Selecting materials in product design

Selecting materials in product design

Thesis
Delft University of Technology,
Faculty of Industrial Design Engineering

ISBN: 978-90-5155-040-5

Subject headings:
Materials selection, product design, user-product interaction, techniques and tools

Illustrations and cover design: ir. Sytse Goverts

Editing: drs. Karen Gribling - Laird

Paranimfen: ir. Barbera Keukens, ir. Boukje Koch

ilsevankesteren@gmail.com

Selecting materials in product design

PROEFSCHRIFT

ter verkrijging van de graad van doctor

aan de Technische Universiteit Delft,

op gezag van Rector Magnificus prof. dr. ir. J.T. Fokkema,

voorzitter van het College voor Promoties,

in het openbaar te verdedigen op maandag 7 januari 2008 om 10:00 uur

door

Ilse Engel Heleen VAN KESTEREN

ingenieur industrieel ontwerpen,

geboren te Haarlem

Dit proefschrift is goedgekeurd door de promotoren:

Prof. dr. ir. J.C.M. de Bruijn

Prof. dr. P.J. Stappers

Prof. dr. P.V. Kandachar

Samenstelling promotiecommissie:

Rector Magnificus, *voorzitter*

Prof. dr. ir. J.C.M. de Bruijn, Technische Universiteit Delft, *promotor*

Prof. dr. P.J. Stappers, Technische Universiteit Delft, *promotor*

Prof. dr. P.V. Kandachar, Technische Universiteit Delft, *promotor*

Prof. K.L. Edwards, University of Derby, UK

Prof. dr. ir. I. Verpoest, Katholieke Universiteit Leuven, België

Prof. ir. B. Ninaber van Eyben, Technische Universiteit Delft

Dr. G.E. Berendsen, Dow Chemical, Terneuzen

Reservelid:

Prof. dr. P.P.M. Hekkert, Technische Universiteit Delft

‘you know that we are living in a material world
and I am a material girl’

- *Peter Brown & Robert Rans*

Table of contents

Figure 1.1
Finding an MP3 player that suits you has become complicated. Electronics stores offer an increasing number of models that differ mainly in appearance.

Chapter 1 Introduction

My favourite product is my mobile phone. Not because I am a frequent caller - I actually dislike being so available all the time – but because I like this product. I like it for the materials that it is made of. It has a high gloss red cover and a soft, mother-of-pearl, flexible inside. Every time I open my phone, I enjoy the little resistance of the spring and the feeling of the buttons. I am a user who is pleased by the considerations the designer made before he selected these specific materials for my phone. I am also a design researcher who is curious about the product designers' approaches of selecting these materials.

1.1 Pleasing users in a changing consumer market

Consumer products, such as the portable MP3 players in figure 1.1, do not only differ from other products in the way they perform, but also in the way they please users. Design researchers as well as the people involved in product development acknowledge that, in the western world, we are nearing the limits of a technology driven and marketing-pushed era . For most people, the design and exterior of products becomes the determining factor for buying it and not the newness of the technology in the product. End-users expect a product to function properly and to be easy to use. Additionally, users prefer to be emotionally touched by the product in some way. This means that not only the functional qualities of products are important but equally the qualities of the user-product interaction. Furthermore, the quality of the sensations and emotions perceived by the end-users, while using consumer products, requires special attention nowadays.

Product manufacturers increasingly need to listen to the needs of end-users and, as Gonález & Palacios (2002) put it, firms that do not attend to their customer' needs in today's highly competitive environment, will not survive. McDonagh *et al.* (2002)

1 E.g. Bonapace, 2002; Desmet, 2002; Fenech & Borg, 2006; Formosa, 2005; Jordan, 2000; Jordan & Green, 2002; Ljungberg, 2003; McDonagh *et al.*, 2002; Sanders, 2001.

explain that in this environment many products are developed by different brands with similar functionality, but different in usability and appearance. Likewise, Bloch *et al.* (2003) state that superior designs distinguishes products from competitors and help to gain recognition in a crowded marketplace. Hence, product manufacturers have started to realize that they need ways to get into the hearts and minds of their customers and optimize their designs to stay in business.

The changes in the consumer market lead to enormous challenges for the product design profession. The product categories in which consumers have a choice to use one product over another, e.g. small electronics, cars or kitchen appliances, require design approaches in which the user-product interaction takes a central position. The process in which the needs and limitations of the user of an interface or product are given extensive attention at each phase of the design process is referred to as 'user-centred design' (ISO 13407, 1999). The aim of this process is to optimize the interaction that the user can have with a product.

