal of a product. If you ask people about their bike they say "I have a green bike" despite all the features and details the experts at Giant, for instance, are talking about"*.

JG almost never makes mood boards, except for a mountain bike project he is currently working on. *"Wina [his partner] did make lots of mood boards for Giant bicycles. To map trends she found at fairs, and to connect trends with existing brand graphics and logos."*. For the current project they designed the brand image and colors from mood boards, however he emphasizes that they will make the final decisions based on samples he has yet to receive. *"I want to etch the graphics out of the frame, but we haven't found good examples yet"*. Their client had provided a photo he had found on the Internet of an exhaust pipe of a motorcycle, the oily colors in the photo were used as a starting point to design the expression of the rear suspension system.

Then JG shows the Illustrator artwork, depicting a 2D drawing of the brand graphics on the bike. *"A rendering like this gives a good idea, but not as good as on the real bike. Only then can you see the real size"* At the office JG shows a prototype of the bike. *"Like Wina used to do at Giant, we print out the Illustrator graphics at various sizes, from 80% to 110%, then we cut them out and tape them to the frame"*. Because of the tubing's curves he had to modify the original artwork to make it look right. The exploration of the placement and scale of the artwork was done together with the client.

Fabrique

Fabrique is a large Dutch design firm with over 100 employees and offices in Delft (product, web and public space design, and branding) and Amsterdam (graphic and new media design). I visited the Delft office [Figure 4.10] and talked to two designers currently involved in a project for Schiphol airport. Arjan Schoof (AS) is an Industrial Design Engineering Delft graduate. He started at Fabrique six years ago, first as a website designer, later moving to product / public



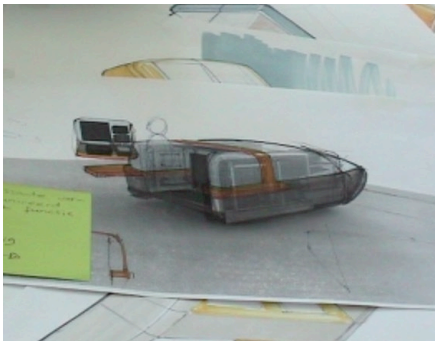
Figure 4.10. *A wall filled with sketches in the office of the Fabrique designers.*

space design. AS works on 5 to 6 projects concurrently, but within the Schiphol project he works on one or two designs at a time. The team for Schiphol consists of two designers. René Bubberman (RB) is also an Industrial Design Engineering Delft graduate. RB is a founding partner of Fabrique and manages the 3D design department in Delft. Most work consists of public space design ranging from bus shelters and phone booths to the user experience of highways.

RB does his initial design sketches on anything, without preferences for paper or pens, but he likes good 3D software for the later stages. AS does have preferences for certain pens and likes Painter (a 2D drawing package) best for making renderings. He doesn't do much rendering with Painter, but he plans to incorporate that as an intermediate step between sketching and 3D modeling. Both think sketching is absolutely essential, and the fluent use of templates and spreading out sketches on a table cannot be replaced by Photoshop or 3D tools.

RB: *"good design distinguishes itself through its details"*. Small details have a large impact on the overall design. His approach is to zoom back and forth between the big picture and the details. He has had bad experiences with leaving details to others, for instance third parties (construction engineers) who have less compassion for the design's intent. He therefore thinks that all the aspects of the design have to be taken into account from an early stage to get a better product. In the early stage of the design process, he constantly switches between sketching, clay modeling, supplier information such as steel beams and engineering guides.

The Schiphol project consisted of multiple designs all to be placed in the departure hall. Fabrique started the project by defining "design principles" to ensure consistency throughout the various products. These principles did not constrict colors or rounding diameters, but contained abstract descriptions such as "a simple base shape". The principles were later used to propose or deny certain solutions. At one time the client proposed a buttonless keyboard, which was rejected based on these principles. Currently AS is working on an automated baggage intake machine. They had started with the configuration of elements, the intake, display and console. *"there were many elements to the design, so we had to make some quick decisions to make it in time."* Then, AS and another colleague had made an enormous amount of sketches: *"For a whole week we made sketches without making any decisions"* [Figure 4.10] *"With these drawings we were looking at the main shape. And it is just as in cars; by changing a little you can make the shape lighter, heavier etc."*. All the sketches were put up on the wall, and sometimes discussed with other designers that



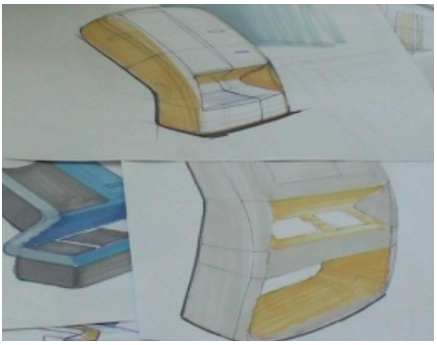






Figure 4.11. *AS showed an enormous amount of sketches. Some sketches are drawn on a simple 3D model of the frame, others include people to emphasize the true size of the object. On the bottom a few of the models AS made for the Schiphol project. Left, a console for the baggage intake at true scale, which as AS explained might look gigantic in his office but is intended for a huge baggage hall. Right, two designs modeled to scale in foam.*

happened to drop by. Sometimes they added people to the sketch to depict size: "*it is not a toaster, but it is quite large*". Some sketches were drawn over a rendering of the frame of the machine: *" we don't want to deceive ourselves by drawing "slim" shapes"* but he quickly adds that using the frame for all drawings would block the idea flow: *"then it is hard to think beyond a rectangular box."* AS explains that during that week he used various sources for inspiration, drawings, magazines, books. *"A nice detail, nice material or rounded shape can be inspirational. When you have been drawing for a week, the inspirational images force you to think of other ideas"*. These sketches were not communicated to the client, but during the presentation they showed photos of the process of sketching and foam modeling [Figure 4.11] to give the clients a glimpse of the process leading to the final design. *"They really appreciated that, they even showed it in their presentations to others"*

After the sketching stage they selected promising ideas that expressed a certain affordance such as "place your baggage here and it will be taken away" or "place your luggage here and then you are done". They selected two ideas and then made foam models and presentation renderings with 3D Software. AS picks up two foam models [Figure 4.11] and explains *"some things look different*

when you see them in a model". He likes modeling because you can do additional shaping to make it look right. They also had a model maker make a 1:1 model, but prior to that they had marked the size of the device on the wall with tape. *"In this room it looks enormous"* indicating the size on the wall, *"but in the departure hall in Schiphol it fits just fine; the context is important"*. Then he showed the machine's console, which was in the room as well, *"also the console looks also big in this room"*.

When asked about mood boards, AS said that they did not make mood boards for this project. RB explains that here the color scheme was already quite specific. In other projects they usually make mood boards to check with the client if they are on the right track *"is this your customer?"*. He shows mood boards made for a kegerator (a home draught beer dispensing device) and explains that they make mood boards before sketching, one is titled "people", (the style of the target group) and another "products" (products that the target group likes to see).

Talking about materials, RB explains that the most important factors of material choice are cost and function. Most materials choices consist of the color of a granulate, the roughness of the mold for the texture and sometimes a coating. In consumer products material is more important than in industrial applications. RB shows a rendering of the kegerator product and explains *"here we've chosen feet with a metallic finish, to avoid the plastic look. It is something people put on their table, by adding those kind of details the product becomes more iconic" "Often we have to defend the choice of such a relatively expensive material with arguments that it will improve sales"*. Materials and details are often expressed in the mood boards or are indicated in sketches. AS: *"In drawings we use color in drawings to indicate "accents" so in the early stages we do think about it but it is not the goal, drawing in black and white is completely different from drawing in color."* RB explains that he advises his team to color objects as soon as possible, when they are working in Solidworks: *"so if you think you are going to make the object yellow, make it yellow, because it will influence your other decisions. That way it is not amorphous clay during the detailing process. Then it comes alive."* Talking about the material for Schiphol, they show some physical samples. *"At first we thought of a high gloss product, probably a composite material. Due to the strict requirements we couldn't do it"*. The manufacturer had a preferred material, which was matte. AS explains that in the end the material could have been done in the chosen finish, but more expensively. *"In some cases such a change from gloss to matte could make us go back to the drawing board, but not in this project."*

RB explains that they make extensive use of physical examples. Designers always look around for inspiration and borrow a lot from others. *"Sometimes I get inspired by images I find on Flickr. It is hard to simulate.... to capture such a feeling in a rendering"* They specify materials to manufacturers using samples. In the case of the feet of the kegerator RB says that the only way to specify the material was to find a product with the preferred metal, and gloss, and to send it to China as a reference. They also use samples to communicate materials to clients. AS: *"sometimes you get really crazy and start looking everywhere to find the exact expression you have in mind... in*

the Schiphol project we found a USB flash drive that had exactly the combination of hard and soft feel we were looking for". They sent the USB flash drive to the manufacturer who immediately recognized the material and could produce it. AS explains that that is the only way.

When asked about colors, RB concludes *"clients have a strong opinion regarding colors, so we are generally very careful"*.

Procter & Gamble Brussels

Procter & Gamble (P&G) is a multinational in consumer goods. I visited the Brussels Innovation Centre (BIC) which is one of P&G's larger research facilities in Europe. The Create and Innovate (C&I) group acts as a design firm within P&G and offers design services to various divisions worldwide. New projects often start with creative group sessions, in which a multidisciplinary group of people generate new ideas in intensive sessions lasting up to three days. The C&I group facilitates many of these sessions. In Brussels I participated in two creative sessions: a small internal (C&I group members only) session for a toothpaste product [Figure 4.12] which allowed me to ask many questions during the session. A second session involved sprayable cleaning products with many participants and spanned a full two days.





Figure 4.12. *The result of an creative session (left). Ideas generated by participants are illustrated by visualizers. The ideation sessions are verbally oriented, apart from the visualizers most participants have backgrounds in marketing and engineering. After a day's session the walls are covered with flip charts and post-it notes.*

On my visit, Tanya van Rompuy, the lead facilitator and group leader, shows me around in their office space, workshops and meeting rooms. During the tour and the meeting Tanya is interrupted a few times to help plan ad hoc workshops and discuss their details. The office space is packed with packages, prototypes and inspirational graphics. While walking through, Tanya picks up samples and bottles to talk about projects they designed. She tells me how they are constantly looking for new materials and ideas and have subscriptions to various services which send them quarterly samples of inspirational new materials.

Julian, born and trained as a designer (BA) in the UK, is a visualizer for the creative group sessions. When I met him he was drawing bottles using 2D vector graphics software. The result of a typical session is a set of about 40 ideas that he draws for consumer presentations. Most of the (brand) graphics he obtains from the requester (the internal client). The presentation drawings are sent to the requester and after a few weeks Julian gets about 4 designs back which are made into 3D prototypes. They always first make a 2D visualization first before the 3D model. In their workshop I met Adrian, who shares the same background as Julian, who makes these models. The gross of the models Adrian makes are made of printed cardboard. Most of the packages on display in his workshop are indistinguishable from real packages, and in order to convey the "incompleteness" of a concept he omits graphics such as safety notices and barcodes. Although most of his work consists of packages in cardboard, he shows me how to make shrink-wrap films that go around plastic bottles. He typically makes the graphics in Photoshop and then deforms the graphics to take into account the shrinking around the 3D shape. Apart from sight models he also makes functional models with an in-house 3D printer. For instance, spray heads for sprayable products or spouts to evaluate pour-ability in user studies. A typical project spans about a week in which he makes a small number of designs for the requester.

Tanya explains their "way of working" by talking me through a project they finished a few months ago in Dental Healthcare. Preparation usually starts two weeks in advance. Prior to a session she speaks with the requester. The idea of the dental care group was to create affordable toothpaste packaging for developing countries. She explains that she then reframed the request to a wider scope "changing the game in dental healthcare" and looking at innovating the toothpaste packaging.

A typical ideation session takes up to three days with about two facilitators, two visualizers who draw out ideas and 15 to 20 participants from various product divisions whose expertise ranges from packaging design, product engineering to marketing research and usability testing. The participants are selected based on the project. *"We look at functions people have within the product category. In this case we needed packaging experts, product research panel (consumer research) design managers, visualizers or conceptual designers, ideally we include also marketing people. And if possible also a few people from outside the "request team", people that have the jobs that we are looking for but work in other categories"* In this workshop they included a few people that do packaging in adjacent categories, fine fragrance packaging, beauty care and cosmetics, also someone from engineering.

She sends an invitation to all participants, indicating when and where, a little background information, and a homework assignment. Homework is meant to open the participants' minds, immerse them in the problem, and connect them with the consumers. Participants are sent templates in which to put their homework, e.g. 'my consumer, her product, the things (s)he loves

about the product, the things (s)he hates about it. Assignments may be to make photos of users, do a store check (go to a store to see how the product is sold), observe and talk to consumers, collect inspirational packages or make collages. *"This research is simple, and done by everybody, including the engineers."*

The session starts with providing background information, usually by the requester and making the participants, who often do not know each other, comfortable. Then the so called download with the goal to is to immerse everybody in everybody's homework. Photos and example products are shown and discussed. *"At the end, the people should be immersed in the problem, fueled to creativity, and inspired"*. This is a lively "show and tell" part with lots of discussion. Ideas and thought are written down on post-it notes and organized into themes for the ideation session [Figure 4.12]. The actual ideation starts by splitting up the group into subgroups of about eight people that brainstorm on one of the themes. Although the facilitators provide plenty of tinkering materials such as bottle caps, straws and feathers, colored pens and paper the ideation part is highly verbal. Sometimes visualizers draw out ideas on request on A3 paper, but they do not take actively part in the ideation process. *"It takes time to explain what has to be drawn"* a visualizer explains to me and *"sometimes we get questions like "I like that shape, can you draw that in brushed aluminum?"* At the end of the day the group comes together and ideas are reviewed and drawn out for a consumer check together with a one-liner to explain the ideas. Those ideas are then presented to a focus group of consumers the next day. A three-day session consists of multiple rounds of ideation, in which each builds upon the previous one the ideas are refined. The consumer check is an important feedback mechanism to check ideas with reality.

After the session Tanya creates a summary, which is a compendium of everything that was produced plus a table of contents. All the material gets organized for later use. Tanya stresses that it is important that nothing gets lost, and already during the session she starts organizing the produced materials. The summary is sent to all participants plus the requester, who often comes back to make physical models.

Results

The P&G interview showed the process of problem analysis to the first steps in conceptual design and was by far the most multi-disciplinary environment and more verbally orientated compared to the other two visits. The Fabrique interview mainly focused on the transition from conceptual design towards embodiment design and the Contour design interview showed all the steps from problem analysis towards embodiment and detailed design. Although the three interviews showed a unique approach to the design process, common themes were found in the tools they use to explore materials in they were designing.

All the participants made use of visual materials and samples in their process. But when asked about material selection, they told us that they were either less involved or that the project offered a limited choice. JG for instance left the design of the fabrics of his chairs to the supplier; the material constraints at Schiphol airport were so strict that they left little room for exploration. At P&G, in a competitive commodity market, the materials consist mainly of prints and shrink-wraps, designers worked with a fixed set of graphics from the brand.

In all three companies the material selection is cost driven. The design effort of the materials goes into making a particular material/process work in the product and making it aesthetically pleasing. Fabrique went to great lengths in finding a finish for their kegerator and P&G spends considerable effort in designing the graphics of their paper and plastic packages. The relationship between JG and the manufacturer is in somewhat different, the shaping of the products is driven by the capabilities of the manufacturers. The client plays a major role in the material choices and is very opinionated about it, often driven by trends and fashion. In the P&G case, designs are checked using qualitative consumer research.

For new tools and techniques that aim to provide design support I draw the following conclusions to refine the findings in the earlier studies of Kolli et al. [1992] and Keller [2005]:

- **Design through examples.** Designers use existing examples, samples and visual materials for inspiration, to communicate materials to clients and to specify materials to manufacturers.
- **No computers or 3D tools for exploration.** None of the designers made use of computer support in the early stage: sketching preceded a stage of 3D modeling and model making. RB of Fabrique indicated that when his designers start making CAD models, he asks them to immediately paint the by default grey surfaces with the color scheme of the concept, because he thinks they make better informed decisions.
- **Computer renderings for clients.** When presenting to clients they make extensive use of computer support, either 3D or 2D tools.
- **Only quick modeling.** Remarkable is that apart from quick foam modeling, all 3D model work was outsourced and not part of the generative process.
- **Shape oriented.** The process is very much shape oriented, none of the designers showed projects with a material as a source for inspiration.
- **Client makes decisions about materials and color.** The designers give their clients suggestions for colors and materials, but leave the final decision up to the client. In the Procter & Gamble visit, the graphics on the package were not subject of discussion, although in the 2D concept presentation the brand graphics were used as an example.

4.4. New Media Tools and Techniques

Computer support has many advantages in the latter stages of the design process, some designs are unthinkable without sophisticated CAD tools and generative algorithms. The field interviews provided little evidence that in the early stage computer support is used other than in demonstrating activities. Moreover, the field interviews revealed that apart from thinking activities, tools and techniques for the early stage foremost need to support the talking activities. In this section, I review some systems and projects underway in the fields of tangible interaction and new media, that support activities in the early stage that I encountered.

Tangible user interfaces are human computer interfaces in which person(s) interacts with digital information through the physical environment. Classic examples of tangible user interfaces are I/O bulb [Underkoffler & Ishii 1999] and Durell Bishop's marble answering machine. Tangible interaction could provide the means for talking activities in designing materials in the use of the physical samples and visual media designers use. New media applications, such as blogs, youtube or wikipedia, allow people to actively participate and contribute without explicit mediation of a professional such as an editor. The following qualities are characteristic for the new media [Croteau & Hoynes 2002]:

- **Collaboration:** the media is specifically aimed at groups of people.
- **Decentralized:** there are no levels; all members participate without being mediated by a third party, such as a facilitator as focus of attention
- **Interactive:** the media facilitate two-way communication.

New media shares goals of engaging design teams, stakeholders possibly clients, in a fluent creative process. New media is generally non-co-located and not necessarily real time, and in order to apply new media in the design studio I add a fourth quality drawn from the field of tangible user interfaces:

- **Digital Physical Transition:** The media is open, tangible and accessible for groups, not confined to a computer screen or laptop.

Various new media tools and techniques aim **to support collaboration** between stakeholders. They usually consist of large display surfaces and tangible objects [Underkoffler & Ishi 1999], pens or multitouch [Han 2005] for interaction. The Envisionment and Discovery Collaboratory [Fisher 2002] for example is a tool to "support social creativity by creating shared understanding among various stakeholders" [Fisher 2002] and has been applied to urban design and decision-making. The large tabletop interface, Figure 5.13, allows multiple participants to actively participate and the impact of decisions is computed and displayed interactively.

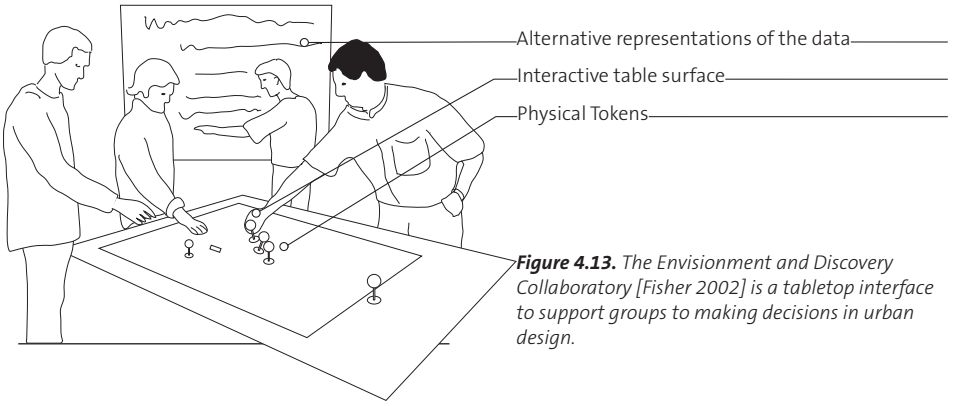


Figure 4.13. *The Envisionment and Discovery Collaboratory [Fisher 2002] is a tabletop interface to support groups to making decisions in urban design.*

Other systems **augment existing representations with digital media** to make interactive prototypes. The Illuminating Clay system [Piper et al. 2002, Figure 4.14], intended for geodesic analysis and landscaping, employs a slab of plasticine that acts as an interactive surface. By sculpting the clay, users interact with a projected simulation. A 3D scanner is used to continuously scan the relatively flat clay surface that has no undercuts and overhangs, but it could be adapted to design applications, e.g. the sculpting of car bodies.

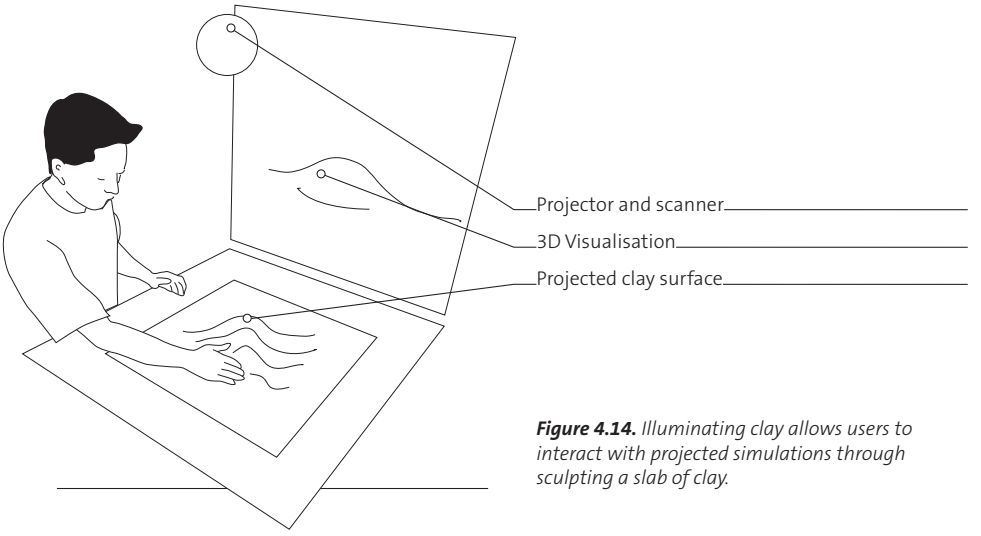


Figure 4.14. *Illuminating clay allows users to interact with projected simulations through sculpting a slab of clay.*

The Mixed Object Table [Binder 2004, Figure 4.15] for architects is an augmented tabletop to be used with physical scale models of buildings. It employs projectors in various configurations. One projector illuminates the table's surface and is used to display floor plans or scenery surrounding the physical objects. With the Texture Brush [Matkovic 2004] the physical objects on the table can be given various textures. Another projector projects photos of the building's intended surroundings on a large wall display. Binder & Matkovic's approach demonstrates the advantages of experiencing models in their context. However the Mixed Object Table interface

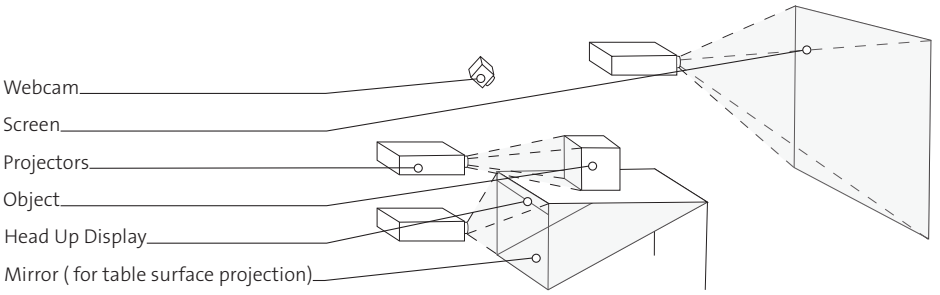


Figure 4.15. *The Mixed Object Table and the texture brush aim to augment architects' scale by coloring the models with projected textures and environments.*

is based on typical Computer Aided Design techniques used in the detailing stages of design and together with the complexity of a multi projector camera setup, it limits the freedom of exploration as found in the Illuminating Clay system.

Likewise, Verlinden et al. [2003] developed the "workbench for augmented rapid prototyping" and augments rapid prototyping models with 3D projections to visualize (engineering) information that is typically available in CAD but not in physical models. His models are placed on a turntable, which limits the degrees of freedom with which the model can be manipulated but eases the involved calibration and complexity of the system. Similar to the Mixed Object Table, the workbench for augmented rapid prototyping supports the demonstrating activities. However both systems require a digital 3D model that matches the physical model, which is usually not available in the early stage.

Some systems **make use of the richness of the world.** The Tangible Project Archive [Ehn and Linde 2004] is a mixed reality environment for presenting and collecting material. The archive consist of a collection of transparent, Plexiglass cube modules in which objects can be collected. Each object in the archive has a rfid or barcode associating the object with digital materials such as videoclips. When placing objects in the so-called organizing zone, the associated digital material is shown on a large display.

The I/O brush [Ryokay 2004, Figure 4.16] avoids traditional interfaces using digital palettes to specify colors and textures. The I/O brush is not a design tool, but a drawing tool for children to explore colors, textures and movements found in everyday materials by picking them up with a physical brush and drawing them on a canvas. The I/O brush tempts children to explore their surroundings in the process of creating their drawings. The I/O brush demonstrates the use of ready-made materials, found to be the preferred way to specify and communicate materials.