To be able to create products that satisfy the users' needs, product designer do not only need knowledge about the user, but also about the materials, shapes and technology available. Wallace & Burgess (1995, page 430) explain that: 'the industrial scene continues to change and modern product designers are subject to demanding pressures, including: intense international competition, rapidly changing technology, increasingly complex technical systems, rising customer expectations, shorter life cycles, greater environmental accountability; severe product liability legislation and working in large, multi disciplinary teams'. An effective product development process is indispensable to withstand these pressures; however, keeping the process effective requires continuous studies and improvements in the process. The rising expectations of the end-user, and the possibilities of applying material technology in products to match these expectations, are of particular interest in this research project.

1.2 Opportunities in materials selection

The quality of a product is highly influenced by the materials it is made from. The materials enable the product to function, to be durable, to have certain costs, to provide feedback and to give experiences among other things. As a consequence, the selection of materials plays an essential role in the design process of products (Doordan, 2003).

Materials selection in user-centred design is a relevant topic, as an effective materials selection process can help to embody the desired user-product interaction qualities. When users interact with products, the users' senses are in contact with the materials that make up those products. Users see the colours of materials, feel the texture and the weight and hear the sounds materials make when moving the object. These sensory perceptions determine the usability of the product and the experiences of the user (Hekkert, 2006). Product designers use materials to create these sensory perceptions. In addition, product designers select materials directed at eliciting certain associations. An example is the metal used in a Rolex that expresses status (Jordan, 2000). Hodgson and Harper (2004) state that materials considerations are pervasive in design, as the substance through which product designers' intentions are embodied. Likewise, Gant (2005) emphasizes that the strategic use of materials is one of the most influential ways through which product designers create deeper, more emotive connections between their products and their users.

Above mentioned aspects go beyond the technology aspects of materials and are in this thesis characterised as the user-interaction aspects of materials (figure 1.2). The technology aspects of materials are the characteristics that define how the product will be manufactured and how well it will function. The user-interaction aspects of materials are the aspects of materials that influence the usability and experiences an end-user can have with a product. For example, the transparency of a material used in a camera lens influences the image quality of a photo (technology aspects); shininess can influence how well users can read from a display, while colours work to create a personality that influences how users experience a product (user-interaction aspects). For high quality products, product designers should select materials that comprise in both aspects.

Hence, materials are considered more and more as a distinguishing factor in a successful user-interaction with a product. To facilitate the selection of materials, many material libraries are being build all over the world, such as MaterialConnexion (www.materialconnexion.com), and many design agencies have a collection of material samples in house. Furthermore, design researches, e.g. within the Design and Emotion society[2], put effort in understanding the relation between product experiences, such

Figure 1.2
Categories of aspects considered in materials selection.

as emotions, and the materials from which a product is made. However, as the field is new, hardly any models or strategies on the materials selection process include user-interaction aspects in a systematic way.

On the other hand, the technology aspects have been studied widely in materials selection and many tools and information sources are available to support materials selection based on technology (Ashby & Johnson, 2002). For example, researchers in the field of materials selection have developed models that describe and prescribe materials selection strategies (e.g. Ashby, 1999; Cornish, 1987; Farag, 1989). Their procedures consist of analytical approaches towards selecting materials and mainly involve describing the mechanical engineering field. An exception is the work of Ashby & Johnson (2002, 2003), who focus on materials selection in industrial and product design. They emphasize that materials play a role in the perception of products and thus in the user-interaction aspects. However, the balance between the materials selection techniques for the technology side and the user-interaction side in materials selection is poor. The challenge is to improve this balance with the intention that product designers are able to select materials for products with high functional *and* high user-interaction qualities.

An opportunity for improving the balance between technology and user-interaction qualities of materials is the continuous development of new materials (Dobrzanski, 2006). New materials offer designers chances for new or improved technical and

2 The Design and Emotion Society raises issues and facilitates dialogue among practitioners, researchers, and industry in order to integrate salient themes of emotional experience into the design profession (www.designandemotion.org).

Defined: Products, materials and people

Products - designed objects that have functionality, interaction possibilities and appearance, e.g. a phone, spectacles or a waiting chair

Materials - the physical substances from which products are made, e.g. plastic, metal or glass

User - the person that interacts with a product, e.g. you or me

Product designer - the person or team that develops a product from initial idea to the full sets of specifications needed for production, a person with a background in design processes, engineering and user-product interaction

Design agency - a company that develops products for external clients

Client - the person or company that employs a product designer to develop a product

Manufacturer - the person or company that fabricates products or parts

Material supplier - the person or company that develops and sells materials

Material specialist - a person with a background in material science or chemistry aesthetical behaviour (Ashby & Johnson, 2002, van Kesteren *et al.*, 2004). Furthermore, Dobrzanski (2001) explains that developments of surface technologies significantly increase the competitiveness of products. Hence, using the potential of new materials offers a chance to enhance products both with regard to technology and user-interaction aspects, but can also lead to new products and functions. On the other hand, new product requirements, for example on user-product interaction, can lead to the development of new materials.

Often there is a lengthy incubation stage between the discovery of new materials and their full exploitation in the market (Burchitz *et al.* 2005; Eager, 1995). Doordan (2003) explains that the efforts of product designers is to help match new materials into existing needs. Furthermore, he states that the appreciation of new materials depends to a large extent on consumers who shape the cultural understanding of materials. The role of the product designers in getting new materials into the market is expanding as the competitive nature of the materials industry grows. Communicating and cooperating with technologists and material suppliers in a design project is therefore expected to increase.

Ashby & Johnson (2002) outline, that the first step in improving the balance between technology and user-interaction aspects in materials selection, is exploring how product designers use materials in their design process and exploring the nature of the information that they require. The next step is to explore methods and tools that bring together the two fields. This is what this thesis intends to do.

Defined: Materials selection

Materials selection is a concept used to refer to many things. For example, it refers to a group of materials that is selected for a certain purpose. Furthermore, it can refer to a specific phase in the development of an artefact, e.g. the materials selection phase. It then indicates a certain time period in a project. The term materials selection is defined *in this thesis* as an activity:

Materials selection are the activities and steps that product designers perform and take from the moment they receive a new assignment until the materials are specified in a document that describes how a new product will be manufactured, how it will function, how it can be used and how it can be experienced.

In this definition, materials selection is referred to as the things that product designers do to reach a certain goal, which are specified materials. Elaborating on this definition, an ***effective materials selection*** is defined as:

The activities and steps that results in a materials specification that includes materials which are the best available options for not only the product's functionality but also its interaction with the user. These steps follow the shortest possible path.

1.3 Research objectives

Product designers find themselves in a field where consumers demand more of their products, where the competition between product manufacturers is fierce and where new materials become available everyday. This leads to more custom-like products as consumers wants a product with a special identity. The emphasis of the design decisions necessarily shifts away from technology, towards the user-interaction aspects, to cope with the new appreciations of consumers for the aesthetic values of materials (Abbaschian & Marshall, 2006). Product designers need to enhance their materials selection activities to include these aspects in their materials selection processes. Furthermore, the number of new materials that become available requires another approach to classifying and selecting of materials (Addington & Schodek, 2005).

In practice there is little knowledge about the effect of material choices on user-interaction aspects of products or the knowledge is not adequately adjusted to the approaches of product designers (van Kesteren, 2008; Karana *et al.*, 2008; Ashby & Johnson, 2002). Product designers are therefore unable to sufficiently predict the results of their material choices on costs and product quality in functionality and user-product interaction. Furthermore, the materials searches cannot follow the most effective path. The development time increases and it becomes more difficult to secure a competitive advantage (Wallace & Burgess, 1995).

The objectives of this research project are to explore the issues that hinder an effective materials selection process – effective in a sense that it leads to high quality products - and to improve the techniques to effectively include user-interaction aspects in this process. The underlying idea is that, with an improved materials selection process, the user-product interaction qualities of a product can be improved. The main question is therefore:

> ***Main question*** *How can product designers effectively include user-interaction aspects in their materials selection processes for user-centred design projects?*

The key questions in this thesis were answered in four main studies and address:

> ***Question 1*** *What is the theoretical role of materials selection in user-centred design?*

> ***Question 2*** *How do product designers currently select materials and what are the problems they encounter?*

> ***Question 3*** *How can product designers effectively select materials in the future?*

These questions are important to the product development field for the reason that the insight can improve the effectiveness of materials selection process and improve the qualities of products. However, although many studies have been directed at improving user-centred design and on materials selection in general, not many studies have considered the combination of these fields. New empirical and explorative studies are therefore necessary. Part of the originality of this work lies in the cross-disciplinary approach that focus on strengthening the connections between the materials field and the user-centred design field.