A number of systems **support storing activities of digital media in the physical environment.** The Cabinet prototype [Keller, et al. 2006, Figure 4.17] doesn't enrich the designer's source materials but aims to manipulate digital source materials with the fluidity found in handling physical

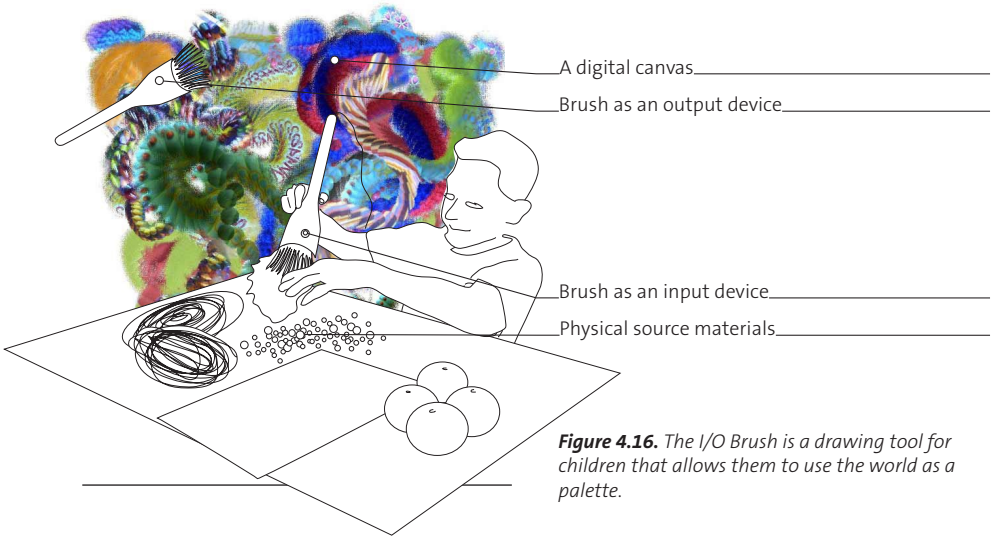


Figure 4.16. *The I/O Brush is a drawing tool for children that allows them to use the world as a palette.*

source materials. Physical images can be seamlessly added to the Cabinet's digital collection with a build-in digital camera. The interface consists of an interactive table display on which images are spatially grouped and thereby provides a non-linguistic way of search and retrieval method.

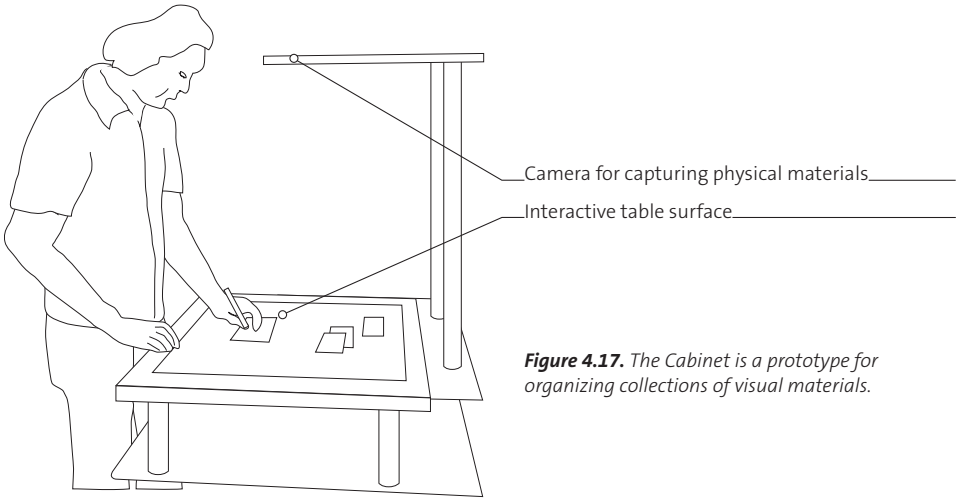


Figure 4.17. *The Cabinet is a prototype for organizing collections of visual materials.*

The Photo Boarding technique [Saakes and Keller 2005, Figure 4.18] is a means for capturing playacting sessions with prototypes. Digital photos taken during playacting sessions are printed in rough grey-scale that invites designers to annotate and drawn upon them. The printed photos then are composed into a poster-type storyboard for retaining and communicating the played interaction.

The Portfolio Wall [Fitzmaurice, et al. 2003, Figure 4.19] is an interactive digital corkboard and allows designers to "throw things on the wall electronically" including 3D work and animations. When designers working with computer and are confined to their screen, the visual culture in the design studio is lost [Stappers 2005]. The portfolio wall was designed for sharing activities and makes digital media again visible in the design studio.

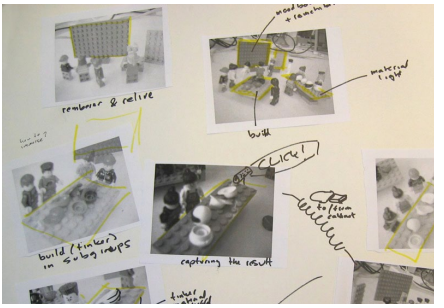


Figure 4.18. *Photoboarding is a technique to capture playacting sessions.*



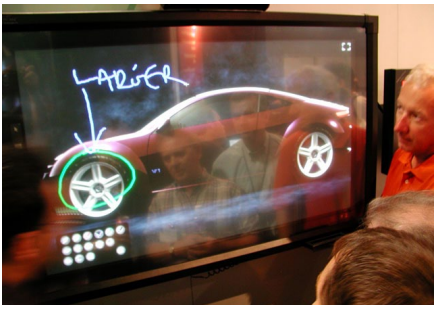


Figure 4.19. *Portfolio wall is a application to share drawings.*

New Media Tools and Techniques for Material Exploration

Blending digital media with the physical representations is a key element in these systems: they provide access to digital information as well as augment physical information to allow for a multi stakeholder process in which participants can engage in a trial and error process of problem solving. The examples of "new media tools and techniques" do not aim to replace existing design activities, but rather augment activities designers already do. In the case of the urban planning tools they visualize the implications of decisions. In other cases they enable handling digital media in physical ways, or associate rich digital media with physical objects.

The challenge for all these systems is to go beyond a technical demonstration and study their effectiveness in the work processes outside the context of the research laboratory. The portfolio wall was commercially available from 2001 till 2009 and the Cabinet has been evaluated in a few design studios in four week periods. Compared to most research prototypes, these examples share a dedicated application domain, and are packaged in "a product" rather than an installation that demonstrates possible applications, and they blend in with a designers current tools and activities.

4.5. Considerations for Tools and Techniques

Based on the literature on design representations, the findings in the field interviews, and the examples of new media tools and techniques, I present five considerations for tools and techniques that aim to support material exploration in the early stages of the design process that will guide the development of the doctoral design. The first two considerations are regarding the fit of the tool/technique to the solution space:

1. **Be explorative and allow conversational cycles.** In the early stage designers make many quick representations to explore the solution space first hand. Current techniques designers use to design materials in products do not support these conversational cycles.
2. **Make the interactions between the scales experiential.** The field interviews revealed the need for evaluating and designing in context: JB explored the prints of his bike design on the actual frame, AS explained the differences evaluating a real size prototype in his office compared to evaluating the prototype in the intended environment and At P&G realistic mock-ups are made to communicate designs to management and users. Likewise, in the "new media tools and techniques" a number of systems demonstrate the use of digital media to put the partial representations in context.

The last three considerations concern the fit of the tool/technique to the user:

3. **Be participative and include stakeholders.** In nearly all the activities designers share their representations with others. Often these others are outsiders to the design team and do not have a design background. In the interviews, participants expressed that their clients play an important role in selecting colors and materials. Pasman calls this consideration "enabling a high level of communicability". Therefore, a tool aims to provide design support should focus on communicating materials in products and the fidelity must be such that the non-designers can participate.
4. **Use natural skills and allow hackability**. Designers use various tools, methods and materials to quickly build prototypes to gain insights. This tinkering, hacking and re-using is a typical designers' trait. In all the activities designers make use of their natural skills, mix digital and physical tools and repurpose existing products.
5. **Make use of the source materials designers have.** In their search for inspiration, designers use various sources to find samples and examples for materials. Pasman calls this "Using Rich Information resources". Materials in products are searched, communicated and specified through samples and examples. Tool and techniques intended for designing materials in products should blend in with the designer's models and should make use of the diverse rich visual information sources they have.

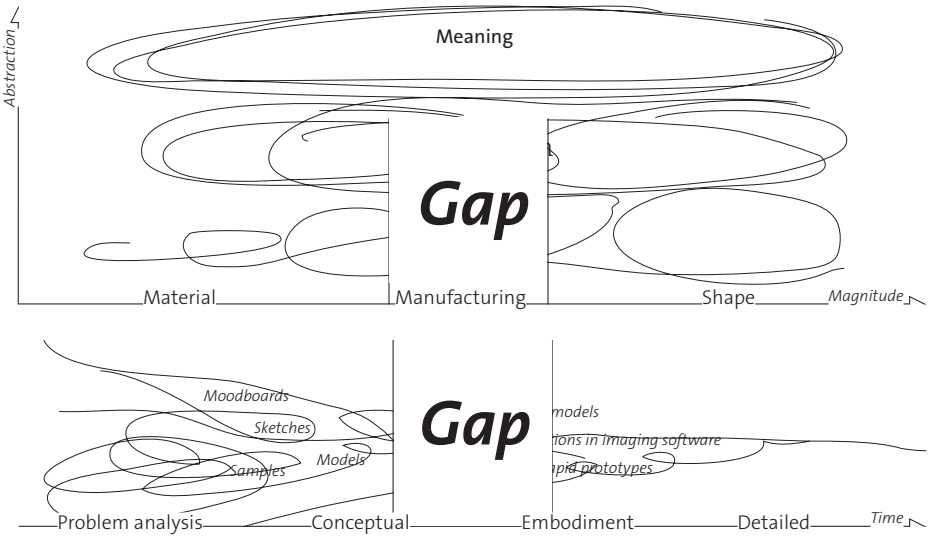


Figure 4.20. *The identified gap in means to explore materials in products: the "material" gap. The gap between the tools used for materials and for shapes (top) and between the representations used in the early stages for exploration and those used to communicate designs to the larger group of stakeholders.*

4.6. The Material Gap

Although most products we use are physical 3D objects, the tools to design these products are mostly 2D; drawings, sketches as well as the computer aided design tools that depict 3D through 2D windows. Despite advanced 3D imaging systems available, car designers still make physical models, true to scale, to evaluate and shape the vehicles they are designing. The 3D models that designers make are quick sketch models to explore shape and interaction without depicting material appearance. Modeling and drawing material appearance takes time and skills and is less suitable for generative activities. Using ready-mades (samples and examples) is the prevailing way designers use to search, specify and communicate materials. Samples generally do not depict the shape nor scale of the product. Moreover it is generally hard to manipulate the materials of samples compared to manipulating shape using foam models. The interactions between shape and material is implicit, and left up to the unaided imagination of the designer.

Based on the insights of this chapter I identify a gap in the means designers use: **Between the techniques of the early stage, and the tools for the latter stages**, Figure 4.20. and **Between the techniques to design shape and the techniques to design materials,** Figure 4.20. The challenge for novel tools and techniques is to bridge this "material gap".

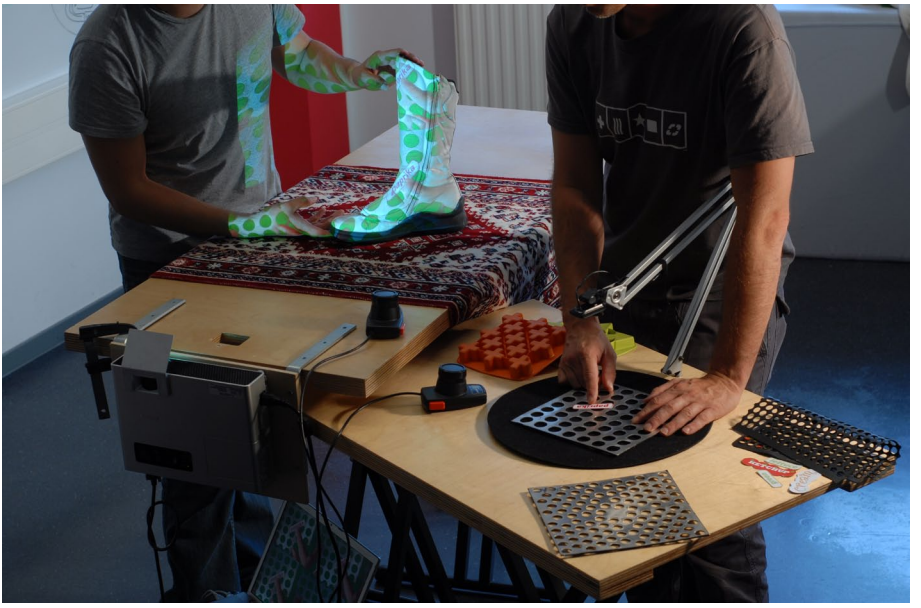


Figure 5.1. *Skin in action. On the left a physical object is illuminated by a projector on the Object table. The material that is projected on the object, is mixed on the Material palette to the left. The material on the object consists of a combination of a digital background (green) and a small graphic on top of a metal sheet with holes, both captured by the camera mounted on a swiveling arm.*

5 Skin 2.0

5.1. Introduction

Computer support such as 3D visualization tools, 2D vector drawing and bitmap editing software has become an indispensable part of the designer's toolbox. Designers variously use these tools with the intent of making presentations to share their designs with the larger group of stakeholders involved in the design process, or to specify designs for rapid prototyping, printing or other means of manufacturing. However, computer support is traditionally found to be problematic in generative activities in conceptual design [Gross 1994, Goel 1995, Hummels 2000, Do 2002, Buxton 2007, Stappers 2005]. Current computer support is rigid in being solely digital, made for precision and therefore thought to be less suitable for the vague, open and unrestricted explorations designers perform in teams. Despite advances in surface computing [Han 2005], today's computer tools for design are typically targeted at single users, whereas the early stage is a stage of collaboration with many stakeholders. Although designers design 3D objects, computer tools represent this third dimension on a 2D screen, making it impossible to judge the scale and relationship with the real world.

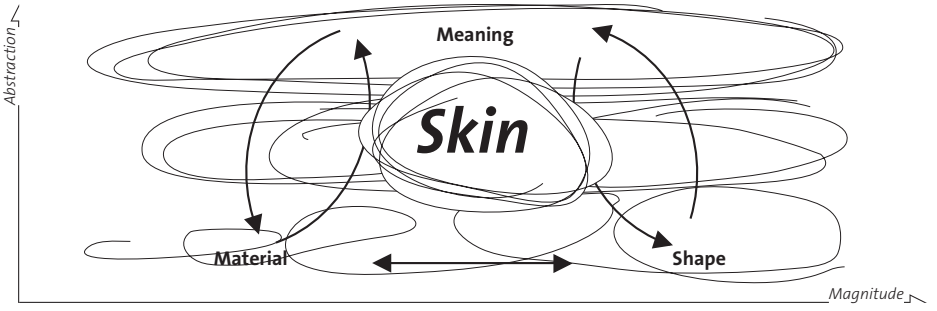


Figure 5.2. *By mixing shape modeling and collections of materials, Skin aims to engage participants in making conversational cycles including both material and shape decisions.*

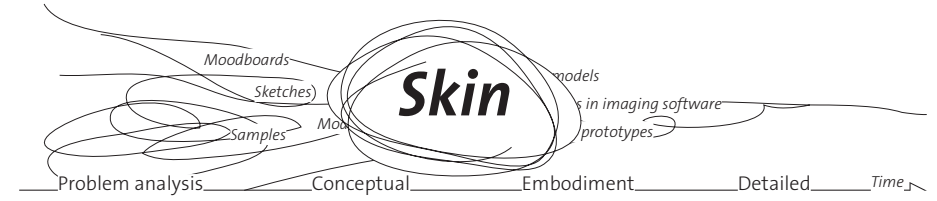


Figure 5.3. *Skin is positioned in between the stages of rough exploring with mood boards and sketches and the latter stages of detailing typically performed with computer tools. Skin's aim is to create a generative stage specifically with techniques and materials from the early stage, enhanced digitally with tools from the detailing stage.*

In this chapter I present Skin. Skin is a new media tool and technique developed to support designing materials in products and is aimed at the early stages of the design process. With Skin, design teams mix their collections of materials with their quick models, Figure 5.2, to generate new ideas, and explore interactions between the various scales in the product, supported by visualizations that currently don't emerge until the detailing stage, Figure 5.3. The design of Skin was guided by acquired insights in the ways designers handle material considerations as well as related work on computer support in generative design tools, both as described in the previous chapter and condensed in the set of considerations for generative techniques that aim to explore materials in products. Scenarios of Skin's use include, but are not limited to:

- **Idea generation sessions.** A large collection of existing packages is augmented with a variety of textures, colors and graphics, to explore the styling of a new brand.
- **Exploring patterns in fashion.** A designer applies and tries many different patterns on a garment before finalizing the pattern design.
- **Interactive design meetings with clients.** Together with clients, a designer interactively shows various options of materials in a product, to visualize the solution space.

5.2. Overview

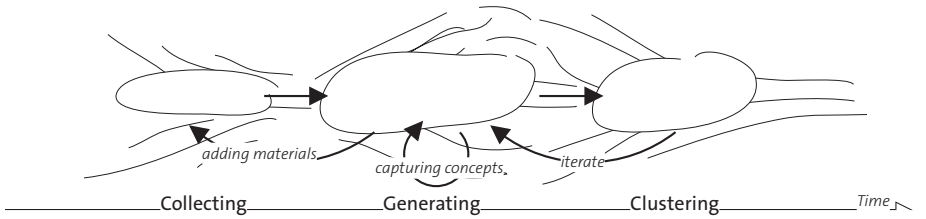


Figure 5.4. *The Skin technique consists of three steps. In the collecting pre-workshop step, participants collect source materials. In the generative step, they create concepts by mixing source materials with the Skin tool and capturing their concepts using a digital camera. Using the Skin tool may give rise to a new search for additional materials. Following the generative step, they group their captured concepts in clusters. The clustering step may result in another iteration with further exploring of concepts.*

The technique of Skin follows the structure of creative group sessions or brainstorms with alternating steps of generating and clustering as depicted in Figure 5.4. The collecting pre-workshop step consists of preparing the source materials: making models, searching for images on the Internet and in magazines, and collecting samples. Both digital and physical materials can be used in Skin. Generally these are the source materials that designers already have. In the generative step, source materials are mixed and altered in various ways with the intent to explore the solution space both laterally as vertically. The lateral approach can best be compared to confrontation techniques in creative processes, trying out a diverse set of materials to create unexpected results. The vertical approach consists of manipulating materials to detail a design, building upon a concept.

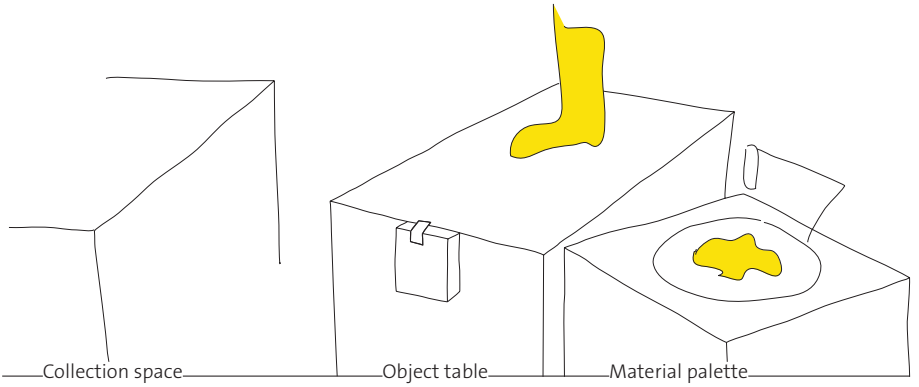


Figure 5.5. *The "Collection space" is for storing the designer's collection of materials. a projector illuminates the models placed on the "Object table" using materials generated on the Material palette. In Skin, the tool, physical materials (colors, patterns, graphics) are captured using a video camera.*

During the generative step designers make photos of their concept and in the clustering step, these photos are displayed on a large wall projection. In an interactive session the concepts are reviewed, discarded or grouped into clusters. These clusters are intended for the decision making process following the session. The generative step might give rise to new searches for source materials to add to the collection. Likewise, the clustering step might give rise to a renewed generating step. However, the diverging and converging activities don't necessarily have to be successive. Skin is designed as an open technique, which users can adapt to their own needs.

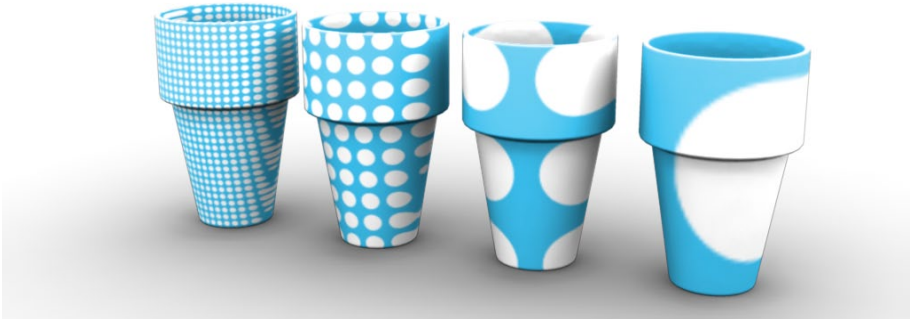


Figure 5.6. *By making use of scaling, Skin the tool supports all scales involved in product expression, from colors (not depicted) to patterns to graphics up to shape and environment. A graphic, tiled, becomes a pattern, while a scaled up a pattern becomes a graphic on the scale of the object's shape features.*

Skin the tool consists of a projector that projects computer generated light on physical objects in order to change their appearance. It consists of large tabletop interfaces to allow for groups of participants. The tool, as depicted in Figure 5.5, consists of two interaction spaces, an Object table to manipulate the designers' models (paper models, foam models, rapid prototypes), and the material table to capture materials (such as found in magazines or samples). A collection space, located near Skin's Material palette, provides storage for materials and models. Skin the tool supports all scales

involved to design materials in products, from colors up to shape and environment. In this work I distinguish three types of visual materials: colors, patterns and graphics. Colors are uniformly applied. Graphics, such as brand graphics, texts, icons are usually applied once on a specific location on the object. Patterns consist of a graphic that is repeated over a surface. With the help of scaling and tiling, these three types form a continuous transformation from the small to the large as depicted in Figure 5.6. When graphics are scaled down, they are automatically repeated to form a tiled image and a pattern scaled up forms a graphic. Likewise, the physical objects can be freely manipulated on all scales.

5.3. Object Table Design

Using projected light to alter the appearance of physical objects has been applied for a long time in art, architecture and entertainment. Peter Greenaway for instance, uses projections as an integral part of his visual style and storytelling. Naimark [in Low 2001] demonstrated the beauty of projected graphics on non-planar surfaces. In the field of augmented reality several sophisticated systems exist that make use of projected light. These systems are generally referred to as Spatial Augmented Reality [SAR] systems, as opposed to augmented reality systems that make use of head mounted displays or see-through displays. In SAR systems, the world is the display: physical objects are illuminated with computer generated imagery. Unlike screens and other 2D based visualizations, the visualization can be experienced in 3D, and unlike virtual reality, in context of the environment. The advantages of SAR systems match the considerations for tools in: allowing designers to use their existing models, augmenting models with digital materials and thereby showing the interactions, and the physical interaction might make it work in collaborative scenarios with design teams.

The prior art shows a number of SAR systems, developed mostly in computer graphics research contexts. Most of those systems are based on the shaderlamp concept [Raskar et al. 2001], the use of physical objects as the canvas for 3D computer graphics. The key insight here is that a projector functions as the dual of the camera, in shaderlamp systems a virtual camera matches the properties of the physical projector. The system tracks the position and orientation of the physical objects and a projector projects a shaded virtual 3D copy on the objects. Vice versa, using a tracked physical brush, the objects can be colored and annotated with virtual paint.

Noteworthy SAR systems are: Low et al. [2001]: a system for large scale projected augmented reality to investigate the potential application for interior design. Virtual worlds and architectural applications using VR technology usually employ head mounted displays with head tracking or CAVE-like systems. *"We want to enjoy the richness, flexibility, and dynamic nature of computer graphics, while preserving some of the physical and mental activity associated with walking around*

or exploring a real site." [Low 2001 pg 94]. They built a multiple projector setup that augments a full scale model of interior spaces. Users could walk freely through the setup and augment walls with annotations. By projecting on the real space they counteract issues found in virtual reality systems, such as limited field of view and geometric distortions. However a disadvantage they found is that the geometry must be static, and the digital model must be prepared in advance. The augmented engineering system [Bimber et al. 2001] makes use of so called see-through technologies, which use a half-silvered mirror to integrate the virtual models in the physical world. The advantage of their system is that physical objects can be annotated and tools can be shown outside the boundaries of the augmented object, however multiple viewers cannot share the device.

Fidelity: Matching the Digital with the Physical

Most of the SAR systems that aim to change the appearance of surfaces pursue photo-realism in their image generation. This makes the setup quite complex. As a result, these systems can produce compelling visual presentations, but do not provide the speed and ambiguity necessary to support early ideation in the way that sketching does. This applies both to the creation of the actual materials in CAD software (addressed in the Material palette, next section) and to the time required to setup the tool. In general, increasing the fidelity of the visualization, makes the requirements more rigid and makes the setup lengthier. Projecting on physical objects, and non-planar surfaces in general, creates a number of issues in the visualization that have to be addressed in order to achieve a desired level of fidelity:

- Projectors project the virtual imagery from a single point, and therefore illuminate the object from one side, moreover concave objects may suffer from self-occlusion. The obvious solution is to build a setup with multiple projectors lighting the objects from multiple sides [Raskar et al. 2001]
- In order to achieve object-dependent color e.g. to color specific parts of the model, the computer system has to have a model of the object. That model can be as simple as an area on the projected image. However, the projector and the illuminated object need to be aligned in order to use the object as a canvas.
- When projecting on non-flat surfaces or surfaces not aligned with the projector, the image deforms over the surface. In order to compensate for these geometric deformations a virtual model of the object is necessary. The projector is then used as the "camera" through which the virtual 3D model is projected, and the field of view and pose (position and orientation) of the projector in respect to the physical object are then matched.
- In order to achieve view-dependent color, for instance to make the object appear glossy, as well as to the position and orientation of the object, the position and orientation of the observer(s) have to be taken into account.