1.4 Thesis outline and research approach

Three main sections can be distinguished in this thesis, namely a background section, a section on analysis and a synthesis section (figure 1.3). Each of the sections copes with one of the key questions in this project. The background section deepens the understanding about the relation between user-product interaction qualities and the role and selection of materials (chapter 2) and focuses the context in which we try to improve the materials selection process (chapter 3). After this, the more detailed approach for the improved materials selection technique is explained in section 3.3.

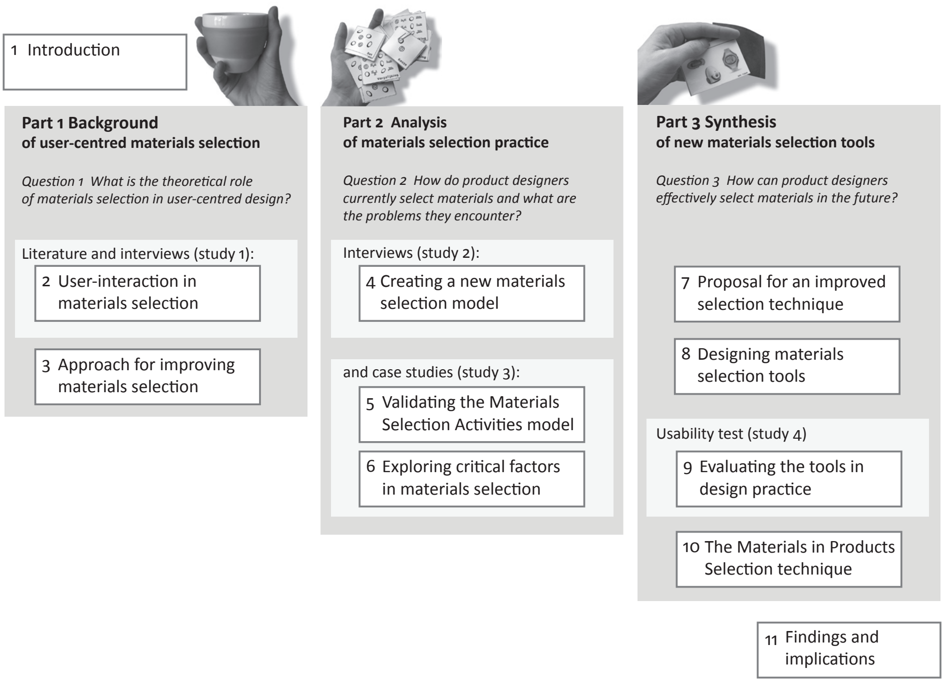


Figure 1.3
Outline of the thesis.

The current materials selection activities of product designers and the critical factors that hinder an effective process were identified and described in the analysis section (chapter 4 to 6). The proposed techniques for materials selection in the future are discussed in the synthesis section. This section starts with the outlines for an improved technique (chapter 7). After that, two chapters describe the design and evaluation of new tools that support this technique (chapter 8 and 9). Chapter 10 closes the synthesis section with the final considerations on the improved technique. It embeds the technique in other design methods and proposes a workshop to translate the results of this study into a practical answer to the objectives of this project.

Four main studies were performed in this project (figure 1.3). The first study deepens the understanding about the complexity of the user-centred materials selection process (chapter 2). The requirements for the improved materials selection technique were obtained by studying the materials selection activities of product designers. To this end, a second study was performed to create a new materials selection model based on interviews with product designers (chapter 4). In the third study, this model is validated and used to evaluate the materials selection steps in different finished user-centred design projects (chapter 5 and 6). In the synthesis part, the fourth study took place to evaluate the tools that were developed in this thesis (chapter 9).

The work in this thesis continuously relied on the input from product designers dealing with user-interaction aspects in materials selection. As the field is new, studying current practice was required to be able to generate knowledge about user-centred materials selection. Product designers were interviewed to deepen the understanding of the field and to create materials selection models. In addition, they helped to outline cases and evaluated the tools that were developed to support the improved technique.

Besides product designers, many other people provided input in this thesis, such as producers, material developers, manufacturers and academic researchers. Their input was required to understand the complex relationships that product designers maintain to select materials. Many of the decisions made in this thesis do not only rely on the results of the studies, but also rely on the input provided by these other people.

Background of user-centred materials selection

Part 1

Section 2.2 is based on:
I.E.H. van Kesteren, P.J. Stappers, P.V. Kandachar (2005) **Representing product personality in relation to materials in a product design problem.** In: Mazé R (ed). Proceedings of 'In the making': 1st Nordic design research conference, Copenhagen 2005

Section 2.3 is based on:
I.E.H. van Kesteren (2008) **Product designers' information needs in materials selection Materials & Design.** Volume 29 (1) page 133–145

Chapter 2 User-interaction aspects in materials selection

The materials a product is made of influence how users can interact with it. For example, materials with a high thermal conductivity can make kettles difficult to handle as they become hot when containing hot water, and woody materials could create a natural and pure look. Product designers use materials to increase the quality of the interaction with the product. In order to do so, it is necessary to carefully select the user-interaction aspects of materials, which are the properties that influence the use and personality of a product. As mentioned in chapter 1, these effects are becoming more important in the highly competitive consumer market. At the same time, little is known about how the user-product interaction aspects relate to the materials from which products are made and where to find information about these aspects.

This background part sets the stage for the exploratory research in this thesis. This chapter focuses on the role of materials in the user-product interaction and the decisions and information required for designing the interaction qualities of products. Chapter 3 explains the materials selection process and tools and techniques available herein.

Section 2.1 explains and defines, based on literature, the user-interaction aspects of materials. Materials selection, however, include the considerations about these aspects and the technology aspects. The theoretical relations between the different aspects considered in materials selection are therefore explored in section 2.2. To make the interrelated decisions in the materials selection process, product designers have specific information needs. These needs, as explained during interviews, are presented in section 2.3.

2.1 Materials in the user-product interaction

Materials contribute more than technical quality for products; they impact on the way users can interact with the product. In the literature, many acknowledge the significant role of materials in creating user-interaction qualities of products[1]. This section explains the user-product interaction and explains how materials contribute to the user-interaction qualities of products. Furthermore, it defines the terminology for material characteristics as used in this thesis.

User-product interaction

The user-product interaction consists of several steps that begin with coming across the artefact. Thereafter, a user senses the product, perceptually analyses it, compares it with the previous cases, classifies it into a meaningful category, and consequently interprets and appraises it (Hekkert, 2006). The user needs these interpretations and appraisals to understand how to use a product and to experience it in a certain way. Like MacDonald (2001, page 43) phrase it: 'we seek delight and reassurance through our senses that we have made the right decision and that we are embarking on the right course of action'. The experiences with products are defined as the entire set of effects that are elicited by the interaction between user and product (Hekkert, 2006). The quality of this interaction influences how easy and joyful it is to use the product and the pleasantness of the experiences.

Sensing a product is key in the interaction and is enabled by the product's appearance (its form and materials). Our senses inform us about the properties of the environment that are important for our survival (Goldstein, 2002). Similarly, senses transmit information about the properties of a product to enable interaction (Ludden *et al.*, 2004; Crilly *et al.*, 2004). Fenech & Borg (2006) emphasize that during the interaction with the material world, senses serve as a medium that gives rise to perceived sensations, which act as a stimulus for emotions. Furthermore, visual and tactile properties of products strongly contribute to the first overall quality judgement of a consumer (Giboreau *et al.*, 2001, Sonneveld, 2004). Hence, the sensorial aspects of materials highly influence the user-product interaction.

The simplified representation of the user-product interaction in figure 2.1 shows that the product is sensed via its materials, which can be considered as the product's interface (Rognoli & Levi, 2004). This sensing results in an understanding of the product. Two aspects are distinguished in this understanding, which are firstly, the understanding of the use ('this is a button') and secondly, the understanding of the product personality ('luxurious feeling'). The product personality is defined as the set of product characteristics that creates the experiences the user might have while interacting with the product.

Although material properties activate the senses similarly for different people, the perception and pleasure attained from sensorial stimuli is not the same (Adank &

---

1 E.g. Arabe, 2004; Cupchik, 1999; Ferrante *et al.*, 2000; Gant, 2005; Karana *et al.*, 2008; Lefteri, 2001 - 2004, 2005; Ljungberg & Edwards, 2003; MacDonald, 2001; McDonagh *et al.*, 2002; Rognoli & Levi, 2004; Wastiels *et al.*, 2007; Zuo *et al.*, 2005.