- In order to have the object appear to be in the environment, the lighting and reflections of the virtual object have to match the environment. Debevec [1998] introduced a technique to probe the environment in order to capture the lighting. In the texture brush project [Binder et al. 2004] a second projector projects a virtual world, so that the illuminated objects can be lighted accordingly.
- When working with dynamic objects, their position and orientation must be tracked, in order to adjust the projection accordingly. Tracking introduces a new set of technological concerns in respect to resolution, update-rate and lag. One elegant solution is to limit the degrees of freedom, for instance with a turntable [Verlinden et al. 2003]. In Piper's illuminating clay [Piper et al. 2002], an augmented table for landscape analysis, the object itself is dynamic. Due to the specific nature of landscapes, relatively flat surfaces with low resolution height differences, he could utilize a scanner to scan the clay surface and match the virtual representation with the physical surface.

The requirements increase both with complexity of the object (dynamic, articulated) and with the complexity of the reflection function (material visualization). The model requirements for Skin are high, it makes use of physical models designers already have, of which they do not have a 3D digital model, and must allow designers to modify the models. However, the visualization requirements are comparatively low, pixel perfect presentations are not necessary, as non-photorealistic rendering is considered better at conveying the unfinishedness of visualizations. Therefore I devised a very simple system, based on two principles:

1. Skin projects materials as flat 2D images, so any captured sample/magazine or digital image can be used right away [see Section 5.5].
2. Skin works without any tracking or knowledge of the 3D object, therefore any object can be used right away as long as it is white or light in color. Objects themselves can be sculpted, manipulated, moved, and turned on the table.

The drawbacks of the simple approach compared to the sophisticated related work are 1) the projection deforms over the non planar object. 2) the projection is everywhere, also behind or under the object, 3) objects and materials must be repositioned the same way to recreate a concept. Having designers capture their concepts with a digital camera and project the photos on a large wall during the clustering stage, eliminating the need to recreate concepts and solves the third drawback. However, these photos are less compelling than the vividly colored physical models, but add the ability to compare multiple designs spatially instead of temporally. Without object knowledge Skin does not have view dependent lighting nor does it correct for deformations (drawback 2). This generally limits the reflective qualities of the objects' material. That the projection deforms on the object, and during direct manipulations of the object, would be a problem in a photo-realistic setting, however in Skin it is a benefit [Saakes & Stappers, 2009]. The rough, ambiguous projection that occurs when moving the objects in the projected light

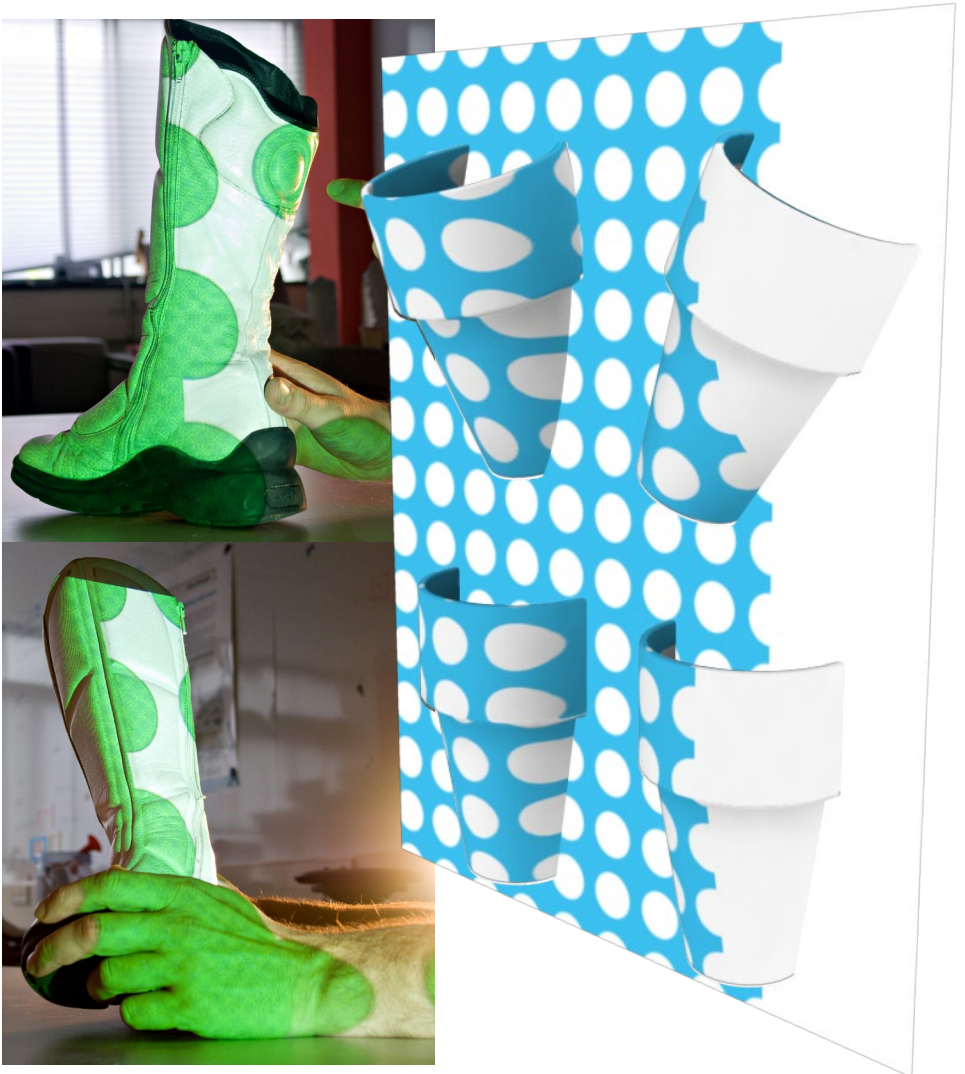


Figure 5.7. *By moving or rotating the object through the projection the material can be positioned. In presentation this would considered a bug, in Skin it is a key component and allows direct, open and fluid mapping of materials.*

and seeing patterns and graphics deform on the physical objects will result in deliberate and accidental indeterminacies, leading to serendipitous discoveries [Keller et al. 2005]: unexpected new combinations. Moreover, by positioning and orienting the model in the projection frustum, the mapping process becomes tangible, depicted in Figure 5.7, and doesn't require an additional user interface.

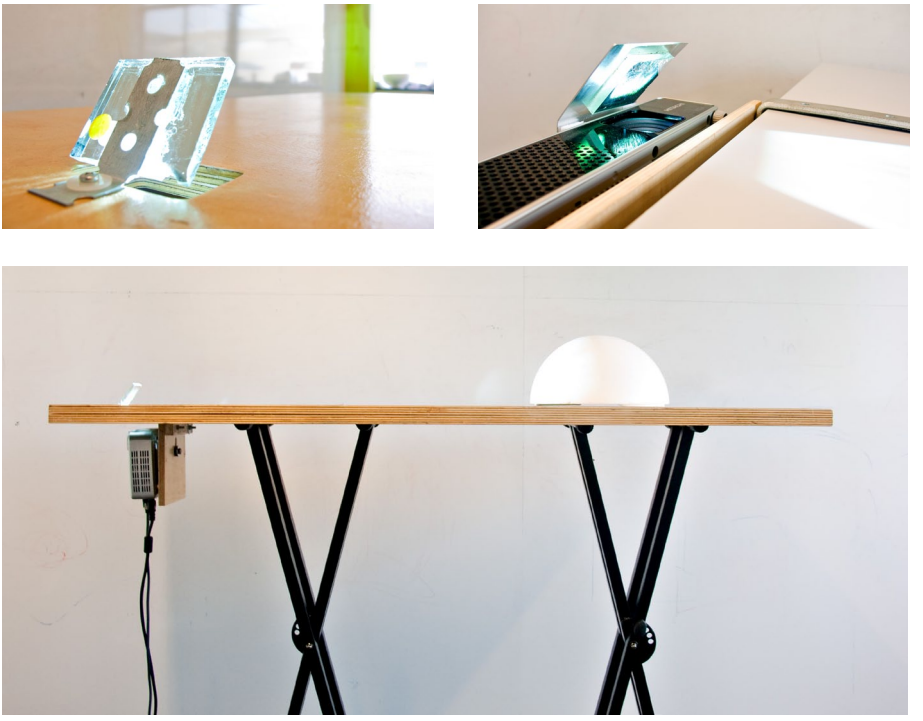


Figure 5.8. *The light from the projector is reflected by a mirror and goes over the table, illuminating only the objects on the table. The light that is not blocked by objects, is washed out by a light source stronger than the projector. A few prototypes of the Object table are depicted. On the bottom, the table with integrated projector. The light is projected through a hole in a small mirror (top left). Alternatively the projector can be attached to any table to make use of available tables on location. Top right shows the projector mounted to the side of a table, with the mirror is then attached to the projector using velcro.*

Skin projects imagery horizontally over the surface of a table, in such a way that only the objects on the table are illuminated, not the table itself [Figure 5.98. The horizontal approach of Skin makes sense in many ways. Products usually have a facing side for interacting with users, horizontal projection causes the least amount of deformation. It simplifies the construction by embedding the projector in the table, but most importantly, a horizontal projection can be elegantly masked. The objects on the table catch the light from the projector, and the remaining light causes unwanted, unfocused, distracting projections on the walls behind the object (drawback 2). These backdrop projections tend to reduce the visual impact of the object, and therefore should be masked. Various methods exist to mask the surplus light. Most systems mask the object using software, when the objects are known and tracked the space surrounding the object can be kept black and thus masked. Alternatives are to use non-reflective backgrounds that absorb the light, for instance a black felt-like material, or to make sure no background elements are there to catch the light. Whereas the latter two solutions do not require knowledge of the objects, they do impose restrictions on the design studio. While designing this horizontal set-up, we found a fourth way:

the surplus light is automatically washed out by a stronger light source from behind the object, such as the natural light from a window. This eliminated the need for masking techniques in software or restrictions on the environment. Moreover, the system is preferably used in normal practice conditions, and light is generally available in a design studio.

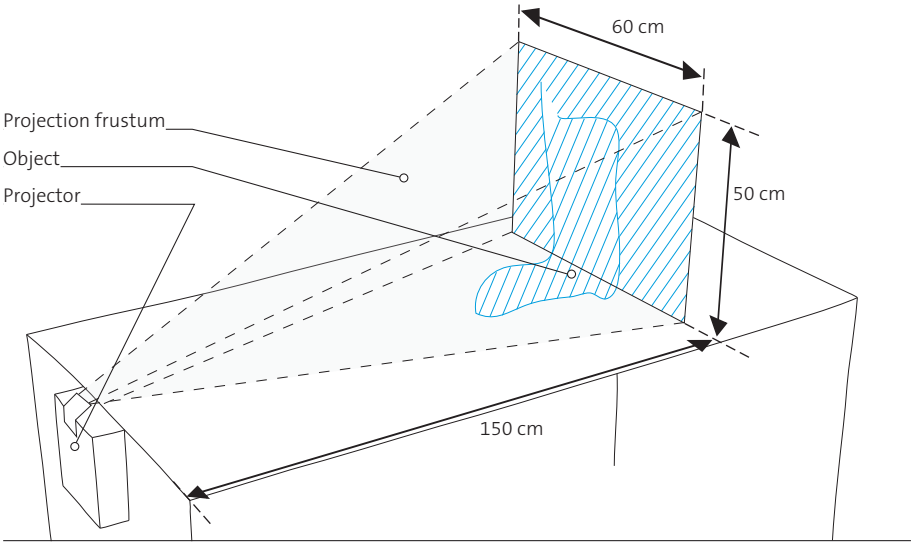


Figure 5.9. *The projector forms a pyramidal frustum over the table, objects of about 50 cm high can be illuminated from 150cm.*

The Design of the Object Table

The Object table consists of a tabletop surface on which product models are placed and manipulated. As shown in Figure 5.8, the projector is mounted vertically and a small mirror bends the light from the projector over the table. The projector may be permanently mounted on a table, with the light from the projector going through a small hole to the mirror mounted on the table as shown in Figure 5.8 For portable solutions the projector can be attached to the side of a table by means of clamps, see Figure 5.8, with the mirror mounted on the projector by means of Velcro. Partly hiding the projector makes that the projector keeps it from distracting the user, and the noise caused by its fans is less disruptive.

Most consumer projectors suffice for Skin. When prototyping Skin I experimented with several, here I limit the discussion to a typical projector, the Toshiba tdp-p8 DLP (Digital Light Processor) specified for producing 1500 ANSI lumen with a resolution of 1024 by 768 and a contrast ratio of 2100:1. The projection throw in Skin is typically shorter than projecting on a screen, hence the illumination per unit of area is higher (32x when comparing a 5 meter projection to a 1 meter projection throw) that makes darkening the room unnecessary. Apart from the cost, the trade-offs when selecting a projector are the size, the produced noise and the picture quality. The evaluated

LCD projectors produced more saturated colors than the DLP projectors, but were slightly larger. The imagery produced by the DLP projector was, due to the color wheel technology, generally harder to capture with video cameras and some photo cameras.

The light from the projector forms a pyramid-shaped frustum over the table, as depicted in Figure 5.9. The projector has a viewing angle of 25 degrees horizontal and 20 degrees vertical, and the minimum distance of focused imagery is 40 cm. This means that object of about 50cm high can be illuminated on the table. The focus range of projectors does not span the whole table; therefore the focus ring of the projector was made accessible for manual adjustments. The resolution on objects about 1 meter away from the projector is about 80 dpi (comparable with a monitor display). Newer high definition projectors produce more pixels, 1920 x 1080, also, new laser projectors don't need to be focused. By mounting the projector and mirror as described previously, the projection center line is not parallel to the table's surface. This causes the rectangular image from the projector to form a trapezoidal image over the table. This is a problem when displaying texts on standing objects. Vertical keystone correction, as found in most projectors, compensates for such distortions by skewing the output image and thereby making it rectangular.

The projection quality is not only dependent on the amount of pixels but also on the graphics [described in Section 5.5] and the surface quality of the object. In general, objects with unsaturated, light colors work best as projection surface. Surface properties remain visible, projecting on reflective, glazed pottery for instance results in a glossy appearance, whereas projecting on fired but unglazed ceramic ware (biscuit) causes a matte looking appearance. In some of the cases we projected on grey clay, due to the contrast caused by the projected light white and black areas could be depicted.

5.4. Material Palette Design

Whereas the Object table's primary function is to visualize materials on 3D physical objects, the Material palette's function is to generate materials. Skin's Material palette 1) makes thorough use of the richness of the world by capturing and mixing source materials designers already have, 2) aims to minimize the time to experience of a material on a model to maximize the tinker-ability through real-time feedback, and 3) provides a physical, open interaction with qualities of the early stages of design.

Some of the previously described augmented reality systems address aim to provide a non-interactive visualization [Raskar et al. 2001], but most systems [Verlinden et al. 2005, Binder et al. 2004, Piper et al. 2002] provide some form of a traditional screen based interface for the tool functions. Typically a specific area of the projection is dedicated to visualizing controls, which can

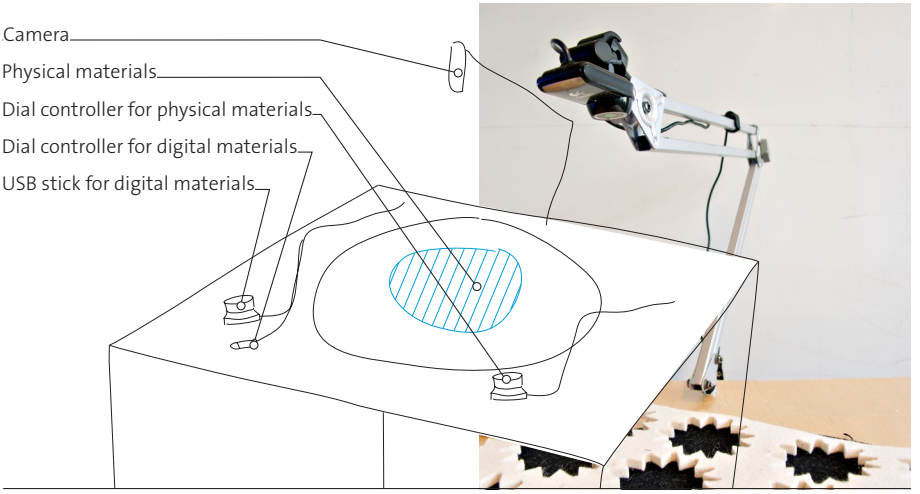


Figure 5.10. *Skin's Material palette consists of a table with an attached camera for capturing physical materials. The camera is mounted on a swiveling arm to scale and crop materials. The area beneath the camera is kept black for "chroma-keying". Digital materials are loaded through a USB Flash drive. Two dial controllers scale the physical materials and the digital materials.*

be manipulated through a mouse or similar input device. Other systems [Matkovic et al. 2005, Bandyopadhyay et al. 2001] use a brush to apply virtual paint directly to the 3D model. The Material palette makes use of a collaging metaphor to allow for a fast paced generative stage rather than painting or constructing materials from scratch, which typically requires more effort per material. The difference with techniques such as algorithmic pattern generation [Perlin 1985] and with the variety of creative tools that make use of the large image base available on the internet [Chen et al. 2009] with some form of machine vision is that Skin makes use of the collection of the designers and thus includes their preferencesCapturing Existing Materials

5.5. Capturing Existing Materials

A video camera captures physical materials and materials can thus be composed out of almost everything: pages of magazines, samples, fabrics, collages made of smaller items. Materials do not need to be planar, 3D objects or stacks of samples can be used as well. The camera is mounted on a swiveling arm on a small table. The table is large enough to place a small amount of materials, as shown in Figure 5.11. A dedicated circle on the table roughly indicates the rectangle in which materials are captured. The viewing frustum of the camera crops the materials to the rectangle that is projected on the Object table. By manipulating the materials on the table, as shown in Figure 5.11, their position and orientation on the object can be adjusted. By adjusting the swiveling arm the cropped area can be manipulated. As shown in Figure 5.12, the captured image is directly mapped on the Object table. With the swiveling arm the height of the camera can be adjusted

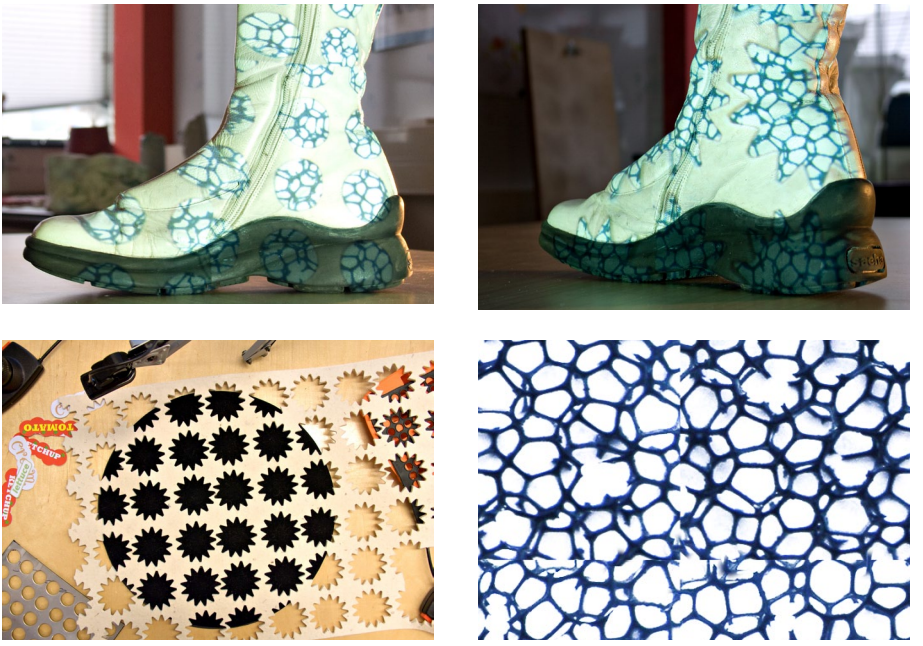


Figure 5.11. *Materials made on the Material palette are directly mapped onto the models on the Object table. At the bottom left are the physical source materials, bottom right shows the digital source material used to generate the designs depicted in the top half of the figure.*

in order to modify the captured area and, to a limited extent, modify the scale. Through use of chroma keying, the surface of the palette is filtered out, so that only the materials are captured. That makes it possible to layer a single graphic on top of a pattern generated by other means. The current prototype uses black as the key color, a color not often found in the materials in the workshops we organized, and worked adequately in controlled light environments. However when using non-planar materials the shading of the object can introduce problems and more sophisticated techniques are necessary.

Besides physical materials, Skin supports digital materials in the form of bitmap images. Digital images are loaded on an USB Flash drive and thus added to Skin. A button on a dial controller allows users to flip through the images similar to a Powerpoint slideshow. But unlike a slideshow, images can be scaled, and are, like the physical materials, automatically tiled.

Scaling Materials

Scaling is the most prominent feature of Skin to generate materials and to map a material to an object, and scaling is also the only transformation that is mediated through a controller: the dial controller. Dial controllers are the preferred solution in scrubbing through time in video, volume in audio, and support, unlike joysticks and buttons, fast and rough changing of value, by giving the dial a swing, as well as precision manipulation. Typically in Skin, users use a very wide range

of scaling, from the very small, displaying thousands of copies of the pattern to showing only a part of the graphic. Users preferred perceptual scaling to linear scaling. With linear scaling the magnification factor in the small was found to be too coarse and in the large too slow. By relating the incremental change to the scale factor as found in the Weber Fechner law this was solved.

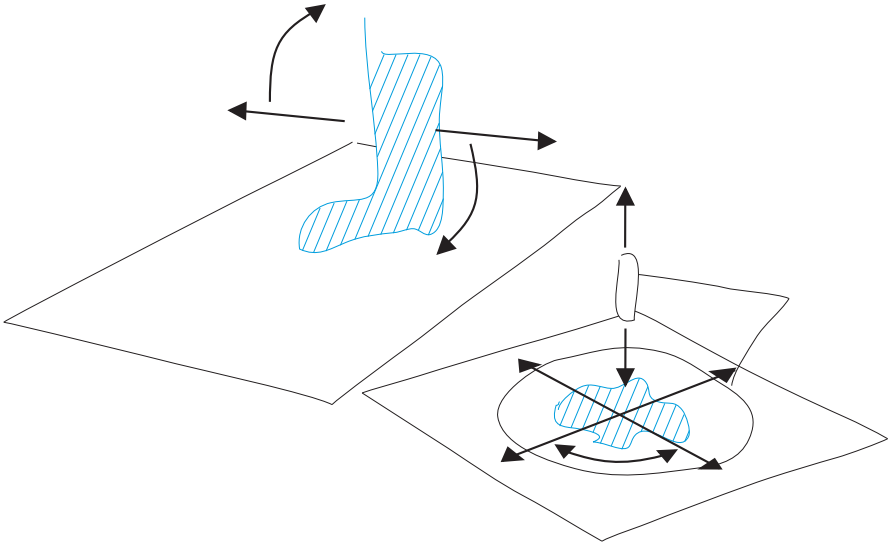


Figure 5.12. *Part of the transformation freedom is achieved by manipulating the objects on the Object table. To translate graphics onto the object, the object is moved perpendicular to the axis of the frustum. Likewise rotating the object on this plane causes a rotation. Scaling of graphics is achieved to a certain extent by moving the object towards or away from the projector. Whereas the above-mentioned methods manipulated the object in the frustum, here the image itself is manipulated. The physical materials are cropped by the viewing frustum of the camera and can be altered by changing the camera height through the swiveling arm. Graphics can be manipulated by translating and rotating them relative to the camera to make them fit the object.*

The projected image that is scaled down to an area smaller than the projection is tiled to fill the projection. So called "seamless" images have matching opposing edges, so when combined, the tiles that make up the pattern of which the edges cannot not be retrieved. However most images are not seamless. [Figure 5.13] Besides non-matching edges, photos often contain an unnoticeable intensity gradient that when tiled results in a blocky pattern that is visually dominant over the image itself. Algorithms exist that make certain textures tile-able [De Bonet 1997] but they are not real-time and require user input for their functioning. A physical material can be made tile-able to a certain extend, for instance, by adjusting the position and rotation, and the height of the camera.

Scaling images in real-time results in quality issues at the scalar extremities. Graphics regularly used in Skin are bitmaps, discrete pixels. When scaling, these pixels have to be interpolated, and matched to the resolution of the projector. When enlarging a graphic above

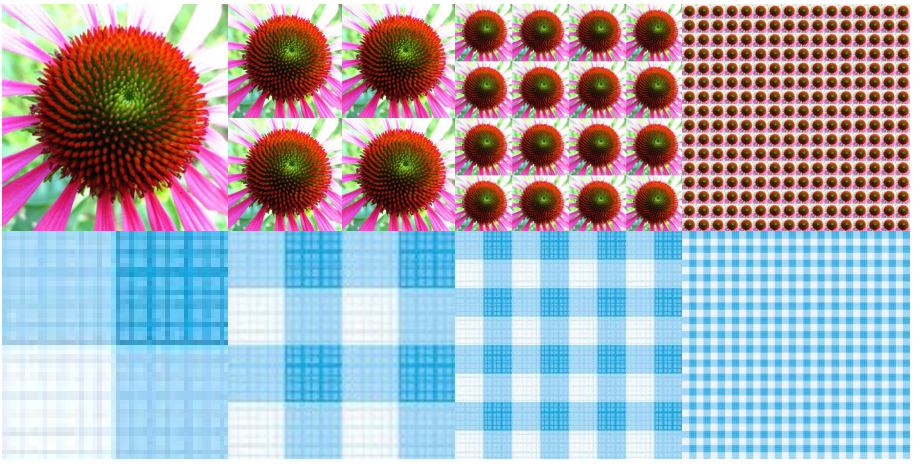


Figure 5.13. *The top half of the figure depicts a so-called non-tileable image; when juxtaposed the edges of the individual tile are noticeable, as opposed to tileable images. Non-tileable images are problematic when scaling patterns down, as the tiling visually distracts from the source image. Below, a tileable image in an increasing number of repetitions.*

its resolution interpolations are noticeable in blocky pictures, but at small scales the interpolations are visually distracting without a proper interpolation algorithm. Various interpolations are available for real-time purposes. Trilinear or bicubic methods produce better results at a small scale than the commonly supported nearest neighbor technique. However custom implementations were necessary to support tile-ability: in standard algorithms the border pixels are interpolated with zeros. When scaling down a single image this is not an issue, but having many tiles a grid pattern appears. Skin interpolates the edge pixels with their opposite neighbors to maintain tile-ability.