2 Double Income, No Kids Yet.

Warell, 2006). It is influenced by contextual factors such as previous memories and experiences, expectations and skills, cultural and social values (e.g. such as explained by MacDonald, 2001). This means that the materials used in a product stimulate the user's senses in a somehow predicable way, but the perceptions, associations and emotions following the sensory interaction are much more person dependent and therefore difficult to predict. However, when the contextual factors are alike – in, for example, a group of 'dinky's'[2], living in an urban area in the Netherlands, in the 21 century, graduated from a technical university - the product experiences are somewhat similar. For this reason, product designers have to use their experience, together with expertise from market researchers and end-users to predict and evaluate the user-interaction qualities with a product for predefined target groups.

Materials and user-interaction qualities

Several studies and examples can be found that investigated the relation between materials and user-interaction qualities of products and how users appraise materials. In the textile field, for example, studies try to classify the visual and touch dimensions of different textiles (cf. Giboreau *et al.*, 2001) and even the sound dimensions (Ui *et al.*, 2002). Giboreau *et al.* (2001) note that instrumental machines have been available since the 1970s, that were to use physical objective means (compression, bending, extension, shear) to predict sensory dimensions (dry, thick, rough, warm) for textiles (e.g. the Kawabata Evaluation Structure). These machines combine the sensory perceptions of a test panel with the objective measurements.

In another example, Zuo *et al.* (2001, 2004a) try to find relations between texture and emotions of materials. They found a relation between smoothness of a material and

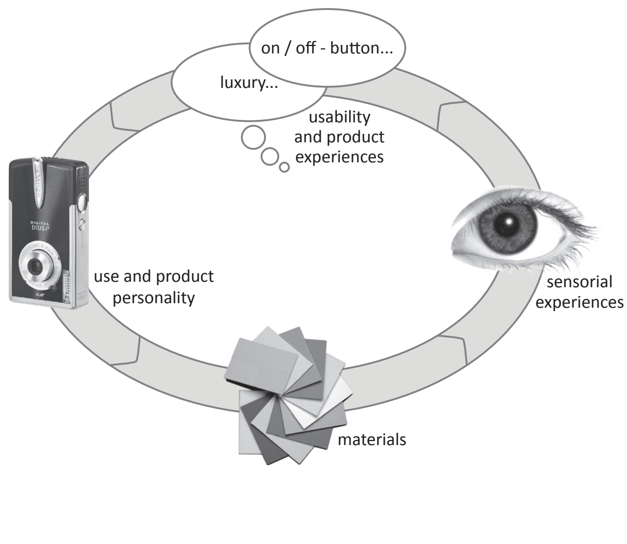


Figure 2.1
The role of materials in the user-product interaction.

positive emotions such as lively, modern, elegant and comfortable. Roughness evoked negative emotional responses such as depressing, traditional, ugly and uncomfortable. Furthermore, MacDonald (1999) and Manzini (1989) explain the relation between the weight of a product and the perception of quality. People are used to associate a certain weight with a certain product and when this differs, the sense of quality is different.

An example of a study that investigates how people appraise materials is the study of Karana & van Kesteren (2006). We studied to what extent people take materials into consideration when describing the qualities of products. The results of this study show that people only mention materials when they are specifically asked to describe a product that they selected on the criteria that they liked or disliked its materials. When describing their favourite product, materials did not appear in their descriptions. Furthermore we found that while describing the materials of products, people concentrated on labelling the materials, the physical characteristics of materials and on the sensorial characteristics of materials. Picard *et al.* (2003) had similar results about the vocabulary that people use to describe tactile aspects of the materials of a car seat. Hence, people are able to recognize the materials from which a product is made, but do not use that to explain the user-interaction qualities of it.

Sonneveld (2007) found, in a blindfolded test, that people try to identify the materials a product is made of first when asked to describe the tactile experiences with a product. Furthermore, Klatzky & Lederman (1995) found that tactile aspects of a product enable people to recognize products even at a haptic glance. Hence, it seems that people need to perceive the materials to form a judgement about the user-product interaction, but evaluate it as a combination of product characteristics in relation to its functioning and experiencing. Wastiels at al. (2007) found a similar result with architects who do not think in terms of materials, but rather in terms of the experience they want to create and the attributes needed for that. The words that architects use for describing materials and spaces are similar e.g. friendly materials and friendly rooms.

The examples described above show that the relation between materials and the user-interaction qualities is a relevant research topic. However, some fields are studied more extensively (e.g. textiles) than others (e.g. influence of materials on the usability). Anyhow, the studies demonstrate that materials influence the sensorial interaction with a product and thereby influence the use and experiences. Therefore, it can be reasoned that there is a relation between the materials used and the user-interaction qualities of a product.