Skin's software has no knowledge of the object(s) placed on the Object table, but typically not the whole area of projection is covered with objects. For scaling and rotation, unlike translation, the origin of the transformation does matter. Without choosing an origin in the center of the object, scaling and rotating can locally appear to be a translation. Therefore Skin assumes that the object resides in the center on the Object table, and places the origin accordingly.

Layering Materials

The current prototype is based on the design for the packaging industry and contains two layers for mixing purposes. The artwork on the package usually consists of a background layer with photos and a brand and packaging-specific-graphics layer on top of that. Thus, in Skin the digital images form a layer beneath the physical materials. Without any physical materials on the palette, only the digital layer is projected, and by covering the palette completely with materials, only the physical materials are projected. Also, the physical layer can be used to color the digital layer. Although the approach using digital and physical layers does work in all application areas, some

require more layers or other inputs. The bluebrush, Skin contextualized for Delft Blue pottery, as described in the next chapter. is an example of an application that needed multiple layers. Delft blue artwork consists of multiple graphical elements, from various sources. The graphic elements needed to be positioned in addition to being scaled.

5.6. Implementation

Skin Software consists of the following components: 1) a full-screen composer that displays the image on the projector 2) a number of layers of graphics whose content originates from various sources and 3) input devices to manipulate the content of the layers. In general the requirements of Skin are modest, Skin could run on hardware equivalent to a iphone. The image generation software, depicted in Figure 5.14, is written on top of OpenGL and makes use of pixel shaders. The first prototypes were written in Python, later prototypes that included the real-time video layer were built in quartz/composer, MAX/MSP [cycling74 1997] and open frameworks [openframeworks 2007]. The key in choosing software is the ability to easily access video cameras and composite videos real-time.

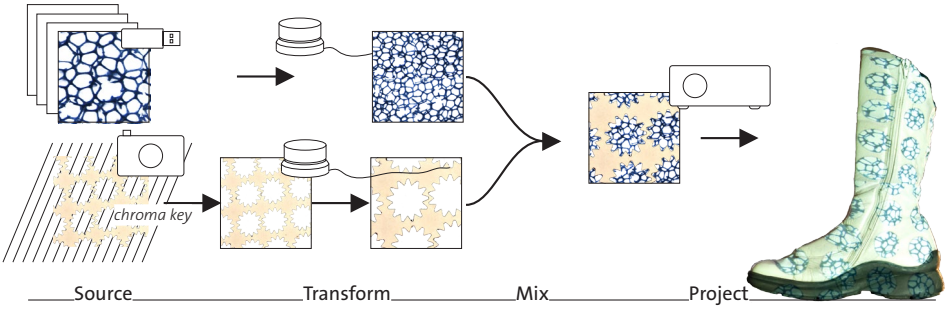


Figure 5.14. *Skin's image generation pipeline. An image collection of a USB flash drive provides a digital image. A dial controller controls the scale of the image and flips through the collection with a button. The camera provides a chroma-keyed frame of the real time video feed. A second dial controller controls the scale. Both images are combined and displayed by the projector.*

A powerbook G4 Apple laptop was used to drive the graphics throughout this project and proved to be sufficient. In the prototype of Skin a Logitech USB webcam (quickcam pro for notebooks) is used as the camera. This webcam had a decent image quality, two megapixels, and a reasonable framerate of 30 frames a second. The angle of view was 60 degrees (wide angle) and the minimum distance of focus was 100mm. The white balance was disabled. For scaling a dial controller was used that could be held freely in the user's hands, not necessarily attached to a table or a device. We used both Griffin Powermates and modified vintage Atari 2600

paddle controllers, which are designed for their comforting grip and ease of manipulation. The internal hardware of the paddle controller was replaced by a Phidget [Greenberg 2001] rotary encoder that connects through USB to Skin's computer as well an Arduino [Arduino].

5.7. Discussion

This chapter has presented the design that is the result of two years of applying Skin in practice that is reported in Chapter 6 and 7.

Contributions of Skin

- Skin is a collaborative, tangible and adapted to a designers' practice of the early stage.
- Skin demonstrates a fast and fluid method to combine a variety of media.
- Skin employs a dedicated controller for scaling and tiling, to map patterns on shape.
- Skin demonstrates a "sketch-like" approach to projected augmented reality. Instead of tracking objects and a complicated user interfaces, Skin makes the physical manipulation of the object part of mapping materials.

Limitations of Skin

- Obviously due to the naive projection setup, Skin supports only a limited model of materials and addresses only the visible domain and in the visual domain only diffuse color. Moreover, the projected (emissive) colors do not match the reflective colors of the materials they are intended to simulate. However, photorealism is not the goal in the early stage, the prototype allowed to gain insights into a variety of designer's work processes and that allowed to focus on and develop the novel interaction styles.
- The Material palette makes it is possible to position decals and color parts of objects, but in general the support for multiple materials is limited. That was a result of a design choice to tightly integrate with the designer's source materials, without employing complex technology. Nevertheless, as shown in the following two chapters, a considerable amount of products and application domains are covered.

Future Work on the Prototype

The current version of Skin is simple in its design, and modest in its use of resources. Better hardware and software would make Skin a better system, however care should be taken to maintain the fluid and rapid interaction and absence of configuration and calibration.

Adding machine vision to recognize objects and the pose of objects would be a logical next step. Potentially Skin could store the materials' mapping, making it easier to revisit earlier ideas on the actual objects instead of capturing the design with a camera. It could also improve the integration with the CAD tools by providing texture maps in the designer's 3D modeling tools.

Sensing the 3D shape with a real-time 3D imaging camera fixed to the projector could mask the surplus light based on distance, without the need for backlighting. 3D cameras could also provide new material properties besides diffuse color such as as surface relief or gloss.

The Material palette can be improved by using more sophisticated forms of chroma keying. For instance, keying with a light spectrum invisible to the human eye, or using a retro-reflective background in combination with a ring of colored light around the camera.

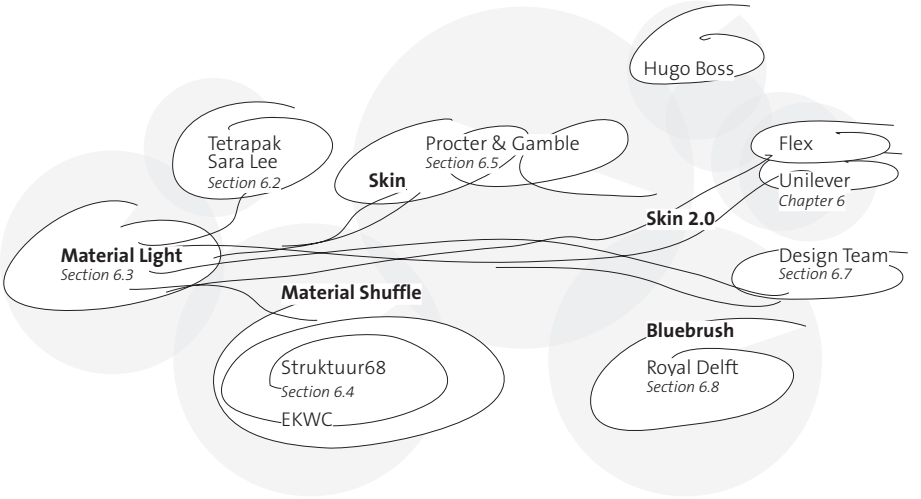


Figure 6.1. *The development of Skin started in 2004 with a prototype called Material Light, illuminating physical models with a projector. Based on the knowledge gained by demonstrating and experiencing Material Light, a second prototype, Material Shuffle was developed to be used on location, in design studios. The further development was largely performed by studying the working of Skin in practice, as designers and artists used Skin to solve real world design problems.*

From 2005 to 2007 Material Shuffle was developed into Skin, and later into Skin 2.0 in collaboration with Procter & Gamble Brussels, described in Section 6. During this period, Skin was contextualized for the needs of creative group workshops in the fast moving consumer industry. A second line of development started in the ceramics industry, inspired by a workshop at Struktuur68, a ceramics atelier in Den Hague. The Struktuur68 workshop resulted in a few workshops at the European Ceramic Workcentre in Den Bosch, and in 2006 a collaboration with Royal Delft, the Delft Blue factory, was started. With Royal Delft a second prototype was developed by Bart van der Berg, the Bluebrush [Section 7]. Bluebrush presents an implementation of a Skin system with a dedicated interface to create a more complex type of graphics.

Apart from the cases described in this chapter, Skin has been demonstrated on several occasions and has been applied at the European Ceramic Workcentre (EKWC) in Den Bosch, Tetrapak in Moerdijk, Sara Lee in The Hague, Koen and Ko in Utrecht, and at the Hugo Boss design center in Switzerland.

6 Using Skin

6.1. Introduction

In this chapter I report of a series of explorative interventions in practice that have led to the design Skin described in Chapter 5. The intent for doing these interventions was twofold: first, to be inspired by, and learn as much as possible from the professionals in the field and involve them as the experts of their own work process. I do that by observing how they apply and adapt prototypes of tools and techniques in their context and process. Second, real world cases, give insight in the benefits of a generative stage including materials in designers/artists work processes rather than evaluating the Skin interaction technique in a laboratory setting. My intention for presenting these interventions is to unfold the reasoning, which went into designing and adapting Skin for specific application domains, in order to show the underlying challenges in adapting Skin for other, currently unexplored domains and scenarios.

Table 6.1. *Skin's design considerations, repeated from Chapter 4. While observing practice and studying design representations in the early stage I formulated two considerations to fit the tool to the solution space and three considerations fitting it to its user. These considerations led the contextualization of the prototypes.*

Be explorative and allow conversational cycles.
Make the interactions between the scales experiential.
Be participative and include stakeholders.
Use Natural Skills and Allow Hackability.
Make use of existing source materials.

In the various cases in this chapter I answer the challenges for tools to support designers in their material exploration [the material gap in Chapter 4] "How can we include the richness of material visualizations found in the latter stages, in the techniques of the earlier stages?" and "How can we bridge between the techniques to design shape and the techniques to design materials?" The design consideration formulated in Chapter 4, repeated in Table 6.1, guided and framed the development process, and are evaluated in Section 6.9.

6.2. Method

Prior to each intervention, the prototype was firstly demonstrated in the lab and if possible I interviewed the participants and observed their current work process. Based on a so acquired shared understanding of the goal of the intervention I then configured the tool to contextualize it for their specific application, intervened in their work process, observed and recorded the session on video. After the session we jointly (with the participants) reflected on the benefits of the tool.

Two longitudinal cases [Section 6.6 and 6.8] include multiple iterations, wherein aspects of the tool or the technique were changed between the interventions. The studies were chosen to cover typical design situations and varied on the following dimensions:

- **The expertise level** of the designers ranging from experienced artists and designers, to beginning designers that just received their bachelor degree in Industrial Design Engineering, to the people involved in the design processes without a design background: salesmen working with clients, marketing managers and engineers.
- **The style of the idea generation** process ranged from solo designers and design teams ("insiders") to creative group sessions and design meetings with users ("outsiders").
- The **design activity** ranged from a designer working on a product ("thinking") to a group designers brainstorming new ideas ("talking") to the more ("demonstrating") sales meeting activities. A few of the approached industries were interested in jointly developing the emerging Skin prototype to replace laptop visualizations or physical models making for presentational means. Whereas this application is a valid and potential commercial application of Skin it was not found to match the objective of a generative design technique.
- **The type of objects** covered small ceramic items, to packages of potato chips to large statues. The objects were chosen to allow experimentation with the visual aesthetics of materials, and cover multiple scales (e.g. shape, details, textures, colors) and matched the technical constraints in the Skin prototype. Cellphones for instance would make a very suitable domain regarding the enormous variation of plastics and patterns but was rejected for this reason as well as collaborations with material manufacturers such as GE plastic ("visual FX" line) and the EXO overmolding system of Dow Chemicals were rejected.

Application Domains

The choice of application domain was mainly driven by interest of industry partners, who allowed intervening in their work process. Two application domains were found: ceramic design and fast moving consumer goods. Ceramics has a long tradition: think of Mediterranean pottery. It is the material of great craft based industries like Wedgwood pottery, valued, sometimes as silver [Ashby 2009]. Ceramic artists spend weeks on modeling statues out of clay before they paint it with glaze. Glaze consists of white or dull colored powders that are transformed by high temperatures into brilliant colors [Reijnders 2005]. Based on the ingredients used, the glaze may have to be fired multiple times at various temperatures. Once out of the kiln, the glaze finally shows its intended color and the end result can be observed for the first time. The outcome of ceramic artwork often looks completely different than it does during the various stages of the design process. Although various visualization techniques are used during the design process (e.g., artists make sample tiles to experiment with glazes, drawings, scale models) the moment of opening the kiln is described as a magical moment. Often there is no second chance or iteration.

Whereas with the ceramic industry we covered artistic and hand crafted products in small series, the fast moving consumer goods industry provided a context for exploring graphic intensive materials in a highly competitive industrial context. The graphics and materials used in the containers of commodity products have not only to convey the contents but also have an on-shelf presence that is appealing and makes the product stand out between the many competing products. The containers themselves are often inexpensive containers made of cardboard or plastic and are subject to many constraints and can not be changed on a per product base, such as the ubiquitous soda cans and milk cartons. The printed graphics and shrink wrap foils provide the only means to differentiate. The product development process in packaging, provides a good contrast compared to the artists in ceramics because of the multi stakeholder workshop format. The perspective projection as used in Skin, is perpetually similar to shrink wrap sleeves in packaging. The printed sleeve is heated and shrinks over the package. The shrinking is generally non-uniform and the graphics have to be deformed in order to make them appear to correctly when shrinked on the package.



Figure 6.2. *The Iitala factory in Finland is famous for their colorfully glazed ceramics. Ceramics provides a good application area for researching tools that support material exploration. Not until the final stage of firing the glazed clay in the oven can the impact of the glaze be experienced on the object.*



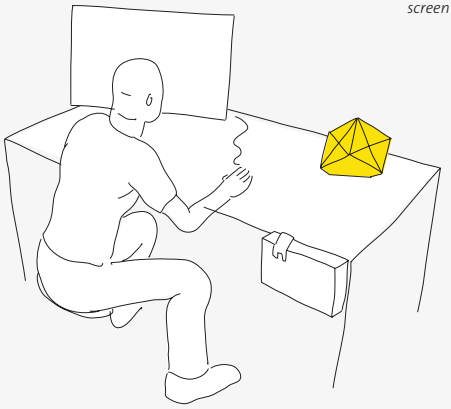
Figure 6.3. *In the packaging of commodity products, the container is made of inexpensive materials such as plastic and cardboard and the graphics are the only way to differentiate the product from the competitors. Shown are three juice packages from Naoto Fukasawa, coconut, banana and strawberry.*

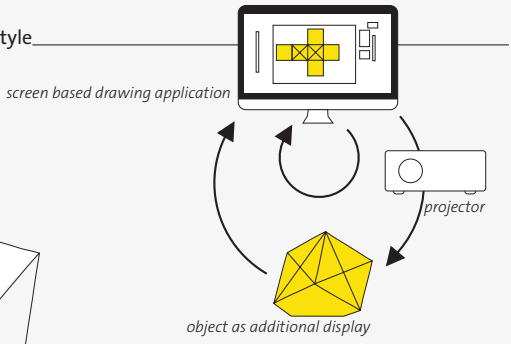
User Interaction Styles

The user interaction styles of the prototypes aim to support specific design activities and specific types of source materials designers already have. Interaction styles employed, varied from traditional CAD interfaces, in which the 3D visualization served as an additional display, to augmented collaging with physical materials.

- In the **drawing style,** users illustrate their designs using off-the-shelf vector drawing software (Adobe Illustrator) and CAD software. The traditional on screen modeling software with extensive toolsets is augmented with an additional visualization on the physical object, next to the screen. Whereas the on screen visualization of the object can show various representations and can be zoomed in on details, the physical object shows the end result

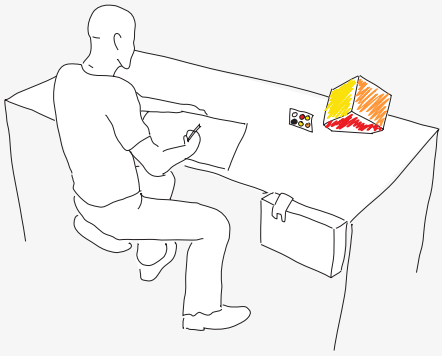
Drawing Style

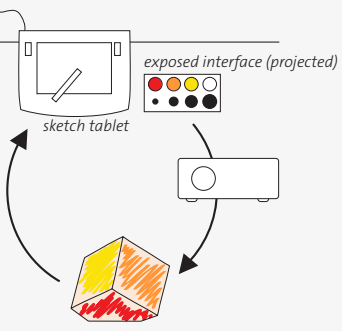




The drawing style provides the participant with an additional "display" on the physical object next to the on-screen CAD drawing application. In the primary display the participant can vary the representation of the object and scale, the projection on the physical object always shows the end result, at true scale. On the right in the figure a stylized flow diagram of the interaction.

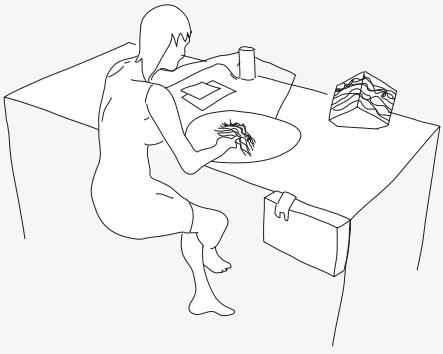
Sketching Style

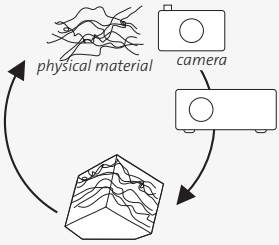




In the sketching style the designer uses a sketch tablet with a minimalistic interface to draw directly on the 3D model.

Selecting Style

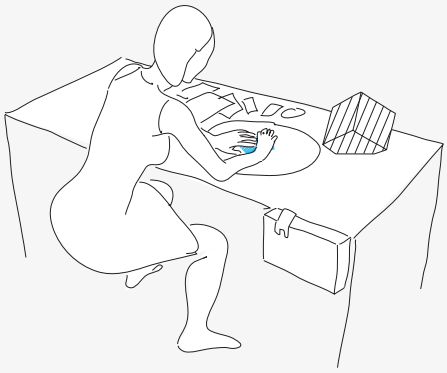


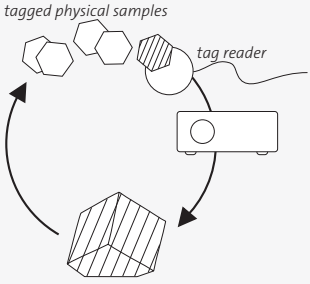


In the selecting style a designer explores a number of materials on the 3D object by selecting from a sample collection.

Figure 6.4

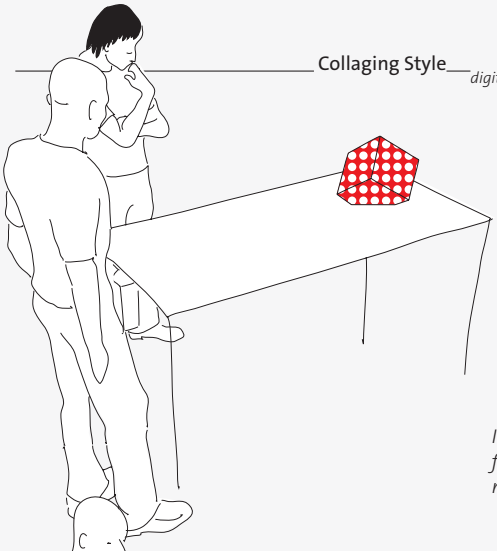
Slideshow Style

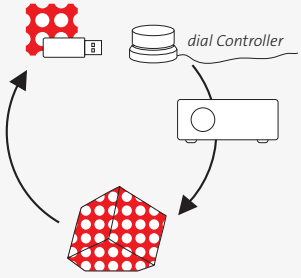




In the slideshow style designers browse through a digital collection of materials which are visualized on the 3D object.

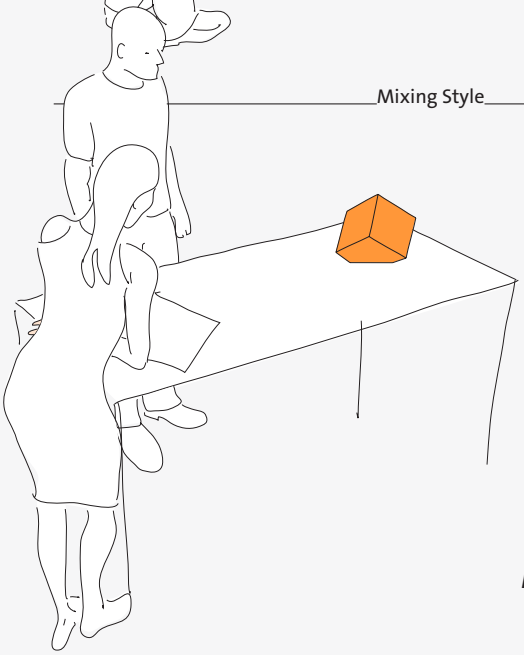
Collaging Style

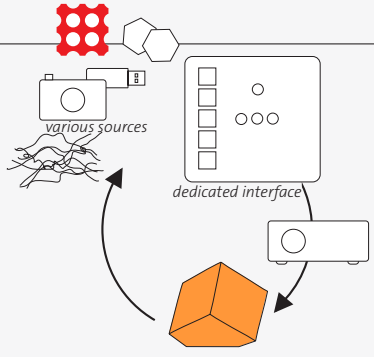




In the collaging style the designer creates materials from raw source materials as if it making a moodboard.

Mixing Style





The mixing style combines various sources to mix and compose materials using a dedicated tangible interface.

Figure 6.4

true scale. The projector is configured as a secondary display, showing a separate view of the drawing that matches the object, and make that the user can work on the primary display without any constraints. The drawing style was explored at two companies, and although the additional 3D representation was found useful, this style of design supports thinking activities and is less suitable for collaborative design meetings.

- In the **sketching style** participants paint directly on their model using off-the-shelf painting software (photoshop) and a Wacom tablet without using any display other than on the object. We expose a minimal functionality including a color palette and brush size on a separate object in the vicinity of the object. Compared to the drawing setup the intent of this prototype was to elicit faster sketch like idea generation process. The sketching setup is explored in Section 6.5.
- The **selecting style** attempts to make use of the rich collection of samples designers have. When browsing through a collection of physical samples, digital materials are projected on the physical object. The selecting style is described in Section 6.3 and 6.6.
- Whereas the selecting style supports physical materials, the **slideshow style** supports digital materials. With a button participants browse through a digital collection of materials, in addition materials can be scaled to make the fit on the physical object. This setup works very fast and requires little preparation compared to the selecting setup. Described in Section 6.4 and 6.5.
- The **collaging style** allows users to make collages of materials on the physical objects. A video camera captures physical graphical elements realtime and the projector projects the captured image on the object in interactive frame rates. Described in Section 6.6 and 6.7.
- The **mixing style** consists of a simplified, tangible version of a drawing tool without a screen. It contains a few layers and each layer can be loaded with text, images or patterns. The interface, the Bluebrush was developed to match the need of the Royal Delft factory. Described in Section 6.8.

The various prototypes and cases presented in this chapter make use of combinations of these styles. The current design of Skin, presented in the previous chapter, consists of a combination of the Slideshow style and the Collaging style, found to be the best of physical and digital collections, and is tuned for use in packaging. Both styles work seamlessly together. All described styles share the in place projection on physical objects. This is based on the assumption that designers work with physical models in the early stage. However scenarios wherein designers have only digital models could also benefit from the explorative and fast paced interaction with materials as presented in the various styles here. These scenarios are however not explored here.

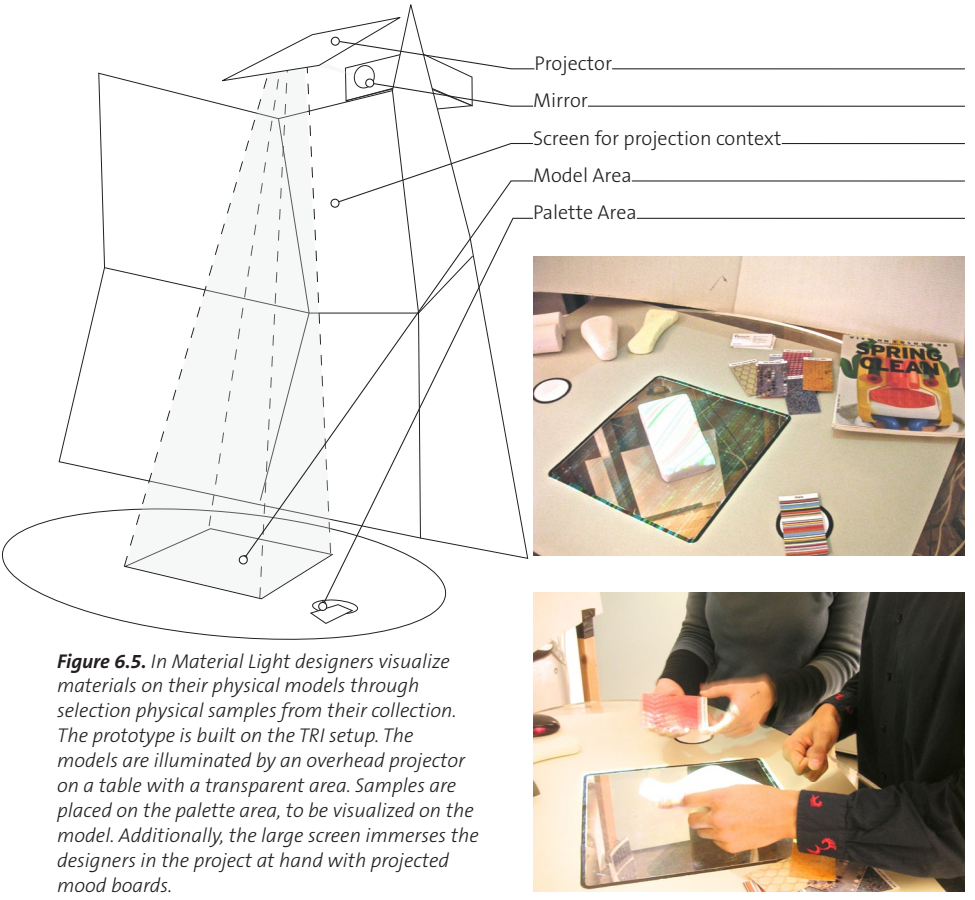


Figure 6.5. *In Material Light designers visualize materials on their physical models through selection physical samples from their collection. The prototype is built on the TRI setup. The models are illuminated by an overhead projector on a table with a transparent area. Samples are placed on the palette area, to be visualized on the model. Additionally, the large screen immerses the designers in the project at hand with projected mood boards.*

6.3. Material Light

Material Light [Saakes 2006b, Figure 6.5], is a prototype that provides a fluid way of experiencing materials in products. Materials are visualized on the designer's physical models by selecting physical samples, thus providing a fast loop of selecting and visualizing materials. Material Light served for over a year as a demonstration in the ID-Studiolab, and was experienced by many visitors from both academia and industry.

Design

The designers' physical material collection is tagged with RFIDs, and each physical material sample has a digital equivalent. Digital materials are printed on physical cards which are also tagged. Material Light consists of a "model area" and a "palette area" When a physical sample is placed on the palette area its digital equivalent is instantly projected on the model. The interaction using physical objects was found in the phicon (physical icon) approach [Ishii & Ullmer 1997].

Here the phicon does not serve as a metaphor for intangible information but is a sample of the real material. Additionally, the physical samples extend the projected material by addressing all the senses and not just the visual.

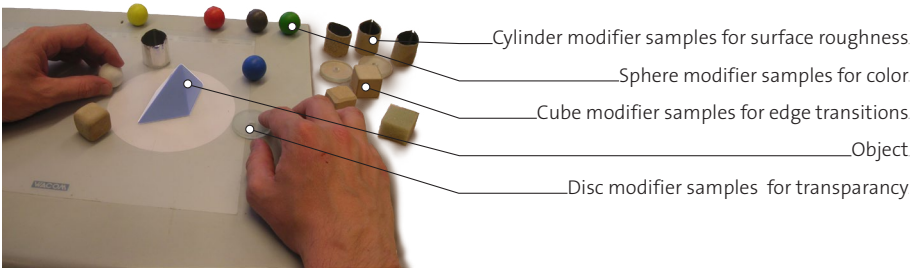


Figure 6.6. *By using modifier samples, properties of the selected material can be modified. The distance to the object scales the influence. The spheres are for color, the cubes for sharpness of transition, the discs for transparency and the cylinders for surface smoothness.*

In addition to the actual material samples, Material Light contains "modifier" samples that address specific properties such as color, roughness or transparency. This idea was drawn from interaction techniques for browsing high dimensional parameter spaces. [van Wijk & van Overveld 2003]. A high dimensional parameter space is mapped in an arrangement of samples on a 2D layout that act as presets. The properties of the presets are inter- and possibly extrapolated over the 2D space, allowing to browse by proximity. For example, Paradiso 's musical trinkets [Paradiso 2000] allow phicons to be arranged in a musical composition. Similar to his phicons that metaphorically represent sounds, the modifier samples must have an iconic language that addresses the properties they modify, Figure 6.6.

Prototype

Material Light was built on the TRI setup [Keller et al. 2000] and makes use of the overhead projector that projects computer generated images on a large table as depicted in Figure 6.5. The table itself is transparent, so only the objects on the table are illuminated, not the table itself. The palette area is adjacent to the model area. Materials placed on the pallet are visualized. Physical samples were photographed and made tile-able. The graphics were scaled to match the physical samples.

Experiences and Implications for Skin

Projected graphics were found to be a suitable way to explore materials on the models designers readily have available in the early stages of design. The deformation that occurred when projecting patterns naively on non-planar surfaces was not to an issue, as the objects could be manipulated to align them with the projected graphics. As a consequence, Material Light does not need a 3D digital model like in the related systems [Section 4.4]. This led to the key insight of direct manipulation of the model for positioning and orientating projected materials. The scale of

a material on the product was found more important than anticipated. Although the size of the projected digital sample was carefully matched with the physical sample, it did not always look "right" on a product. This led to the key insight to add a dial controller to control the fit between the projected material and the object.

However, the TRI setup hindered perceiving Material Light as a design tool. The transparent table surface turned out to be not so effective. Tiny scratches on the surfaces were detracting when lit by the projector and the floor and cables visible through the surface, made a distracting background. Although the "sketch-like" aesthetics of the TRI setup were intended to provide a "designerly" type of virtual reality, its size and the noise produced by the computers and projectors were counterproductive. This led to an improved setup described in Section 6.4. The interaction technique of Material Light assumes scenarios with prepared collections of materials with matching pairs of digital and physical representations. That makes it less feasible to apply in interventions in practice, due to the time and effort to prepare a designers personal collection. This led to the slideshow interaction style employed in Material Shuffle in Section 6.4.

6.4. Material Shuffle

Material Shuffle is a prototype that supports designers in quickly exploring large amounts of materials on their models. Material Shuffle improves on Material Light in three ways. First, it is portable, easy to setup by making use of horizontal projection and standing objects. Second, it only shows materials only in context of the shape of the model, by making use of digital materials described in the slideshow interaction. And lastly, it improves the mapping of a material on a object by allowing change of scale.

Design

Material Shuffle, as shown in Figure 6.7, uses a horizontal projection through a mirror/projector housing that is attached to a table in such a way that only objects on the table are illuminated and not the table itself. Without masking the illuminated objects the projector would cause a negative image on the environment behind the objects. This is a problem in many scenarios, however Material Shuffle counteracts the unwanted projection with a light source stronger than the projector lamps. The presentation quality of illuminated models improved over Material Light due to the standing objects on a table. Additionally, the backlight provided a casted shadow in front of the objects. Optionally a small projected "head up display" provides a reference to the filename of the source material.

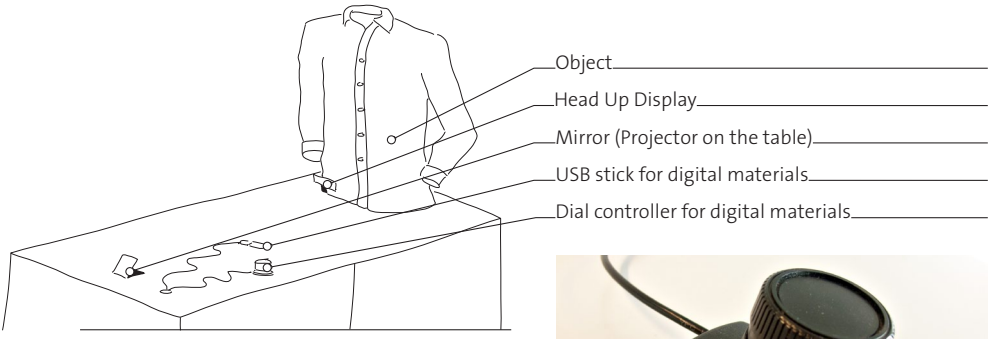




Figure 6.7. *Material Shuffle employs a projector attached to a table. A small mirror bends the light over the table onto physical models. DIgital collections of materials can be loaded through a USB stick and scaled with a dial controller. Optionally, a small "head-up-display" (also projected) provides the filename of the projected digital material for reference. Participants interacting with Material Light. The prototype makes use of a modified paddle controller from an Atari 2600.*

Instead of a physical materials library, and implicitly focusing on detailing materials, Material Shuffle contains only digital materials. Materials consist of digital images that do not have to be prepared other than gathering them on a USB Flash drive. A dial controller, Figure 6.7, allows users to flip through the material collection like a slideshow and to scale (and tile the materials to make them fit on the models.

Experiences and Implications for Skin

The lack of overhead projectors made a setup that can be easily attached to any table, made the setup small and portable; and thus feasible as a tool in a design studio. In addition, the horizontal projection with standing objects made the projection technology unobtrusive and the illuminated objects on the table appear to be magic. This setup led in a few iterations to the projection design of Skin that is described in Chapter 5.

Unlike Material Light, applied materials could not be judged prior to experiencing them on the model. That led to a key insight for Skin in that often let to surprises or use of materials different than intended. Scaling by means of a dial controller improved the mapping of materials on objects over Material Light. The dial controller allows both fast changing of scale as well as detailed manipulation.

6.5. Expert Designers

During a design meeting I observed two ceramic artists, Hans van Bentem (HvB) and Pepijn van den Nieuwendijk (PvdN), working with Material Shuffle. Both participants had multiple years of experience in designing ceramics and were in the process of modeling large statues. Both were frequent and experienced computer users, and used 3D modeling and digital painting tools to visualize and design their work. The session took half a day and was hosted at atelier struktuur68, a studio in The Hague that facilitates large scale ceramic projects, Figure 6.8.



Figure 6.8. *Ceramic artists spend weeks sculpting their statues looking at grayish clay although they intend to glaze them in vibrant colors.*

Method

In addition to the slideshow style they experimented with painting on the model by means of a pen tablet and off-the-shelf painting software earlier described as the "painting style". The painting technique was requested by one of the artists because it allowed local application of color. His statue was figurative and consisted of multiple parts, each of which was intended to be a different color. Prior to the workshop we asked the artists to send us the visual materials they wanted to use during the workshop. On request of one of the artists, we also added a collection of marble and stone patterns. This collection resembled the patterns in his visualization software library. During the session they showed us several ceramic tiles containing experiments with patterns of splattered glaze, which we photographed and added to the collection as well.

Prototype

A projector with a brightness of 3000 ansi lumen and a 500:1 contrast ratio turned out to be sufficient to light up the grayish clay statues with vivid, saturated colors under daylight conditions in the workshop. Although a projector cannot make objects darker, the contrast when projecting made the unlit parts appear to be black. The projector was due to the size of the objects mounted on a tripod. The dial controller was attached to a long cable so the artists could walk freely around their statues and still browse the projected artwork [Figure 6.9]. For the painting technique, we provided a Wacom pen tablet. Brushes and colors were selected using the laptop screen, the statue was directly used as the canvas [Figure 6.9].

Observations

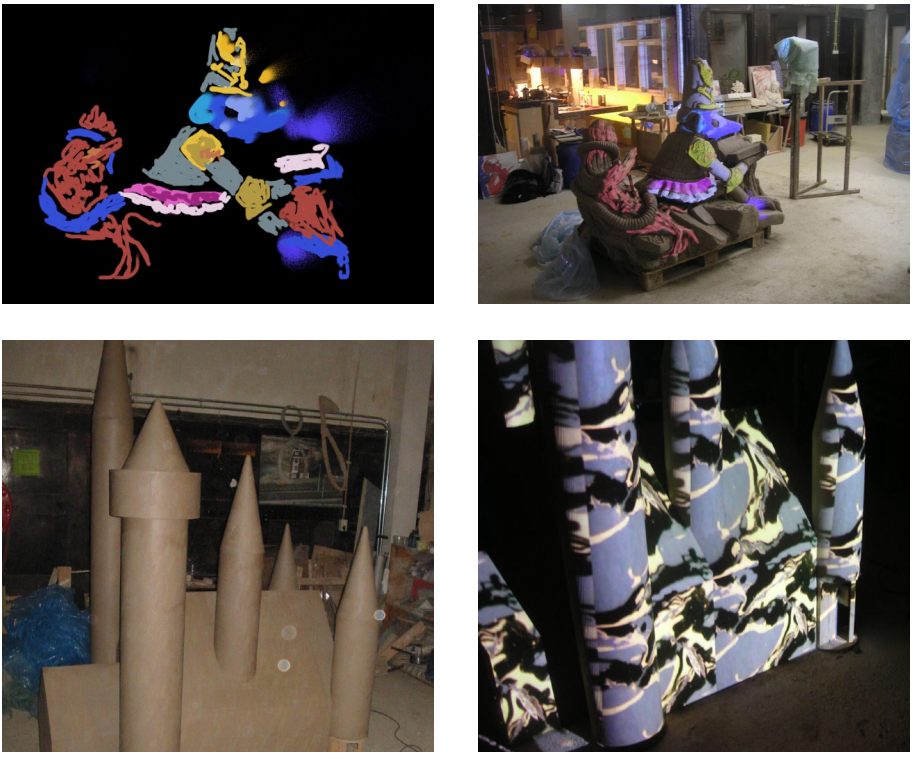


Figure 6.9. *At the top: The statue "After War delight" is painted by PvdN using his statue as a canvas. Although black cannot be projected, the contrast in illumination makes the unlit parts of the grey clay appear dark and brightly lit areas appear white. On the bottom, HvB is browsing through materials on his statue. Left the clay model and right the augmented model.*

From the first moment the artists were amazed by the magical effect of seeing their statues at true scale, flooded with colors: *"Wow! This really does something to me"* [HvB], *"this immediately gives a classical feel,"* [PvdN] commenting on a marble texture on his statue. *"I like the way the stones are colored here,"* [PvdN] pointing at a specific area of his statue. Projecting colors and patterns on the clay radically changed their ideas and made them experiment with new mixes of glaze, which they had not previously used on ceramics. Patterns of dark purple marble with white veins inspired discussions on how to recreate the effect in glaze. Enlarging and thereby exaggerating marble patterns triggered a range of new experiments with painting marble patterns. When using the dial controller, the tiled patterns seemed to have specific scales on which they interact the shape and details.

I expected the artists to talk about technical issues of our tool. However its properties, such as deformation of the patterns on their statues, or the shadows caused by occlusion were not a topic. The artists started lively discussion about the statues and the expressive effects. Often they walked up to the statue to show specific areas to each other, for instance how a particular

curve lined up with the projection. They seemed to focus on detailed areas of their statues and it seemed that getting the whole visualization right was of lesser importanDiscussion and Implications for Skin

Although both artists had made several visualizations prior the session, experiencing their statues in full color at true scale did change their ideas about the glaze, and opened up previously unconsidered ways. I found confirmation that using projected imagery inspired new ideas that could not easily have been encountered by exploring glazes or shapes separately. The physical objects invited the artists to actively discuss and comment on their designs.

Deformations of the projected graphics on the models as well as non-tileable pictures [visible in Figure 6.9 and 4.1] seemed not to be a problem during the workshop, the artists focused on details or on the effect of a particular pattern in total. In general the artists were engaged with their work, and not hindered by the interaction qualities and limitations of the prototype. This led to confirmation that the limited mapping technology of the 2D projection on the 3D object, as a consequence of not having a 3D model, is not an issue. The mapping of materials by means of scale, as designed in Material Shuffle, worked well. HvB found distinct scales in both low and high frequency repetitions where he felt that the patterns resonated with his artwork. However, flood filling the object with a single pattern did not work for the figurative statue of PvdN, that needed a per part material. In this workshop that was solved with the drawing interaction style, which resulted in a slower "thinking" activity, found less suitable for collaboration.

Experiencing their statues made them think of trying other source materials. Capturing existing materials during this workshop took time and should be made easier and more efficient. As a consequence, this led to an improvement to Skin in implementing fluid acquisition of physical materials, described in the next Section.

6.6. Creative Group Sessions

Creative group sessions and workshops are commonly used to generate new ideas and facilitate collaboration in the early creative stages of the design process. The workshops not only provide new product ideas, they also help the various stakeholders to establish a shared understanding of the task at hand [Kleinsman, 2006]. These creative sessions contain cycles of generating and selecting. After exploring the problem, rough ideas and themes are developed into concepts. Facilitators steer this process, using flip charts and whiteboards for note-taking [Figure 6.10]. Sometimes, visualizers are present to translate written or verbalized ideas into idea sketches. Such visualizations aid the shared visual memory of the group [McKim 1972] and help communicate the session results to the company. Even though these stakeholders actively



Figure 6.10. *Typical creative group sessions are verbally oriented and result in many ideas usually captured using flip charts and whiteboards.*

participate and contribute to design solutions, their input is primarily verbal or written. Involving facilitators and visualizers makes for an efficient multi-stakeholder process, but it also means that such meetings do not fully support the intuitive, doing-first types of exploration of the solution space. This is in contrast to regular design meetings designers make fluid and extensive use of sketching as well as building small prototypes. Here participants actively contribute and explore the solution space by doing, as opposed to seeing and thinking [Mintzberg & Westley 2001], by building foam and paper prototypes and playacting interactions.

In this study we [Saakes & van der Lugt] explored how to engage participants of a creative group session in a doing first style of exploring the solution space. For this, we developed a "Media Toolbox". For the development of Skin, the creative group sessions presented the opportunity to study it's use in multidisciplinary teams, which resulted in the development of the Skin technique, and the collaging interaction style.

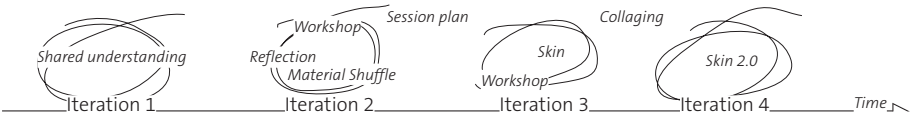


Figure 6.11. *A schematic representation of the study. The study consisted of four design iterations. In the first iteration a shared understanding was established by observing each others practice. Then in three consecutive workshops Skin was developed and made suitable to the Procter & Gamble process. In the third iteration we focused on where to embed Skin in the process, and in the fourth iteration we introduced the "collaging style" and renamed "Skin" to "Skin 2.0". Each of the workshops ended with a reflection session on the toolkit.*

Method

The intervention is performed at Procter & Gamble Brussels in collaboration with the packaging design & prototyping group. [previously described in a field interview 4.3; hereafter referred to as: Brussels team]. The team, consisting of designers, visualizers and a facilitator, facilitate intense multi-disciplinary two-day workshops for various product divisions developing new product ideas. Typically, these ideation workshops have about twenty participants, whose expertise ranges from packaging design, product engineering to marketing research and usability testing.

The study consists of four iterations, as shown in Figure 6.20. In the first iteration we established a shared understanding between the facilitators in Brussels and the researchers in Delft. [Saakes & van der Lugt, hereafter referred to as: Delft team] We interviewed, observed and participated in workshops in Brussels to provide a baseline for our study and demonstrated our tools to the Brussels team. The second iteration consisted of a workshop. This was the first experience of the tools, for both the practitioners as well as the researchers. The third iteration consisted of a workshop in Delft where we focused on how to embed Skin in the process. The fourth iteration took place in Brussels and the collaging style was added. We captured all workshops on video and each workshop concluded with a plenary reflection session. Before each workshop we redesigned the tools and updated the intervention plan [Figure 6.12] resulting from the preceding workshop. All the workshops (except in iteration 2) had commercial goals, and the results were relevant and used by the company in latter design stages. The facilitation was gradually transferred from the Delft to the Brussels team.



Figure 6.12. *Each workshop was extensively play-acted using Lego and Photoboarding.*

Iteration 1 : Media Toolbox.

In the first iteration we interviewed the Brussels Team and participated in two ideation workshops to observe their process [field interview Section 4.3, Figure 6.13 provides a summary]. We showed our tools, Material Shuffle and Cabinet [Keller et al. 2005], to the Brussels team and so jointly formed ideas for the Media Toolbox for creative group meetings.

The aim of the Media Toolbox was to engage the participants in a fluid visual orientated environment by immersing them in their generated representations during and after the workshop. All source materials and externalizations created by the participants, ranging from ideas on post-it notes to drawings, examples, models, moodboards and photos were real-time digitized step, using a modified version of the Cabinet software. The collective memory was then used and reused in various ways:

- Throughout the workshops we immersed the participants in a slow-paced slideshow of images on a wall. The slideshow mixed inspirational images and materials of the collective memory in a playful manner [Gaver et al. 2004]. The slideshow provided ambient access to the generated materials intended to keep them alive during the session. In particular, including the photos taken of participants engaged in activities, helped them remember and build on previously generated ideas.

- During the review steps the wall projection provided a way to group the results spatially, accessible to all participants, thereby providing a cognitive access to the materials similar to the portfolio wall. [Fitzmaurice et al. 2003]
- Material Shuffle was renamed into Skin. With Skin participants could explore the solution space first hand instead of being mediated by the visualizers.
- During the concept rounds the large group was divided into smaller teams that created 'rich digital summaries' of their concepts, again with a modified version of the Cabinet software. They had access to all digitized materials from previous rounds, including the photos taken of concepts created in Skin. The groups could create rich, expressive representations showing their concepts in relation to their ideas, mood-boards and other visual material. Subsequently in the review session the summaries were merged into the collection and the groups presented their designs to each other on a large display. The summaries, created by the participants, functioned as the rich documentation of the workshop's outcome, to be used by the design team in the design activities following the workshop.

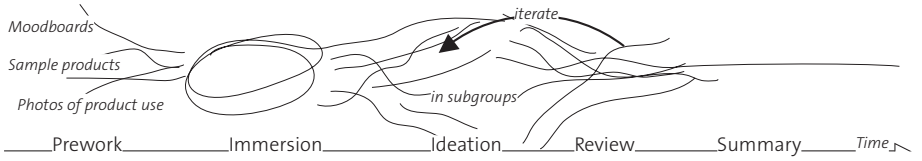


Figure 6.13. *Overview of an ideation workshop. Prior to the workshop the participants do homework: collecting sample products related to the project, making photos of users and making mood boards. At the start of the workshop they present their "pre-work" to each other and formulate goals and themes to explore. Then in two rounds of ideation the large group splits into subgroups of about 5 to 6 participants, each generating ideas in the ideation, and then report their findings and ideas back to the group in a review step. After the workshop the facilitators collect all the produced data and organize it into an executive summary that is sent to the participants and the product division that requested the workshop.*

Iteration 2: Music

In a workshop with a fictional goal of a music-related product for a food brand, with both the Brussels and the Delft team, eight participants in total, the ideas for the Media Toolbox were explored with our existing tools. We planned two rounds of idea-generation. In the first round the structural ideas were generated on paper and grouped using the Cabinet software. In the second round the promising ideas were further developed into physical prototypes using paper modeling and Material Shuffle that contained a collection of Album Artwork. A plenary presentation of the concepts on Material Shuffle concluded the workshop.

We were surprised to notice that the physical prototyping in the second round did not lead to new insights. In the first round, the sketches were already detailed in drawings (note that all participants worked in design or had a design background) and the physical prototyping didn't generate new ideas and had minimal additional value other than demonstrating the ideas:

making a nicer presentation. The participants, through their training and in-company experience, were trained to complete their spatial conceptualizing early during sketching, paper prototyping and using Skin was new to them. This led to the conclusion the second round of ideation was too late to use Skin. In the following iterations we adapted the tool to better fit the physical prototyping and experimented with the placement of the technique within the rounds of ideation.



Figure 6.14. *The media toolbox supports creative group workshops with digital media with the goal of engaging the participants in a doing style exploration of the solution space.*

In the review of the second round, the participants had difficulty reproducing previously created concepts. This led to the insight of having the participants make photos of their concepts, and group their concepts using the Cabinet software.

Iteration 3: Potato

The workshop goal was a new party package for a brand of potato chips. This workshop was held in Delft with 15 participants, facilitated by the Delft team and participated by graduate students from Delft (stand in for regular participants) and the Brussels team. Compared to the music workshop, we changed the workshop plan and had the participant engage in physical prototyping directly from the rough ideas on post-it notes. To increase the prototyping efficiency we prepared a large amount of white sub-assembled tinkering shapes that could be glued together into physical concepts, shown in Figure 6.15. We located the prototyping shapes near the table of Skin in order to invite the participants to build shapes and explore materials concurrently.

We extended the collection of materials in Skin, added the materials users brought from their pre-work assignments, and expected it would give rise to more serendipity in the exploration. We grouped the source materials into several collections fitting the party theme of the workshop. Collections could be selected with tagged cardboard cards. A second set of cards was made to mix party graphics and brand specific logos on top of the textures. Instead of reproducing the concepts in the reviewing rounds, we supplied digital cameras to the participants and used photographs to capture the concepts. During the review and presentation a wall projection was used to display the photos, Figure 6.14, and the Cabinet software allowed the photos to be grouped in concepts, combined with the other materials in the "collective memory" of the toolbox.

We observed participants working with Skin in small groups creating and reviewing the various designs in an active, lively way [Figure 6.16]. However we did not observe the participants working simultaneously on material exploration and physical prototyping. Participants first created shape before looking for materials. Despite the effort of providing sub-assembled white shapes that made the construction easy, we didn't manage to integrate physical prototyping and material exploration.



Figure 6.15. *White and sub-assembled tinkering shapes*

Despite, the extended and extensible collection of source materials, the participants still felt restricted. *"If we are doing powder cartons or something, in some of the other big workshops we have done, we might have 50 or 60 concepts which are quick to prototype and instead of finding colored material logos you could make white prototypes and then have some stock logos, maybe some mountains or something and build yourself a little graphic and project that."* [a P&G visualizer]. In the evaluation round in the workshop several solutions came up, namely further extension of layering artwork and ad-hoc adding of artwork; which we addressed in the next workshop: *"Why not just put a picture somewhere and project that directly because then you could use everything around you, and you wouldn't have to digitalize it first before using. Then you could get these [pointing] and you could build something like maybe a structure or something and you could put it under the camera and have the effect on the package"* [a design student].