Definitions of material characteristics used in this thesis

Materials are the substance from which products are made and influence the user-product interaction with its characteristics. Various descriptions can be used to classify these characteristics and the ones that are used in this thesis are described hereafter. A distinction is made between the properties of materials and aspects of materials (table 2.1).

Table 2.1
Definitions of material descriptions used in this thesis.

Materials properties	
Physical	All quantifiable characteristics of materials, like strength, density, conductivity
Sensorial	All characteristics of materials that can be perceived by the human senses. For example, tactile aspects like smooth, cold, or visual aspects like matt, translucent, shininess and colour. Sensorial properties have physical equivalents
User-interaction aspects of materials	
Use	Aspects related to use and ergonomics, such as weight, cleanability and slipperiness
Personality	
Perceptive	Aspects related to what we think about materials after sensing and the meaning we attribute to materials, like aggressive, pretty, modern and secure
Associative	Associations are defined by Ashby & Johnson (2003) as the things a product reminds you of, the things a product suggests. The associative parameters require the retrieval from memory and past experiences and finding the things a particular material brings to mind; such as the association of the early Celluloid billiard balls with ivory
Emotional	Aspects of materials that focus on the subjective feelings (Desmet, 2002) e.g. “It makes me feel comfortable” or “this material surprises me”

The term ‘materials properties’ is used for measurable characteristics of materials such as transparency and roughness. The materials can have these properties, even when they are not processed into a product. The term ‘aspects of materials’ is used for characteristics that are related to the materials’ responses once processed into a product and used. For example, the manufacturing aspects of a material explain which techniques can be used to shape the material and the user-interaction aspects of materials are defined as the characteristics of a material that contribute to how a person can interact with a product.

Two kinds of material properties are distinguished, which are the ‘physical properties’ and the ‘sensorial properties’. Both properties lead to different clustering of materials. The physical properties are categorized as mechanical, electrical, thermal, chemical and optical properties (Ashby, 1999). Clustering materials based on the sensorial properties leads to groups that have the same visual and tactile characteristics, but do not automatically include the same materials. For example, the material ceramic groups closely to aluminium because neither can be transparent (Johnson *et al.*, 2002).

The user-interaction aspects of materials are of interest in this thesis and are divided in ‘use’ and ‘personality’ aspects of materials. The ‘use aspects’ are related to the functional use of the product, such as the shininess of a display. The ‘personality aspects’ of materials enables the experiences that user can have with the product. The term personality is thus used as a characteristic of an object and the term experiences as the responses to those characteristics. The definitions of Ashby & Johnson (2003, page 28) are followed in this: ‘Personality of a product is created by the material’s aesthetics (colour, form, feel, etc.), its associations (the things it suggests), and the way it is perceived (the emotions it generates in an observer)'.

Use aspects of materials
The functional use of a product can be influenced via the sensorial properties of the materials used in a product. To enable an end-user to use a product easily, it often has some visual or tactile clues about where to activate a functionality of the product. When more functions are present, these clues can indicate the different activators. A simple example is a remote control or calculator. Different flexibility properties are used for the materials of the casing and the buttons and different colours indicate the different functions that can be activated with a button. Furthermore, sound properties of materials are important for the feedback in use. Imagine a keyboard of your computer without the auditory feedback when typing. It probably slows down your typing speed. Even in the simplest products, for example a cup, sensorial properties influence the interaction. A cup made of flexible materials makes it a challenge to hold the cup without spilling fluids.

Personality aspects of materials
Ashby & Johnson (2002, 2003) state that materials, as a separate characteristic, contribute to the experiences a user can have with the product. One material can have different personalities depending on the product is it used for. For example, plastics used in food packaging looks cheap, environmentally unfriendly and disposable, while used in an I-Mac computer it looks cared for, trendy, expensive and happy. But materials also have a personality of their own, which make them suitable for certain applications. For example, wool has a warm and nature like personality which makes it suitable for winter clothing and cosy carpets. Some materials are closely related to certain design styles, such as plastics with the Pop Art style. Sonneveld (2004) explains that materials can contribute to the creation of this personality, as materials properties are often used to characterize people, for example weak, strong, hard, soft, flexible, rigid. Likewise, product personality can be characterized by the physical properties of the applied materials.

2.2 Materials, user-product interaction and other decisions in materials selection

The user-interaction aspects of materials are not the only aspects considered in materials selection. There are many more, such as costs, shape, environment, use and function. Product designers use considerations about these and other aspects to guide them in creating a product form, but not by considering them one by one. Many of the aspects interact, which makes designing a balancing act between different aspects.