Reflecting on Skin a P&G designer and facilitator argued that we had positioned Skin too early in the process: "*The tool is too specific, it didn't help me on the structural packaging design... For instance in a project where we are not going to brainstorm on the structural design of the packaging but we are going to brainstorm... because of whatever restrictions we can't change the structural design but we still want to want to make it stand out on the shelf through the materials, the graphics or whatever... than this would be fantastic*". In contrary to our earlier ideas, the reflection session suggested that the solution space was too open for Skin. In the fourth workshop, we confined the solution space to a more dedicated task.

Iteration 4: Iron

This workshop was held at P&G in Brussels and facilitated by the Brussels team. The aim of the workshop was related to ironing clothes, with participants from marketing and engineering. Instead of browsing collections and working digitally with materials, we changed the interaction



Figure 6.16. *Participants collaborating and interacting with Skin.*

style to the collaging style. We also addressed the need for ad-hoc capturing and using materials found in the environment. In the new version of Skin we added real-time capturing of new materials using a video camera, as described in the collaging interaction style. The cardboard cards, previously used to select logos and graphics, could now be put in front of the camera and be projected on top of the textures. With the new design we expected to see an increase in exploring, experimenting and playing with material expression on the concepts.

We observed participants actively searching their surroundings for textures and actively browsing magazines for materials. They also created artwork with markers and pencils, made collages and explored the graphics on their concepts. The ad-hoc adding of materials made the tool accessible and adaptable for the participants. The physical composing of artwork made the activity match to the tinkering with physical prototypes.

The participants embraced the idea of Skin and found it fun and intuitive to work with. We observed participants working on Skin in small groups creating and exploring and reviewing the various designs in an active and lively way. *"At first I had the same comments as IT (the information technology group to whom we showed the tools during a break): I can do the same with Photoshop. But it is really helping me when we are building concepts. It helps me stay active and it becomes a team effort."* [A participant from marketing]

Results and Implications

In this study we applied Skin in creative group studies at the very start of new product development. We focused on the converging stage of handling Skinned models and developed the Media Toolbox to embed the skinned models in the other materials participants produced.

In the second iteration in the Proctor & Gamble case, we had the participants make prototypes from paper and cardboard. Deeply engaged in their modeling activity, they didn't consider using Skin. In the third iteration we offered an extensive and extendable collection of materials on Skin, restricted the solution space to a toolkit of glueing pre-formed foam together. We changed the spatial arrangement of the tools to merge shape modeling with Skin. Participants used Skin, but after making their physical model. In the reflection the participants mentioned feeling restricted by the limited collection of source materials in Skin. Eventually, in the fourth iteration they used Skin. We had restricted shape modeling to the modifying an existing object and opened the solution space of materials with the collaging style. The current set of workshops can not answer if this is a fundamental problem of Skin, if the design assignment is not framed for Skin, if the application domain requires the collaging technique, or if the participants need more time to adapt the Skin technique to their work process.

A second problem that emerged is how to retain and document the many concepts participants make on Skin. We solved that by having the participants document their results and grouping and ordering the results spatially using a large display. In this way, participants could mix source materials and sketches to these groupings to summaries ideas.

Although the goal of the Media Toolbox was to digitize materials in order to re-use materials in multiple ways, using physical materials on Skin made the interaction tangible for the participants and allowed them to create interesting and complex designs. Despite the fact that the "doing first" approach was not observed, the physical interaction allowed the stakeholders to express themselves in designerly ways.

6.7. Design Teams



Figure 6.17. *The design team working with Skin.*

In this case I show how a design team came up with creative new ideas using Skin, found a way to combine Skin with physical prototyping and how they advanced from their "Skinned" object directly to product prototypes. In this workshop Skin setup as described in Chapter Five was used. The design team consisted of three students with a bachelor degree in industrial design engineering, currently enrolled in the master

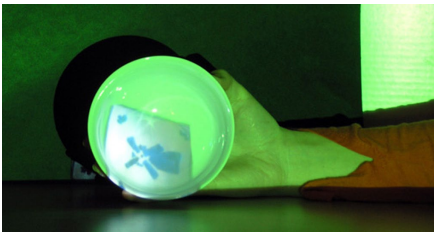






Figure 6.18. *Top Left an augmented white bowl showing a typical Delft Blue tile. Right a photo of the glazed end result. Bottom: After the workshop the design team printed the photos they had taken as contact prints and from these prints directly glazed and baked their concepts onto ceramics.*

program "Design for Interaction". The three worked as interns at the Royal Delft delftware factory to design a new collection of Delftware that would appeal to a younger generation of customers. The workshop was hosted in our lab, Figure 6.17, which is practically next door to the factory.

Method

The workshop took half a day. Prior to the workshop, the designers had made sketches and collected visual materials. These materials were used during the session. They had bought a large variety of white earthenware products on which the graphics were to be projected. All concepts were made within the constraints of Delftware, blue graphics on white ceramic objects, and the session focused on aspects of composition, decoration and figurative art.

Observations

The team enthusiastically talked and commented on their artwork visualized onto the tableware models. *"This design is typically from Department Store X"*. Often they found a nice graphic on one object and then tried it on various other objects. Some of the concept designs could be traced back and directly attributed to the use of the Skin projection technique. When the students projected a traditional tile pattern, and moved a ceramic bowl through the beam of light, the pattern became partly visible and deformed over the curved surface, as shown in Figure 6.18. This effect gave rise to various explorations of traditional Delft blue graphics projected in unconventional ways on the objects.

Discussion

In only a few hours the design team had explored the solution space extensively and generated many concepts which were photographed. To our surprise the team created glazed ceramic objects immediately following the workshop, without any further iteration, visualization, or evaluation

of the concepts. They had printed their concept designs thumbnail size, Figure 6.18, similar to a contact-sheet for photos, and used that as a quick reference while painting the glaze. It seemed that during the workshop they had not only explored and generated designs, but they also had evaluated designs to a sufficient degree to move straight into producing earthenware prototypes, indicating that the ideas and visualizations during the workshop had matured significantlyThe large quantity of ceramic shapes turned out to be an efficient tool for shape manipulation. Often when they had generated a pattern on one shape, they then explored the patterns on other shapes. Exploring colors and patterns on the physical objects inspired new designs, which were unlikely to have been discovered in separated stages of shape and graphic design. Compared to the Procter & Gamble case, the solution space was more confined, and allowed the team to make conversational cycles that spanned both shape and material.

6.8. Client Meetings

Royal Delft is the last remaining factory from the seventeenth century that produces ceramic pottery by hand with distinctive hand-painted blue decorations, see Figure 6.19. It takes decades to acquire the skills of a master painter who is allowed to design new decorations on the products. Prior to our intervention, Royal Delft had no experience using computer tools in their design process. In four iterations [Figure 6.20] we [Saakes & van der Berg] developed a tool for Royal Delft, the Bluebrush, to provide an interactive visualization of artwork on the physical ceramic objects in the client meetings.

Iteration 1

At first we targeted Skin at the painters, to support them generating new ideas. In a few workshops it became clear that although they appreciated the technique, and could imagine using it in their artistic projects, they couldn't relate it to daily practice. When studying the design process at the factory we discovered that what we considered to be 'designing', i.e., determining artwork and composition, happened at an earlier stage, during the sales meetings. To our surprise, the master painter saw his value in the execution of strokes rather than in these aspects.



Figure 6.19. *Painting the typical Delft Blue decorations is a skill that takes years to acquire.*

As shown in Figure 6.21, top, the design and layout of a plate is discussed in a meeting between the client and a salesperson, which

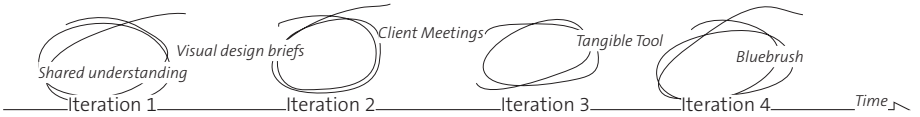


Figure 6.20. *The intervention at Royal Delft consisted of four design iterations. Similar to the P&G intervention we started by establishing shared understanding. In the second iteration we focused on the communication between the sales(wo)man, clients and the painters. Gradually over the third and fourth iterations we developed a tool to be used in client meetings by the sales people.*

results in a verbal description. Then, a painter draws the design on a plate with pencil and a photo of this sketch is returned to the client for approval. Often, several iterations are needed before the client is satisfied and the design is finalized in glaze. As a result, in the next iterations we targeted Skin at the design meetings in order to provide visual design briefs.

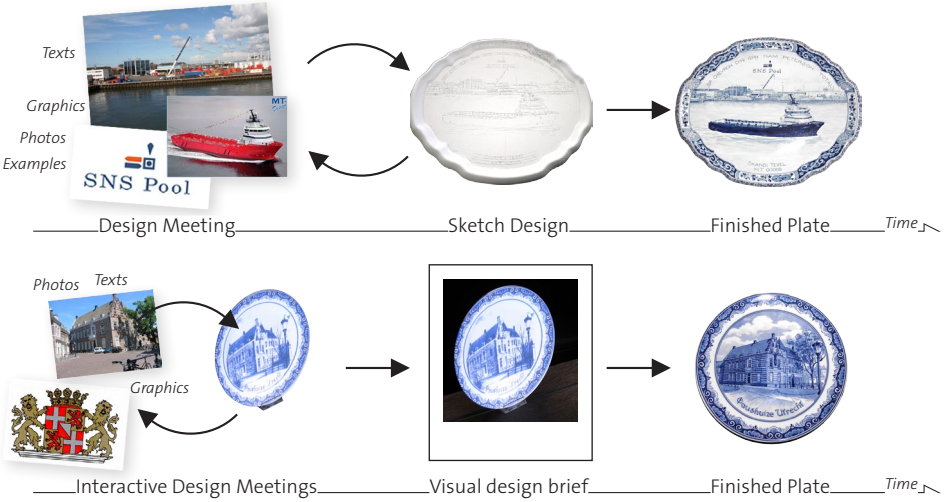


Figure 6.21. *At the top the existing workflow: when designing custom-made Delft Blue earthenware, first the layout and artwork is discussed in a meeting. Then, based on a verbal description, a painter draws a design with pencil on a plate. Often several iterations of these steps are necessary before the design is finalized and glazed. With Bluebrush, bottom, the various design decisions are now visualized during the meeting and projected onto a physical plate. A photograph of the augmented plate serves as a visual design assignment for the painter, who will transform the "sketch" into a typical Delft Blue style plate. The time-consuming iterations of the original workflow, sketching designs on actual plates, are now efficiently replaced by the interactive design session.*

Iteration 2

The goal of the second iteration towards Bluebrush was to establish the feasibility of creating visual design briefs instead of verbal briefs by augmenting plates. The decoration on custom-made plates follows a strict traditional format, consisting of a border, artwork such as an image and a company logo, and a few lines of text. The existing Skin prototype was extended to handle multiple layers (to be operated by the Delft researchers)



Figure 6.22. *In the fourth iteration we designed Bluebrush to be suitable for operation by sales employees.*

and included a collection of frequently used border designs. To visualize the typical delft blue style, a pixel filter ("delftware filter") was created to make the captured photos and other artwork appear to be made out of delftware. The image thus created is projected on to a physical plate placed upright on the table.

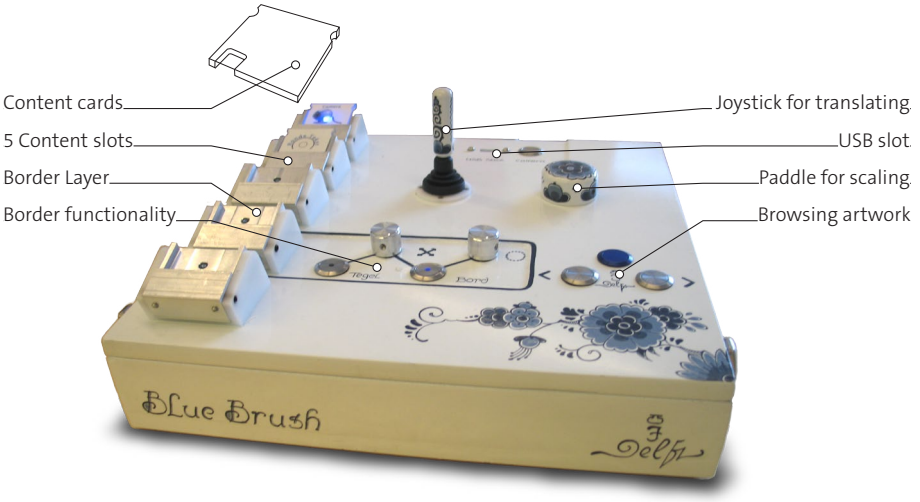
We went through dry runs of various previous custom-made assignments and discussed the new "visual assignment" with both the painters and salespeople. The visualizations were very much appreciated and the examples made by van der Berg were soon used as "visual contracts" and sent to clients. However, the delftware filter brought up fundamental discussions about the authenticity and the craftsmanship of painting delftware. The visualizations were presented with great precaution to clients, explaining that it is only a rough impression, and should be evaluated as such.

Iteration 3

With the benefits of a visual design established, the goal of the third iteration was to explore the value of interactive visualizations during client meetings. In two meetings van der Berg operated his software according to the directions of the client and sales employee. In this way we could study the functioning of the technique in real world client meetings, without having to design a user interface suitable for operation by inexperienced users. The resulting visual design briefs were handed to the painter who made sketch designs that didn't need any iterations before glazing the end product, Figure 6.21, bottom.

Iteration 4

In the fourth iteration Bluebrush was designed and made suitable for operation by the sales employees [Figure 6.22]. In our earlier studies, we employed a minimal interface with only controllers for scaling and browsing all other functionality could be achieved by physically manipulating either the artwork or the model. The design of Delft blue plates and tiles is specific and contains a small number of graphical elements including text. Bluebrush therefore contains image generation software consisting of five layers that can be loaded with computer-generated digital images, text, and live video input.



The Bluebrush

Bluebrush exposes its functionality in a physical panel. as shown in Figure 6.23. The left side of the panel consists of five slots, representing five layers. Layers can be selected by pressing on a slot. Each layer can be loaded with artwork using a physical token. Bluebrush has tokens for digital images from a USB flash drive, images from a network folder, snapshots taken with an attached webcam, curved texts, and lines of texts (to be entered with a wireless keyboard). By inserting a token into a slot, the layer is loaded with the corresponding media and can be manipulated with the controls on the right of the panel. The controls consist of a dial for scaling, a joystick for positioning, and a next, previous button to browse through the images that are on a network folder or USB flash drive. One layer is visually differentiated and represents the border of the plate (if the object is not a plate but a square tile, this layer controls ornaments in the four corners of the tile). The media in that layer are mapped along the border of the plate (or in the corners). The five layers were found to be sufficient for most of the custom-made objects. The tangible approach to exposing the functionality was favored over a screen-based interface for a few reasons:

Figure 6.23. *The Bluebrush panel consists of a tangible, dedicated interface for designing Delft Blue earthenware. The left side of the panel houses slots for media, the right side of the panel houses various controls to manipulate the media. Media is loaded into a layer by insertion of a token (right) into the corresponding slot. There are tokens for the various media types: images captured with a webcam, texts, and collections of images, for instance, from a USB flash drive.*

- A screen-based interface would focus the attention away from the object.
- The salespeople were not comfortable using computers during the sales meetings.
- The interface makes the possible choices explicit (unlike regular computer interfaces, which remain obscure for the onlooker).
- The dedicated controls would invite the client to take over control.

In two salesman/client meetings Bluebrush was used to project al thus generated delftware decorations on a white, unfinished ceramic plate with, visualizing the various options that were under discussion. Van der Berg was present in the background to assist the salespeople. Both the clients and salespersons highly appreciated the tool. It helped the salespersons show what was possible and the clients to express their wishes. Clients commented with remarks as *"This edge goes very well with the portrayal"* and *"The stylized edge fits the modern style of the picture very well."* We also observed how clients influenced the composition of elements by indicating the size or position of images. Salespersons confirmed that such interactions with their clients did not occur in their regular practice. Sometimes edges of artwork didn't line up on the plates. When that happened, the salesperson emphasized the skill of the painters: *"The painters will get that right, try to ignore it for now"*. In general, the discussion focused on the artwork and not on the technology.

We observed that the clients were getting more deeply involved in the design process, and in a sense became co-designers of their products. The iterations that seem to be necessary for clients, to discover what they want and to see what is possible, now took place during the meeting instead of in iterations over a few weeks. When the design was finalized, a digital photograph was taken, serving as a visual contract. After the Bluebrush session, the painter painted the plate by hand, based on the artwork used and the composition as sketched with Bluebrush.

Discussion

The Bluebrush solved two problems with the current process of generating custom-made designs: First, the representation of the decorations, by means of a pencil drawing, is a bad predictor for the painted end result. Second, designs always contain compromises, and a few iterations are inevitable for the client to agree with a solution. These iterations are currently costly in both time and labor, and suffer from discrepancies caused by the verbal instructions given to the painter. The visual design brief, consisting of a photo, taken during the meetings did not need any further iteration. Thereby, the amount of the labor intensive iterations at latter stages was reduced. Projecting on physical objects, also helped to keep the discussion focused on the design and not on the tool or computer technology that generated the visualizations.

In 2009, a redesign of the Bluebrush is in permanent use at the sales department, and the first products designed with the Bluebrush are sold. The redesign enhances the described design with the ability to "freeze" designs in order to review and compare them. The main use of the Bluebrush remains to quickly create visualizations for requests that are handled by email.

6.9. Discussion

The cases presented in this chapter provide insight a number of application domains and configurations of participants. During the cases the prototype of Skin progressed, as well as the insights. The initial ideas of a design tool changed into a design technique that could be evaluated in practice. In this discussion I will evaluate how Skin performs using the consideration for tools and techniques introduced in Section 4.5. In the next chapter I evaluate use the Skin prototype, described in Chapter 5, developed in Section 6.6, and used by the design team in Section 6.7.

The Fit of the Tool/Technique to the Solution Space

In the presented cases, all the prototypes **made the interactions between the scales from material to shape, experiential**. Due to the naive projection setup, the solution space of materials was restricted to diffuse color. Supporting specular shading could be beneficial in a number of the described cases such as supporting metal glazes in ceramics. However, none of the participants mentioned that being problematic, in most cases, the technology seemed to suffice for the early stage, although it emphasized exploring patterns and graphics.

Skin was **explorative and allowed for conversational cycles.** Mixing source materials participants already had, resulted in previously unconsidered combinations, often resulted in surprises that changed their ideas. Using known materials didn't restrict their search. The Bluebrush supported conversational cycles during the client meetings and gave the client an idea for what was possible.

The slideshow and collaging interaction style were found most fitting the source materials designers have. When combined in Skin, most source materials can be used. The slideshow style emerged as a "browsing" technique that supported participants to quickly go through a collection of inspirational artwork, similar to browsing through a magazine or surfing the internet for inspiration. The browsing technique contains an intentionally hidden collection of digital materials that evoked serendipity. It also prevented pre-judgement, reviewing materials prior to experiencing in context, on the physical model. Scaling completes the browsing technique, by supporting both course and fast as well as precise changes in scale. Detailing materials was observed in the "collaging" interaction style that supports composing materials out of physical source materials by use of a camera.

Except in the design team case, I didn't observe participants make conversational cycles that included both material and shape decisions. The design team had acquired a large variety of ceramic objects, which allowed them to see how a particular pattern "worked" on a particular curvature of shape. In the Proctor & Gamble case we couldn't get participants to use Skin, until we restricted the shape modeling to slightly adjusting an existing product in the last iteration.

The solution space of the design problem in Procter & Gamble case was larger compared to the design team, which they felt more appropriately explored with shapes modeling, before exploring materials.

The Procter & Gamble case and the design team case revealed the necessity of a converging step in the Skin technique. In Bluebrush, with a static object and a more extensive interface, users can store and retrieve designs to compare the generated designs, a feature requested and greatly appreciated. In Skin, comparing concepts and revisiting earlier conceived ideas is difficult, both spatially and temporally. By capturing the pose of the object, as suggested in the future work in Chapter 5, storing design can be solved and made applicable to Skin, however requires additional user interface elements. Nevertheless, capturing designs by making photos was found efficient in the converging stages when using spatial organizing tool to group concepts in the Procter & Gamble case. The design team independently came up with a similar technique of printing contact sheets. However photos cannot replace the rich experience of seeing the materials on the real object.

The Fit of the Tool/Technique to the user

Skin was **participative and included stakeholders.** In the Procter & Gamble case, iteration 4, Skin supported participants from marketing and engineering to actively participate. Stakeholders that are used to be mediated by visualizers. The Bluebrush allowed salespeople to interactively show the options of Delft Blue decorations in client meetings, whereas they are used to show example books and tiles. The clients became more directly involved in the composition and directed the salespeople changes. In the redesign, the clients are likely to take over control and use the Bluebrush by themselves.

Skin does not use a traditional interface and **allows to use natural skills**. We observed the design team orient their physical models to map their graphics. At Procter & Gamble, 4th iteration, participants positioned brand graphics using the collaging technique. However, as shown in Figure 5.14, positioning the camera, framing the graphic, and orienting, translating the artwork, together with the dial controller was difficult to master and understand. I didn't observer **hacking**. For most participants the technique was their first experience, and the workshop format didn't allow participants to master the tool and integrate it in their daily practice [Bouwmeester 2006].

Skin made intentionally **use of existing source materials**. In the case of Struktuur68, the source materials came from the artist' personal collection, although mostly marble, the patterns worked well and elicited new ideas. In the 2nd and 3rd iteration at Procter & Gamble I provided a "stock" collection of source materials, that made the participants feel restricted in their search.

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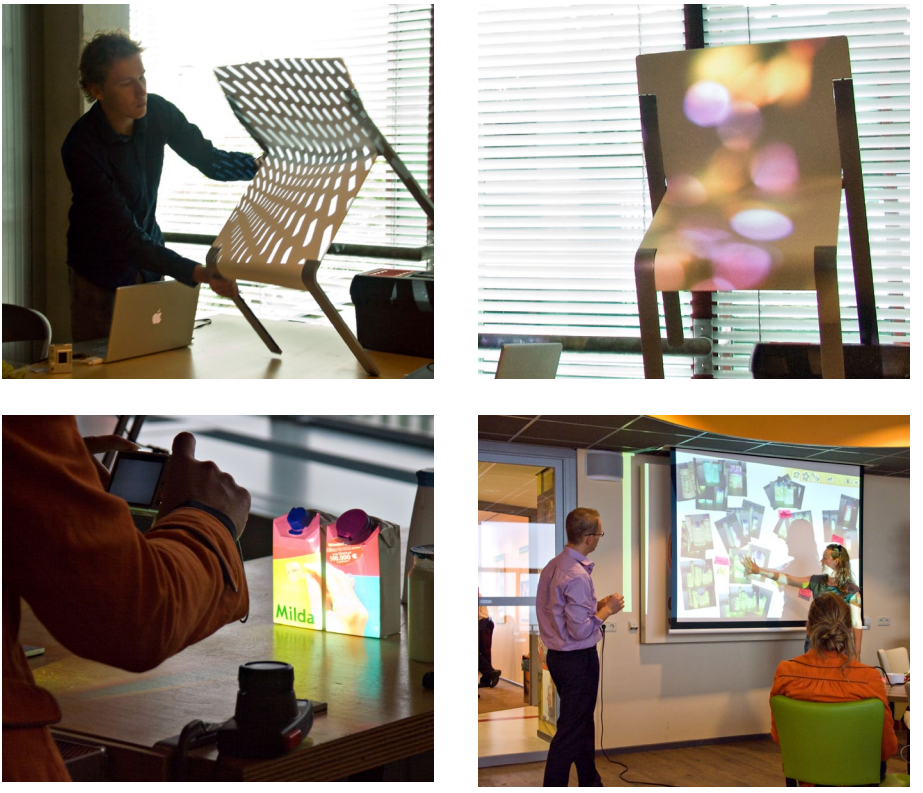


Figure 7.1. *An impression of participants in action during the workshops. Their physical models are colored with projected light (top). Top left, a participant orientating his model to experiment with the alignment of the projected pattern which gave rise to a discussion about adding holes to the opaque material. Top right, a pattern that gave rise to a discussion on applying a screen-printed padded textile to cover the seating area. Top right, participants investigate the on-shelf presence of a dairy product with graphics that span multiple products. Bottom, participants clustering their ideas on a large wall display.*

7 Material Design Workshop

7.1. Introduction

The Skin technique aims to support design teams in their exploration of the visual appearance of materials in products at an early stage of the design process. In the previous chapter I showed how Skin integrates into a design process, how it supports activities of the early stage, and how it supports design teams in generating ideas. In this chapter we [Saakes & van der Lugt 2009] evaluate Skin as a sketching technique for materials in products. The objective is twofold: 1)To see how participants go through conversational cycles using Skin; how it supports their thinking process back and forth between expression and manipulations in the representation. 2) Whether their conversational cycles include the scales involved in product expression, e.g. if a manipulation of "color" triggers a manipulation of "shape".

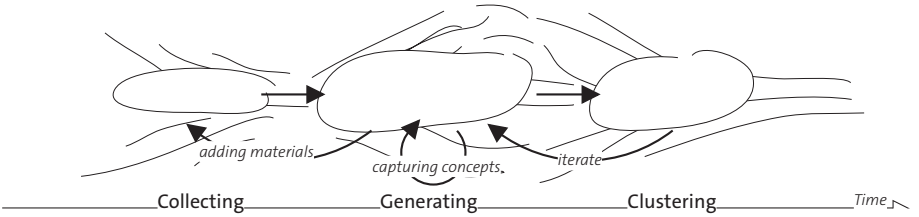


Figure 7.2. *Working with Skin consists of three steps. Prior to the workshop participants collect source materials consisting of material samples, sample products and images (collecting). In the diverging step of "generating materials" they generate ideas by browsing through and mixing their source materials, mapping source materials onto their physical models, and adjusting their physical models. The session concludes with a converging step, clustering the generated ideas into concepts.*

We applied the Skin prototype and technique as presented in Chapter 5 to two design teams in the Netherlands. The technique, as depicted in Figure 7.2, consists of three steps: 1) A pre-session step, gathering source materials to be used in the session. 2) A diverging step, exploring ideas: mixing and browsing source materials, mapping source materials on physical models, and manipulating physical models (e.g. adding details, changing the shape). 3) A converging step , clustering ideas into interesting and viable concepts. Prior experience [Section 6.6] taught that step 2 often causes participants to add new source material (step 1) and step 3 inspires renewed divergence (2). We packaged the technique in a half-day workshop format that we offer at companies. We analyzed how the design teams generate ideas with Skin, reflect with the participants on the technique and compared it to their usual techniques.

7.2. Method

For the study we selected two companies in the field of designing consumer goods design: a well-known design consultancy and a large multinational with an in-house design team. We sourced both companies through our network at the ID-Studiolab atthe Delft University of Technology, and at the time of the study, both companies were at the stage of a design project where they were developing the first manifestation of the product and had physical models available. Earlier experiences [Section 6.6, 6.7] showed that having physical models confines the solution space to one that is manageable to be explored in a half day workshop. Other criteria for selection were: working in teams and suitability of the models for applying the projected light method of the Skin prototype.

Each workshop was held on location, in the company. We captured the workshops on video using a single camera located in a corner to unobtrusively capture the collection space, the Object table and Material palette [Figure 5.3]. The facilitator [van der Lugt] was assisted by a technical facilitator [Saakes] and a photographer to capture the context of the workshop. Two weeks in advance we sent the participants an email linking to an online video [http://www.studiolab.nl/skin] of Skin, to give them an idea of the workshop contents, and asked them to start collecting source materials. A week prior to the session we visited the company to prepare the source materials for the design session. Where necessary, models were painted white to make them suitable for projection. We specifically asked the participants to collect both physical and digital materials. Brand graphics were printed on transparencies and cut out for use in the Material palette. Digital images and patterns were added to Skin's digital collection.

Table 7.1. *The workshop setup.*

10 Minutes	Introduction team members
20 Minutes	Warm-up exercise with the Skin technique
Up to 60 minutes	Manipulating materials (step 2, diverging)
10 Minutes	Break (to sellect pictures)
About 30 Minutes	Clustering ideas (Step 3)
30 Minutes	Reflection on the applicability of Skin

Each workshop [Table 7.1] started with a short introduction round and a warm-up exercise to familiarize the participants with the Skin tool. In the exercise one of the researchers [Saakes] explained how to use Skin by demonstrating the manipulations they had previously seen in the video: browsing and scaling of digital materials, moving physical objects to align them with the projected graphics, browsing physical artwork and mixing physical and digital artwork. Following the demonstration we engaged the participants in a 15 minute warm-up exercise in which they had to design an earthenware product family to be designed for a fictional fruit-



Figure 7.3. *The surface modeling toolkit consists of bendable plastic sheets that can be joined using velcro stickers. The intention for the surface toolkit was that it allows fast prototyping of a shape, and offer more shape freedom than a volume modeling toolkit such as described by Sanders [Sanders & William 2001]*



Figure 7.4. *An unpredicted use of source materials. On a few occasions participants bypassed the Material palette and projection system of Skin and applied brand graphics directly to the physical model. Note that the striped pattern is projected and the text "Milda" is a printed transparency held in front of the container.*

yogurt brand. For the exercise we offered cut-out physical images, various fruits, digital images related to breakfast and dairy, and a simple toolkit [Figure 7.3] to prototype shape. The toolkit was designed to sensitize participants to include shape manipulations in the diverging step. We planned 60 minutes for the generative step, in which we gave the participants the assignment to create many new ideas for their project at hand. A short break between the generative step and clustering step allowed the facilitators to prepare the photos participants made to capture their ideas. The clustering step was planned for 30 minutes. We concluded the workshop with an open discussion chaired by the facilitator [van der Lugt] to reflect on the Skin technique. We reflected on how the technique fit their design process (what did they like/dislike, would they use it, how did it differ from their regular practice) and on the user interaction (what worked well, what would they change).

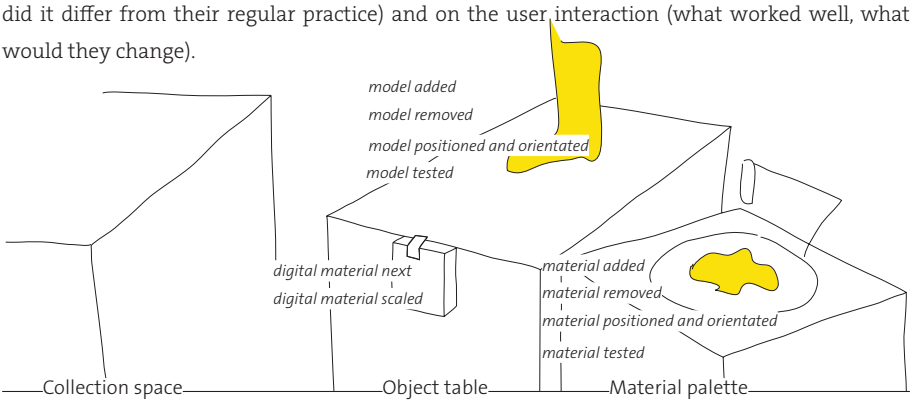


Figure 7.5. *The annotated actions on Skin*

Analysis

Following the workshop we analyzed the videos of all the steps including the reflection. The videos were transcribed and the actions in the diverging step were fully annotated and chunked using Vcode [Hagedorn et al. 2008]. We recorded the actions depicted in Figure 7.4, for physical source materials, digital source materials and objects. Sometimes, participants "tried" a material/

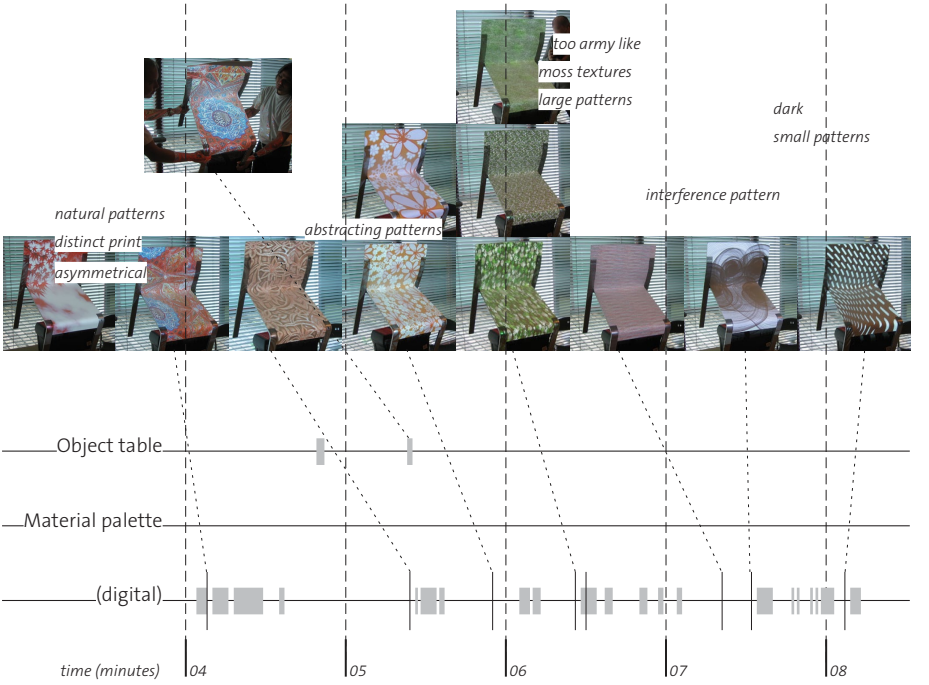


Figure 7.6. *Excerpt of 4 minutes browsing digital materials. At the bottom, the annotated actions on Skin. Most activities involve the digital collection: a vertical line indicates "next" and a horizontal bar depicts "scaling". In-between minute 4 and 5, participants align a graphic by moving their model on the Object table. At the top photos taken by participants, in the middle the discussion summarized in keywords.*

The excerpt starts when participants experience a distinct, figurative graphic on their chair. They discuss the placement of the circle on the chair, the symmetry, and scale the graphic to explore its fit. Around minute 5, they orient the chair to play with the placement of the graphic. Between minute 5 and 6 they advance to the next pattern, which none of them really like, they play a bit with the scale and discuss if abstracting the pattern would make it better. They advance to the next pattern, just before minute 5, and talk about scales of patterns that "work". Some participants favor the small, texture like patterns whereas others favor the larger scales and they keep discussing scales the rest of the excerpt. Between minute 5 and 6, a pattern (not depicted) is scaled a bit and rejected within four seconds without discussion. A camouflage print is disliked: "too army like", but when scaled down, a moss-like texture emerges that is in line with their pre-workshop thoughts of a "natural" material. An "interference pattern" was quickly rejected before they find a "subtle pattern" that they later selected in the clustering stage.

In four minutes the participants explored eight patterns that supported them explicitating and communicating their preferences. It made them think of textures versus the distinctness of images on the chair, abstract versus figurative patterns and scales of patterns that work.

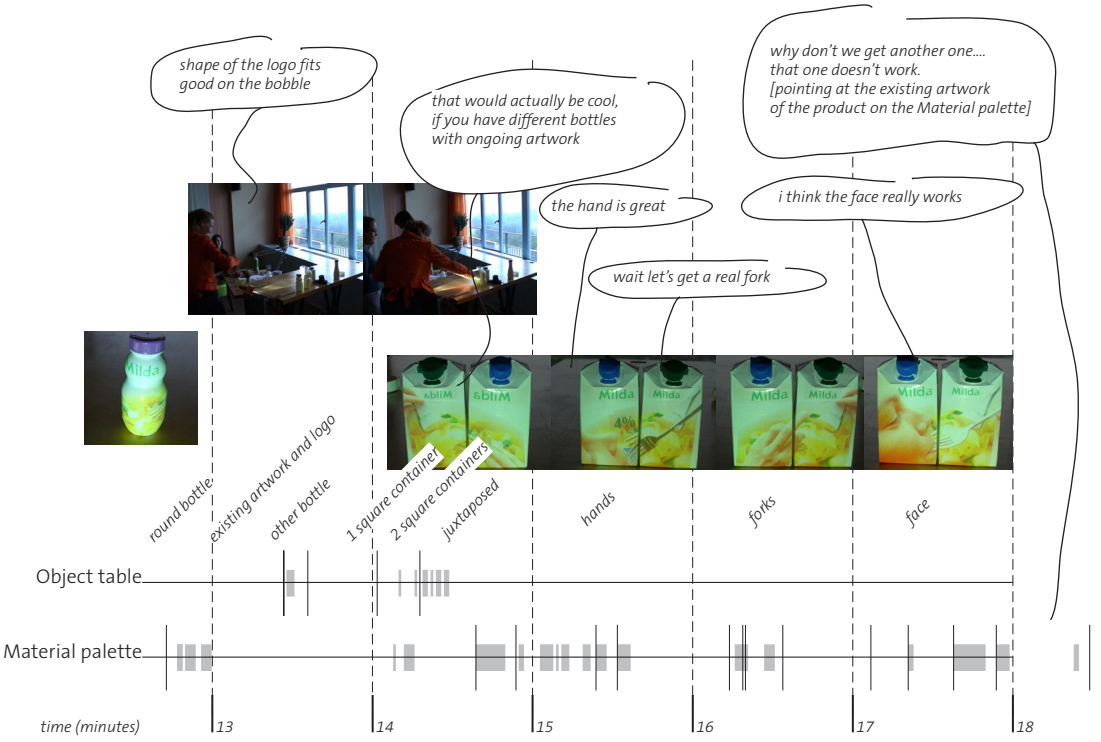


Figure 7.7. *Excerpt of five minutes collaging on the Material palette. At the bottom, the annotated actions on Skin. Most activities involve the Material palette: vertical lines indicate artwork added,removed or tested and horizontal bars indicate "scaling". Likewise, on the Object table a vertical line indicates: object added or removed and a red bar indicates object oriented or translated.*

The excerpt starts with existing artwork and logo of the brand on the Material palette, and a round bottle on the Object table. The bottle is replaced by another bottle, and then the group searches for a square container which is positioned at minute 14 and the artwork on the Material palette is scaled to fit. One participant adds another squared container which results in a discussion on artwork that spans multiple containers. When one participant positions the logo on the Material palette, the others are surprised by the effect of the fingers projected on the container. In the next three minutes, participants play with physical items on the Material palette, forks and later one participant's face. The excerpt ends when the brand manager expresses that she wants to explore other artwork for the background.

In five minutes the participants explored the existing artwork of their brand before rejecting it. They evaluated the artwork on a few containers, made the artwork span multiple containers, and extended the artwork with on-the-spot created imagery.

object for a few seconds on the Material palette/Object table without actually placing it. Then we noted "tested" On a few occasions participants applied source materials directly onto their model without using the projection [Figure 7.5], for these occasions we added a fourth category "material on model". We also indicated when participants took photos. The analysis is representation centric, we didn't find it necessary to analyze the contribution of individual participants and focussed on the participants interaction with Skin during the moments the group split up into two sub groups. With this analysis we expect to find:

- Manipulations in Skin that give rise to discussing product expression.
- Discussions on product expression giving rise to new manipulations
- Manipulations on the Material palette giving rise to manipulations on the Object table and vice versa.
- Sequences of combinations of the first three points that indicate a cycle.

Figure 7.6 and Figure 7.7. provide two excerpts of the analysis. Figure 7.6 describes a typical use of digital materials, Figure 7.7. a typical use of physical materials in combination with the Object table.

7.3. Workshop with a Team of Designers



Figure 7.8. *The Flex designers in action.*

The first workshop took place at FLEX/ theINNOVATIONLAB (Flex), a large Delft based design consultancy. Flex was founded in 1989 and has about 30 designers. Flex designs a large variety of professional and consumer products. When we contacted Flex, they immediately wanted to apply the workshop to a chair design. They had just prototyped a model, and started thinking of materials. Four designers participated in the workshop, shown in Figure 7.8, of whom one had previously collected a number of samples of organic materials he wanted to apply, and one had, at our request, browsed the internet for digital images. The digital collection of 99 images, a sample is depicted in Figure 7.9, contained a wide variety of imagery ranging from wallpaper patterns, abstract figures, to photos of food and flowers and figurative paintings.

As shown in Figure 7.11, in the first 13 minutes they using with digital patterns. The average time to experience, scale, judge and photograph a pattern was 25 seconds. A pattern was rejected within 3 seconds. 47 images were visualized, of which 15 were immediately rejected. Obviously

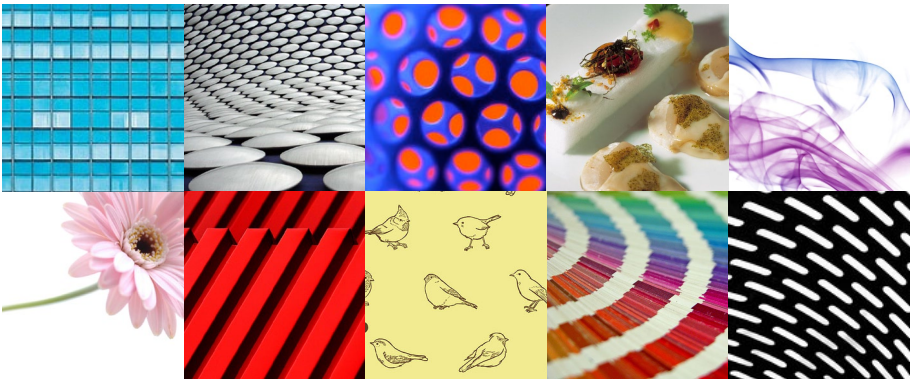


Figure 7.9. *A small sample of the collection of 99 digital images used in the Skin session. The collection showed a wide variation from abstract figures to photos of foods.*

with only browsing and scaling there isn't much scope for detailing. Detailing occurred on two occasions where the designers moved and rotated the chair in order to line up the material [Figure 7.1]. On one other occasion they found a pattern that they carefully, subtly scaled, discussing the implications of the graphic in relation to the proportions of the chair.

One of the designers had selected the pictures, as a consequence, browsing through the images and experiencing their effect on the chair often resulted in positive surprises for the others. The surprise effect was mentioned in the review, they liked the speed with which the chair became textured and the fact that it was like zapping through television channels: *"Bang, and you have a completely different chair!"*

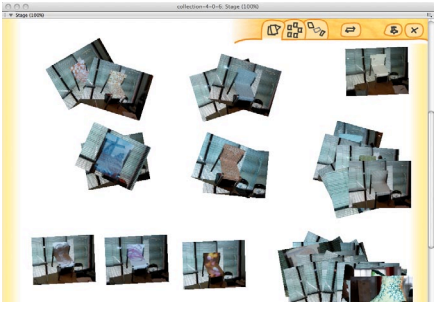


Figure 7.10. *The Flex workshop resulted in seven clusters of ideas. On the bottom right the pile of rejected ideas.*

Several discussions about the expressive quality of the materials took place. Scaling the images to the extremes evoked discussions about print versus pattern and texture, wherein the designers disagreed, their discussion continued during the clustering session. Other discussions went beyond the visual domain and included the manufacturing process, how to weave or silkscreen certain patterns, about metal meshes and embossed fabrics. A striped pattern, created by tiling a small fabric, evoked discussions on how the pattern/graphic could enhance the shape of the chair: *"The plain leaf pattern emphasizes the legs nicely compared to this noisy pattern"*

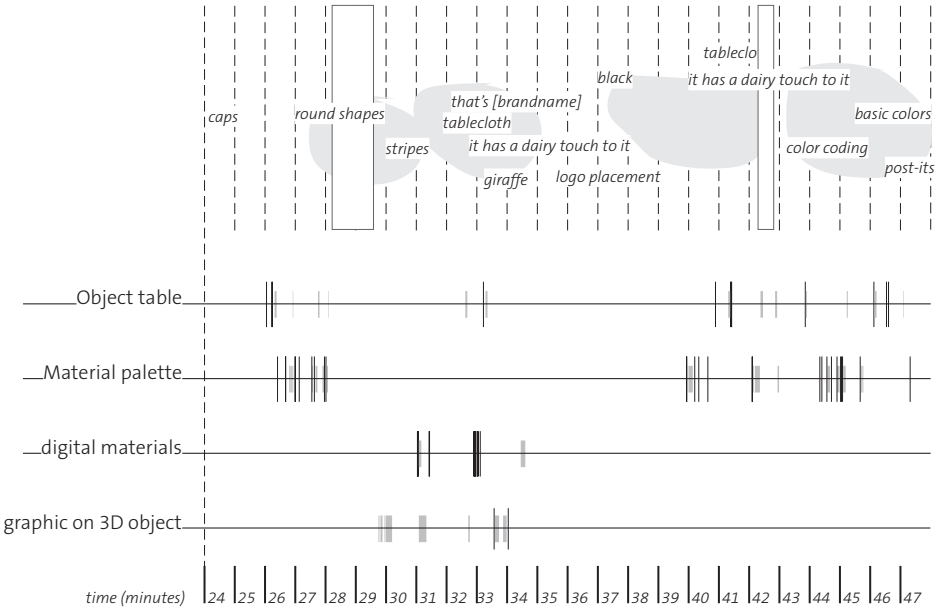


Figure 7.11. *A graphical overview of the session activities. In the first 13 minutes the designers browsed and scaled digital patterns. The last 12 minutes they used the camera to explore physical materials. At the top the discussion captured in keywords, then the activities. In digital materials, a vertical line indicates a "next image", a horizontal bar indicates "scaling". In the Material palette, a bar depicts moving/scaling materials and a vertical line indicates adding or removing materials. The Object table is relatively clear of activity, on a few occasions designers grabbed the chair and moved it around. The light gray areas depict the detailed manipulation.*

The Skin session took about 25 minutes in which the designers took about 42 pictures, of which in the clustering session they selected 17 ideas, clustered in 7 groups [Figure 7.10]

7.4. Workshop with a Multidisciplinary Team

Unilever is a multi-national corporation which owns many of the world's consumer product brands in foods, beverages, cleaning agents and personal care products. The European packaging design team is located in Vlaardingen, the Netherlands, and provides design services to various brands. A typical project at Unilever starts with a creative group workshop with a multidisciplinary team with participants from brand management, marketing, engineering and user research. Based on the results of the workshop, the design team then builds a small number of prototypes which are communicated back to the brand manager. They always produce physical models, because it is their experience that in communicating their design proposals to marketing, the graphics and packaging have to be made explicit. Once a project receives the "go ahead", the technical design process is started. At a latter stage the graphics are outsourced to an external design firm in a separate process.

The goal of the Skin workshop for Unilever was to generate new ideas for a dairy product for a specific market. These days, all dairy products have similar form factors and graphics, making Unilever's brand less recognizable. Therefore the starting point was to look for new packaging, while keeping the materials and graphics (which were strictly defined) in the current style.





Figure 7.12. *At the top, the Unilever participants in action. Below all the packages used during the workshop. Prior to the workshop the participants had collected a large number of packages to work with in the workshop.*

The workshop took place in a large conference room and had six participants, three Vlaardingen-based designers, one Vlaardingen-based technical packaging expert (informed outsider), a packaging expert from the product division and the brand manager, both from Scandinavia. Prior to the workshop we collected the existing brand artwork and disassembled it into the graphical elements, which we printed at various sizes. Some of the artwork, such as text, was printed on transparent sheets. We asked the participants to bring inspiring packages to the workshop. As shown in Figure 7.9, they brought a large amount, over 30 different containers, including dairy products, health care products and beverages. The participants started by exploring the existing artwork on various packages, but soon the brand manager made it clear that the graphics were not so strictly defined as had been assumed by the designers. The designers quickly fetched new source materials, such as magazines and colored paper. Later more source materials were found in the kitchenette of the conference room, such as cutlery. They tried many different shapes before settling on the existing container. The participants felt confident that they could achieve their goals by changing the graphics, an unexpected and surprising result of the workshop. Without a workshop like this they would not have thought of changing only the graphics, as they would have outsourced them.

Compared to the workshop in the previous Section, this workshop [Figure 7.13] took almost twice as long. Except for a few minutes (between minute 30 and 33) the session was dominated by manipulation of physical source materials. The team came up with a -to us- unforeseen use of cut-out brand graphics: they glued graphics onto the models while still projecting over them. The session also contained a large amount of shape manipulation: testing various packages and groups of packages. The discussion between the participants was far more extensive compared

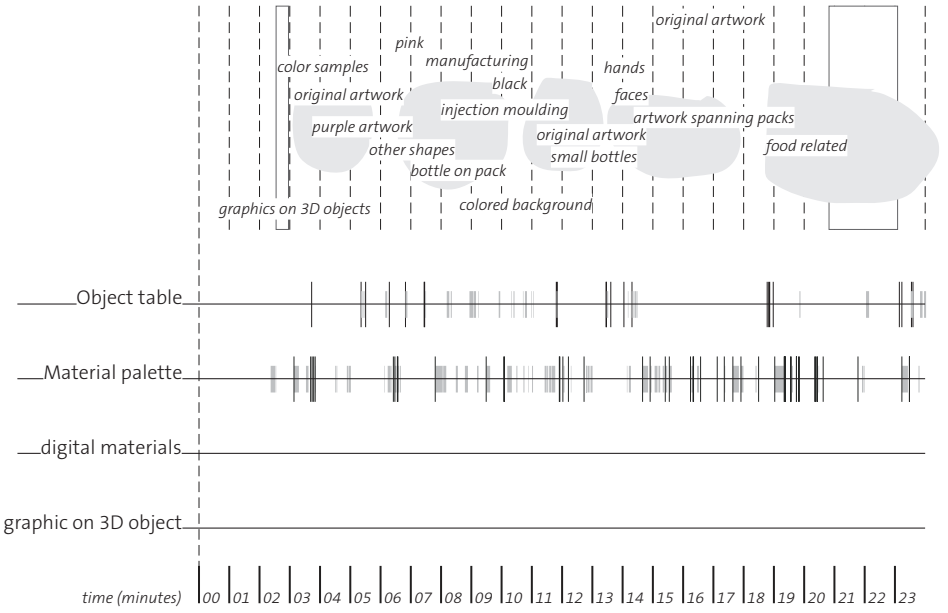




Figure 7.14. *The Unilever workshop resulted in 5 clusters of ideas.*

to the workshop in the previous Section, spanned many subjects, and they took more time to generate and detail their concepts. A few concepts were created by accident: while manipulating the physical artwork the hand and fingers of one participant were visualized on the pack, and made them try out and play with faces and hands and cutlery as graphics. Other discussions involved using photo content on the package or basic colors. Sometimes they liked what they had built, but found it inappropriate for the brand *"ooh i think this one has shelf impact... but you just don't know how they are going to take it with [the dairy product]"* [the brand manager reflecting on a concept].

The participants changed roles from active manipulating on Skin, to commenting and discussing in the background. Generally, one or two participants were actively engaged using Skin and the composition naturally switched when onlookers took over control. We identified seven distinct concepts during the Skin session, and during the review, Figure 7.14, 29 photos in 5 clusters were selected.

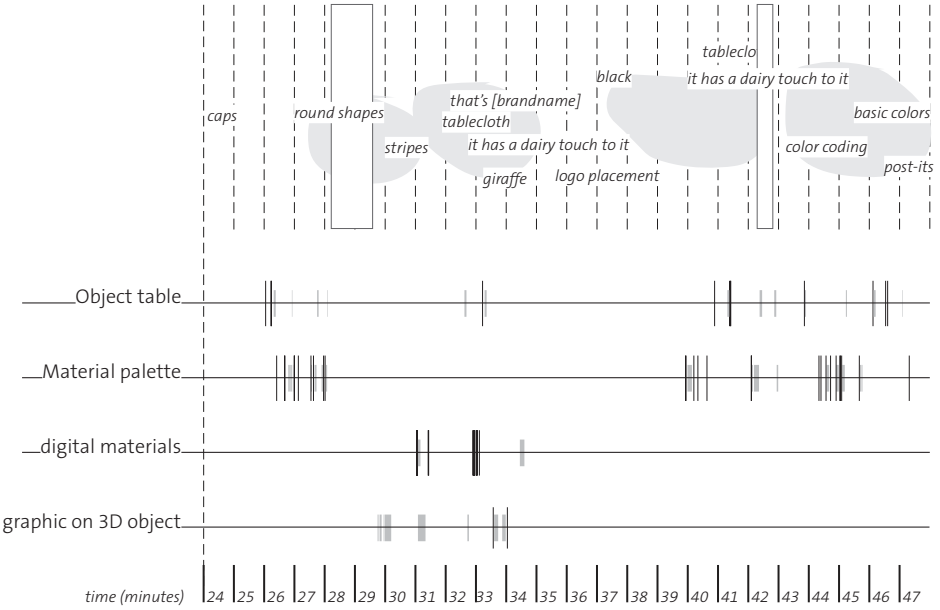


Figure 7.13. *A graphical overview of the session activities. Compared to the design team session, [Figure 7.10], this session was almost twice as long. The team came up with an unforeseen use of cut-out brand graphics; they glued them on the physical models (graphics on 3D object). There were a couple of breaks, some with technical issues indicated in white boxes. The circled areas indicate concepts.*

7.5. Discussion

Even though we started out with the same workshop plan for both workshops, the context of the workshops was very different. The Flex team consisted of designers that had worked together for a long time, whereas in the Unilever workshop not all participants had a background in design and they came from various departments, which meant that there was more focus on getting a shared understanding. This resulted in a slower process. The Flex chair assignment was more straight`forward, a material for the seating area on an existing chair design, whereas the Unilever assignment was earlier in the process with much more design decisions to make, including shape, materials and graphics, as well as functional solutions. In addition, the full-sized chair in the Flex workshop was less likely to be manipulated than the small bottles and containers of the Unilever workshop.

For certain products Flex would like to have their clients participate in a Skin session, in order to jointly explore the product brief. The Unilever team figured that they would use Skin sessions to better brief designers from external graphics design firms. The participants of both workshops expressed that they would not easily share the results with their clients or with marketing because of the picture quality, and mainly due to the distractive background in the pictures. A neutral background, or a for the product relevant background would be preferred. Nevertheless, following the workshop the brand manager of the Unilever workshop had requested the photos

made during the workshop to communicate the concepts, not as an "as is" but as a possible way for packages. In this instance, the designers told us that the "sketch-like" nature of the photos made it clear that it was not a finished concept.

When comparing the Skin technique to computer aided design and drawing techniques they regularly use, all designing participants expressed that working was faster and more intuitive. *"Sure, we can do the same by applying decals Solidworks or by making masks in Photoshop but then you automatically take much more aspects into account. here you are experiencing and playing."* [a designer at Flex]. *"In CAD tools you have to consciously add an image, apply it, and those steps require you to think of the applicability of the picture before you see it. Here I was often surprised by the effect of a particular image on the chair"* [a designer at Flex] and *"Usually I would have done a similar process... but than in Photoshop. printing it and gluing it on the pack... But that would cost us some days after a workshop... this is maybe less refined but you have far more options that you can easily reject"* [a designer at Unilever]. Similar to brainstorms techniques, the many quick concepts that were created during the diverging step, were easily rejected in the converging step.

All participants expressed the wish for additional tools to be added to Skin. Both teams expressed the need for a simple button to make a picture, because in the current workshop, they feel a break in their creative flow when they have to take a picture to capture a result. The designers of Flex suggested to add layers, controls to manipulate colors, whereas the marketing and engineers at Unilever were looking for tools to see their design in shelve environments by copying multiple packs and suggested performing the workshop in a store environment.

Supporting Conversational Cycles

Browsing through a collection with a wide variety of images [Figure 7.9] supported the Flex designers to explore the solution space. It made them think and talk about abstract versus figurate, large versus small, simple versus chaotic, and made the levels of perception and meaning explicit and discussable. *"This is good but we need to...."* other than expressing their thoughts, the browsing technique didn't allow them to apply modifications to the projected graphics. That made the browsing technique fast, no detailing, and allowed to explore the solution space in large steps than, for instance, compared to the narrow collection of marble patterns in Section 6.5. Over the span of a few patterns, they developed ideas of what graphics worked and subsequent patterns could be evaluated fast.

The collaging technique allowed detailing: applying modifications, and resulted in short cycles of manipulating and experiencing. It allowed "happy" accidents such as including unusual objects, fingers and heads in the graphics. Compared to browsing this process allowed cycles of trial and error, but was slower and thinking activity mostly performed by a single participant. In the Unilever workshop we worked with a large group. This meant that a few people where directly

working on the tool, and other people had a more observing and reflecting role. This was not necessarily bad because different people take turns, during the course of the session. However, it may lead to the outside group loosing interest and attention.

Both teams felt the clustering step was essential and talked about multiple iterations or merging the diverging and converging steps. *"We definitely want to iterate and go back to Skin... Actually I want to try out new right now."* [a Unilever engineer in the review]. The analyses of the two workshops [Figures 7.11 & 7.13] shows that participants naturally take short breaks after 10 to 20 minutes of exploring, to change gears for a new exploration. That suggests multiple, faster iterations of the diverging step 2.

Conversational cycles seem to happen in three time spans. In the short "collaging" on the Material palette, in the middle long when reviewing a number of source materials using the browsing technique and over a workshop, in which the insights of the workshop are applied to the next design stage.

Including Scales

In the Flex workshop, due to circumstances, the designers had a single chair that didn't allow them shape change shape induced by experiencing materials. Nevertheless, experiencing the effects of the visual materials on the chair did not only evoke discussions on screen printing [Figure 7.1], but also on the larger scales such as perforating the seating area with a pattern of holes [Figure 7.1], open knitted surfaces and applying upholstery.

The participants of the Unilever workshop discussed the applicability of the various containers they brought to the workshop with respect to the strict regulations of dairy products. The use of many existing containers, allowed participants to explore shape, similar to the workshop described in Section 6.7. Except for mixing bottle caps with containers, it effectively hindered them to engage into detailing shapes as observed in Section 6.6. At certain moments, they swapped containers to experience the projected graphics on other shapes. Sometimes, they simply placed a few containers of various shape on the Object table to observe and compare spatially rather than temporally.

8 Conclusion, Recommendations and Future

8.1. Introduction

I have identified a latent user need, invented a novel solution, made designs, and evaluated prototypes of the designs in practice. This concluding chapter presents the findings. First, in Section 8.2, the research question is answered. Section 8.3 provides recommendations for tool and technique developers. Section 8.4 looks back on my approach to this project and Section 8.5 provides recommendations for future research and design.

8.2. Main Research Findings

The starting point of this thesis was the question: **"How can we support designers in their exploration of material appearance in products in the early stages of the design process?**" In order to answer that question I first needed to answer the following: **"What is the role of materials in product expression?"** [Chapter 3] and **"What are the tools designers use to explore materials in products"** [Chapter 4]. Then, through the development of Skin [Chapter 5,6,7], the main question was answered.

"What is the role of materials in products?"
A given manufacturing technology, capable of shaping a certain material within the constraints dictated by performance or cost, allows designers to design perceived materials in a product in a manageably small solution space. However, advances in both manufacturing technology and material science reduce the impact of the manufacturing process on the appearance of the product. This results in a larger solution space and transforms the selection process of materials in products into a design process in which materials are designed specifically for an application.

Designing the appearance of materials in products consists of the translation of meaning into a physical object. However, a perceived material in a product is not a consequence of a physical material. It involves aspects on various scales in the product, including the interactions with

details and shape. Although various methods exist to describe how people experience materials or products, these methods do not allow for designing or specifying materials in products. Thus, materials in products are "matter formed into shape". The material can be the clay to make pottery, but also the prefabricated structure in corrugated fiberboard, and include features on scales that traditionally belong to the domain of shape. The challenge is to support designers in their translation of perceived materials to physical matter, as well as across the scales, all the way up to shape, so that the interactions become manageable.

"What are the tools designers use to explore materials in products?"
The field study in Chapter Four revealed that tool for designing materials should support not only a designer's thinking process, but should also support design teams and invite other stakeholders in the design process to actively participate.

Currently, designers and stakeholders search, communicate and specify materials in products using ready-made objects: material samples or example products. Ready-mades are more effective in conveying and interpreting the experience aspects than language, and faster than drawing and prototyping materials. However, their use restricts designers to a finite set of options, opposite to the unlimited freedom designers have to externalize thoughts on shape, and thereby providing limited support for design thinking in cycles of externalizing and (re) interpreting. In contrast to the early stages, in the later stages of the design process almost all design work is performed with computer aided design tools. Advanced computer support allows designers to visualize materials in products and to depict material properties in detail. However, these visualization techniques are designed for demonstration, and are not adequately adjusted to support thinking across scales, nor do they support the fluidity, ambiguity and speed necessary in the early stages of design.

Solving the current dichotomies between both the techniques used in the early stages and the detailed visualization tools of the later stages, and between techniques for designing shape and those for designing materials, is the central challenge in bringing support to designers and stakeholders.

"How can we support designers designing the appearance of materials in products in the early stages of the design process?"
Design support for designing perceived materials in products was studied through the development of the central prototype in this thesis, Skin.

"The plain leaf pattern emphasizes the legs nicely compared to this noisy pattern" [designer, section 7.4] Skin makes the interactions between shape and material experiential with an augmented model. The projected graphics on the physical model make the interactions explicit and thus

invite the participants to discuss the influence of a material on details and shapes. A key aspect is the adjustable scale of the projected graphics, supporting the exploration of their fit on the physical model.

To support designers I devise "sketching" techniques that make materials in products explicit, experiential and interactive to support rapid iterations that make design thinking possible, while supporting stakeholders in these iterations by making them active participants.

8.3. Recommendations

Designing Skin, and studying its use in industry through several participatory action research cycles, led to four design principles recommended for tools and techniques that aim to provide support in form-giving activities in the early stages of product design.

Minimize the time to experience and iterate.
"Bang, and you have a completely different chair!" [designer, Section 7.4] Skin tries to minimize the time to experience a concept. It supports cycles of externalizing and (re)interpreting through an interactive augmented model. Changes in the augmented materials are quick and effortless to encourage play. Two complementary interaction styles emerged. A "browsing" style supports lateral searches through the solution space using a large number of digital source materials from the designers' collection. A second, "collaging" style is slower, but supports creating new materials from physical source materials through mixing and combining. This style supports vertical searches through the solution space. Concept generation using these two styles takes place in the temporal domain and should be combined or alternated with steps of convergence in the spatial domain to allow for conversational cycles over groups of concepts.

Maximize the opportunity to make chance connections.
"Ooh! I think this one has shelf impact." [brand manager, Section 7.5] Skin tries to maximize the opportunity to make chance connections. New ideas are often based on unexpected or unintended uses of existing solutions. Many of the results participants gained from the Skin workshops originated from artwork or combinations of artwork used in ways completely different from the original intention. To avoid pre-judgment of materials, the browsing style intentionally hides the collection of materials from the user, and in combination with extreme scaling, leads to surprises and new ideas. More ideas are caused by "happy" accidents through the built-in ambiguity: the deformations that occur when naively projecting graphics on the physical object; unintentionally captured and projected body parts; the repetitive patterns caused when large graphics are scaled down; and large graphics cropped by the silhouette of the physical object.

Make it impossible to detail and beautify designs. Yet, make the results look attractive.
"Wow! This really does something to me" [artist, Section 6.5] In Skin it is impossible to detail and beautify designs, however the projections look attractive and grab your attention due to the richness of the designers' source materials. Tools that allow detailing concepts lead to vertical searches in the solution space, thus preventing the discovery of new directions. The tangible interface and naively projected graphics in Skin prevent users from detailing their concepts. In addition, Skin tries to maximize the solution space for the interactions between material and shape. However, for an effective lateral search, it restricts the solution space of shapes to the representations designers already have.

Make it group-accessible, and make sure that everybody can express themselves.
"This is really helping me when we are building concepts. It helps me stay active and it becomes a team effort" [a participant from Marketing, Section 6.6]. The early stages of the design process include many stakeholders, of whom not all have a design background. Skin tries to make these stakeholders active contributors who can express themselves through explicit representations and tangible interaction and so explore the solution space first hand.

Skin is group accessible. However, care has to be taken when working with large groups. In Skin's case this meant that a few people were directly working with the tool directly, and others had more of a observing role. This is not necessarily bad as long as different people take turns during the course of the session. However, it may lead to the outside group loosing interest and becoming inattentive.

8.4. Reflection on the Approach and Results

Skin was applied to a representative variety of design situations, varying in team composition, participants' background, application domain and type of products. The many skilled designers and artists who participated in the studies provided the key insights to make the tool and technique relevant to design practice.

Skin
The focus of the prototypes was implicitly set on integration with the early stages, with the representations designers already have. Thus Skin could easily blend with current practice. Less effort was spent on "storing" concepts to help bring the generated results back into the design process. Photos of the generated concepts cannot convey the rich experience of the augmented physical objects. On rare occasions [for instance Section 6.5] users felt disappointed that the projections were only temporary and not real. In some cases the photos sufficed to produce prototypes or products using the photos as a reference. [Section 6.7, 6.8]. In other cases users

found the quality of the photos made with the prototype not yet sufficient for communication to clients. However, in the case described in Section 7.5, a select set of photos of the results was used to convey new lines of thought to peers and higher management. The poor quality of the photos helped convey the unfinished status of the ideas. Future integration into computer aided development tools is neccessary.

Despite efforts reported in Section 6.6, I did not manage to integrate Skin with physical modeling activities. Although Skin provides a unified experience of material and model, Skin's use of the designers' source materials resulted in two separate interaction spaces, one for physical models and one for source materials. Unification of interaction spaces could possibly help, as well as more time to master Skin to the fullest extent. However, it might also be that manipulating shape engages participants in a process that does not allow them to think of materials concurrently. The explorative cases in this study could not confirm this hypothesis and further studies of this subject are necessary.

Action Research

Rapid iterations of prototypes and user evaluation made an effective process to identify user needs. I gave users open tools by means of prototypes, to avoid restriction by my preconceived assumptions. In the studies they worked with their own materials on their own problems, in a familiar and relevant context. By thus relating the use of the prototypes to their practice, they were supported in reflection on how they work and identification of their needs and wants. It also enabled them to invent novel uses of the prototypes they worked with. However, testing prototypes in practice from an early stage in this way does not allow for complex technology, nor assumptions regarding future technology or future practice. Skin's prototypes had to work with the materials designers had, at their workspace. Consequently, the solution space for innovation was reduced, which I consider a limitation of this approach.

Double loop learning

The proposed double loop learning model consisted of small loops of contextual action design that drove a larger, knowledge-directed loop of answering the research question. The roughness of reality made this not as clear and well organized as planned. Due to the availability of companies, the diversity of design situations, time constraints and my opportunistic approach, insights gained in a contextualized small loop could not always be followed up or continued in subsequent cycles. By performing the contextualized small loops of interventions the focus of the research changed:

- It guided the research from the initial intention of developing a software tool targeted at individual designers, towards a tool suitable for group sessions, including support for participants that are commonly less involved in generative activities.

- It became clear that the focus should not be on improving the qualities of projected graphics in the prototypes, but on developing interaction styles that supported the designers searching the solution space, both laterally and vertically.
- A novel tool requires a change in the way designers work. It revealed a need for converging stages, which was addressed in the technique development in Section 6.6 and resulted in the workshop format described in Chapter 7.
- The cycles provided initial evidence on restricting the solution space of shape manipulation in order to optimize material manipulation.

Evaluation

The amount and the variety of studies presented in this thesis together with the accompanying videos provide the evidence of how designers use Skin, how it changes their practice, and provides insights into how to shape future tools and techniques. I took care to include companies and people that are well-known and successful in their respective areas, willing to innovate and expressed a benefit from including Skin in their design process, as I expected to learn the most from them [von Hippel, 2005]. However, the huge differences between design problems and approaches designers take, made it difficult, or even impossible to compare cases and to gather inter-case statistics, even when employing a strict protocol such as in Chapter 7. The pre-intervention interviews as well as the post-intervention reflection, revealed the status quo, and functioned as a base-line for comparison.

The design documentation in Chapter 5 and the software allow understanding of Skin's technical functioning and allow peers to replicate the design and repeat the experiments.

8.5. Future Research and Design

Confirming the benefits of applying Skin in a development process

The explorative workshops in practice allowed identification of user needs, but in order to gain insights into the effectiveness of the solution, further studies are necessary. A large company with numerous design projects, employing a standardized design process, would allow quantitative comparison of the proposed technique to the status quo, studying the technique's effect on the latter stages, and studying its use when its as an integral part of the designer's toolbox.

Including other modalities in Skin

That Skin only allowed manipulations in the visual domain, did not prevent participants discussing how to manufacture the materials they experienced or talking about other senses. Engaging designers in iterative cycles of trial and error in other modalities would be a logical next step. In [Saakes et al, Koizumi et al. 2010] we demonstrate the first steps towards a specialized



Figure 8.1. *"Delft Blue by Me" in the Delft office for Tourism. Inspired by the Bluebrush [Section 6.8], a simplified version is on permanent exhibit at the Delft Tourist Office. Visitors can portray themselves on a Delft Blue plate and send customized digital postcards. A new version of "Delft Blue by Me" is under development for the Royal Delft store with on-the-spot manufacturing of user-created plates through transfer printing. Design in collaboration with Hoog & Diep.*

projector that can make local, non-configured shape changes in physical objects through the embedding of memory metals. Similar technologies could allow Skin to include surface relief for tactility.

Skin as a user toolkit for mass customizing

Many companies that offer customization of their products do not engage the user in a trial and error process. [von Hippel 2005]. Companies like Nike or Freitag offer websites for customization that include these trial and error processes but restrict the user to a relatively small solution space. The goal of these mass-customization efforts is not to eliminate designers' tasks, but to save costs and time on development [von Hippel 2005] and allow users to become more deeply involved with the design process [Fisher, 2002]. However, as I myself experienced myself in the introduction, von Hippel puts it: *"That wide-tire option did look great in the picture, but now that the car has been delivered, I discover that I don't like the effect on handling. Worse, I find that my car is too wide to fit into my garage."* A technique like Skin, possibly applied using the VirtualMirror technology of the Frauenhofen Henry Hertz Institute [www.virtualmirror.de], could solve these issues and in addition, expand the solution space.

A derivative of the Bluebrush: "Delft Blue by Me" [Figure 8.1] serves as an example. As a permanent exhibition for the Delft Tourist Board, "Delft Blue by Me" captures portraits of visitors on a Delft Blue plate. Additionally, the customized plate design can be sent as an e-card. A next version of "Delft Blue by Me" is in development for the Royal Delft store, featuring in-store manufacturing of user-created plates through transfer printing.

Rewritable Product Skins

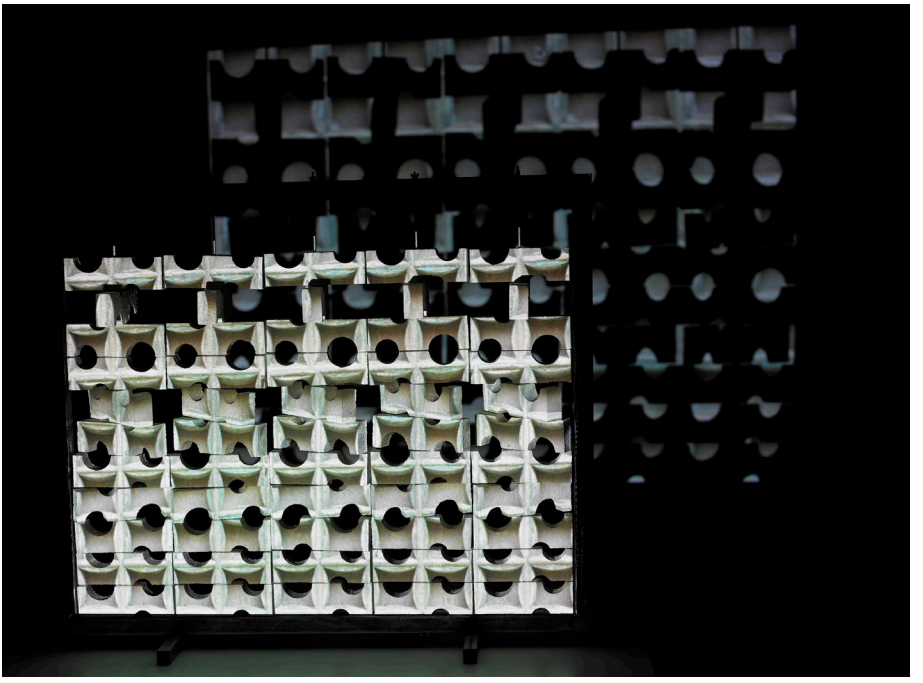


Figure 8.2. *Part of "Brick, the Exhibition" in collaboration with Christine Jetten at the Rotterdam City of Architecture 2007. After lengthy Skin sessions in which Jetten explored numerous designs, we decided on an interactive exhibition, making Skin part of the exhibition. Visitors could browse, animate and scale a select set of patterns.*

Despite any mass-customization, once a product is fabricated it cannot be undone or modified. This is unlike digital products that can be updated and changed constantly, only needing to be discarded when they are made obsolete by new technology. On various occasions during workshops, I had to tell artists that the artwork they generated with Skin was only a sketch to be filled in and detailed later. On one occasion the artist couldn't decide which pattern to choose and decided to keep the artwork interactive. [figure 8.2]

What if we could flash a skin onto products, not just a prototype, but to make it stick on the actual product, either temporarily or permanently? Temporarily, or updatable printing of skins on objects makes sense for artistic purposes, but could also bring the next level of product customization. Obviously there are after-market products to personalize items with which we can do the same, and the replaceable covers for cellphones have not become commonplace in today's market. However, with rewritable skins, changes become reversible, are effortless and therefore are more likely to be experimented with in a trial and error process that takes place during the use time of the product.

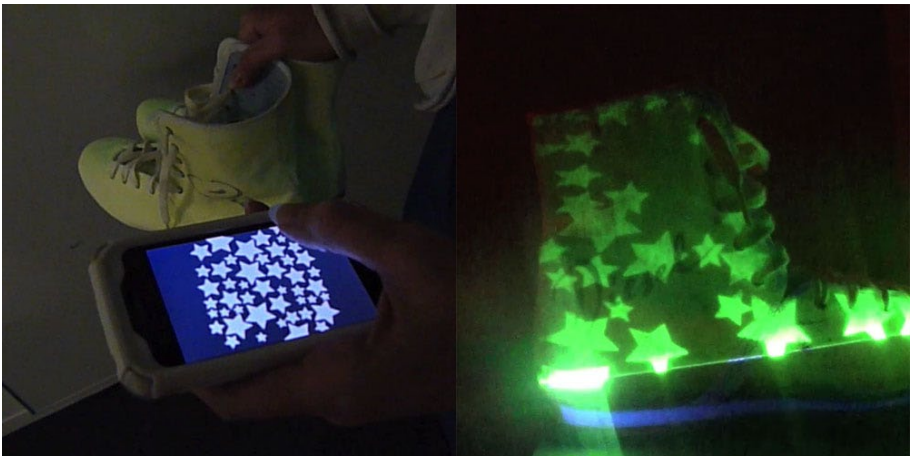
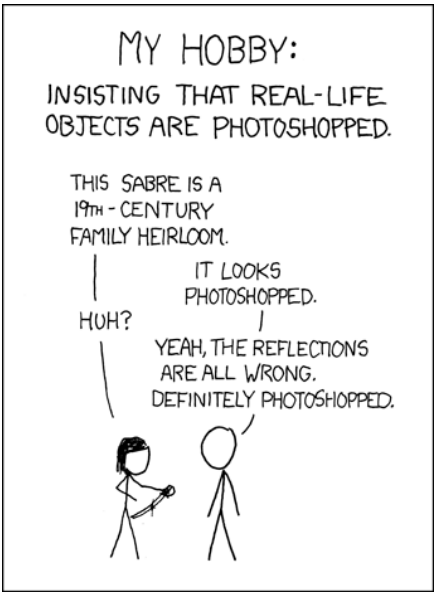


Figure 8.3. *The Slow Display is a projector display that has high resolution but a very slow frame-rate. Once objects or surfaces are written, the color change sticks for minutes, hours and potentially days.*

Initial steps are taken in the Slow Display project [Saakes et al. 2010], a rewritable projector display that is high resolution, but with a very slow frame-rate. Objects and surfaces are painted with commercially available light-reactive monostable materials. A special projector activates these materials locally in order to write designs, as shown in Figure 8.3. Once activated, the color change stays for minutes, hours and potentially days. The decay rate of today's commercially available monostable materials is currently a limiting factor in the applicability of the prototype. However, newer bi-stable materials will be able to cause a color change that stays until it is erased.



Photoshops by XKCD [http://xkcd.com/331/]

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About the Author



Daniel Saakes was born on October 11th 1973 in Bussum, the Netherlands. He studied Industrial Design Engineering at the Delft University of Technology and graduated in 2001 on story telling in virtual reality applications at the Dutch National High Performance Computing Center (SARA).

Daniel is a maker and his designs have been featured in blogs, magazines, books and are exhibited in FreeDesigndom Amsterdam, Netherlands Architecture Institute (NAi), Hangaram Design Museum in Seoul, Taiwanese Designers Week, Dutch Design Week, Ars Electronica and Siggraph Emerging Technologies. The cost effective motion capture technology he developed for kung fu toys with audio feedback, resulted in two successful startups in toy and sports industry.

In 2009 Daniel joined the Camera Culture group in MIT The Media Lab where he developed new ideas inspired by Skin. Now he is back in Delft, and enjoys the wildlife in Rotterdam City.