The aim of the exploration presented in this section is to come to an integrated model that shows the materials – user-product interaction relation embedded in the relations that materials have with other elements in materials selection. Therefore, different key elements were derived from design methodologies. The integrated model was made to provide insight in the complexity of the relations of the elements in materials selection.

Design decisions in current design methodologies

The design methodologists that will be discussed in this section have formulated models to make the topics of consideration in a design project comprehensible. The models show the topics and relate these, e.g. function, form and use. Attention for user-interaction aspects of materials is relatively new, so not all methodologists include use and personality in their models. However, many include considerations of materials. For example, Ashby has studied the interaction between materials, making, shape and function (Ashby, 1999). Shercliff & Lovatt (2001) developed an approach for process selection that deals with the complexity of considering materials, design and manufacturing processes. Ljungberg (2003) stresses that production methods, function, user demands, design, total price and environmental aspects are important criteria in the selection of a material. It is assumed that the materials – user-interaction relation can be combined with the known materials relations to other elements in design.

Ashby (1999) describes the design process as an introduction to a methodology for selecting materials. According to Ashby, the starting point for a design project is function, which dictates the choice of materials and shape. Shape includes both the external shape (macro-shape) and the internal shape (e.g. honeycombs). Manufacturing processes give materials their shape, but are influenced by the choice of materials e.g. their weldability or machinability. These four elements: function, shape, materials and manufacturing processes interact. Ashby terms these interactions as the central problem of materials selection.

Ashby (1999) does not mention a 'use' element in his model. This can be a result of the focus on mechanical design in contrast to product design, where users play a larger role. But there are more aspects that Ashby does not include, such as cost price, environmental issues or life in service. Pugh (1991) defines a checklist for aspects that need consideration when specifying a product design. This checklist contains 32 aspects for product designing and is referred to by Pugh as the product design specification (PDS). Pugh (1991) does mention aspects in the PDS that concern the user, namely 'aesthetics', 'ergonomics' and 'customer', but only in broad outlines. Some of the aspects of product personality are covered by the 'aesthetics, appearance and finishing' aspects. Table 2.2 compares these aspects to the elements defined by Ashby and shows that all aspects fit in Ashby's model. Although Ashby does not include a use element, his elements cover the aspects that concern the user.

Roozenburg & Eekels (1995) describe the design process and the role of materials in this process. They give two conditions for a product to function. Firstly, the product-form (both shape and materials) and secondly, the way a product can be used. When designing for these conditions, product designers reason in the opposite direction:

Table 2.2
Combination of the four elements of Ashby (1999) and the aspects of Pugh's Product Design Specification (1991). Many aspects of the specification influence considerations on more than one design element. Aesthetics, Ergonomics and Customer are related to the user, but are only broadly described by Pugh.

Elements by Ashby	Aspects of the Product Design Specification of Pugh
Function, Materials, Shape, Manufacturing process	Product life span, Quantity, Safety, Testing, Environment, Packing, Competition
Materials, Shape, Manufacturing process	Performance, Life in service, Documentation, Standards & specifications, Legal, Patents, Quality reliability, Product costs, Disposal
Materials, Shape	Installation, ***Aesthetics***, Maintenance, Weight
Function, Shape	***Ergonomics***, Market constraints, Politics, ***Customer***
Materials, Manufacturing process	Company constraints
Materials	Materials
Shape	Shipping, Size
Manufacturing process	Manufacturing facility, Processes
None	Shelf life storage, Time scale

based on a needed function they design form and use in such a way that when the user utilizes the product as defined in the prescription of use the needed function is realized. Product designers choose the form and the way of use based on the required functions. A product form is made via the manufacturing processes by making changes to materials until the designed product form is reached. For example, milling the product will give it its shape and e.g. hardening processes its material form. During manufacturing, the shape of an object goes hand in hand with its materials: changes in one result in (small) changes in the other, although mostly these changes are not aimed at simultaneously. Roozenburg & Eekels (1995) define this as the core of the design problem. The elements they define as being part of the design problem are thus function, use and product form (both shape and materials).

According to Ashby & Johnson (2002) consumers do not only expect the products to function properly, but also to be usable and to have a personality that is attractive for consumers. Materials are initially given two roles by them, namely materials make products function technically and they create a product personality. They state that balancing between use, function and product personality is key to innovative product design.

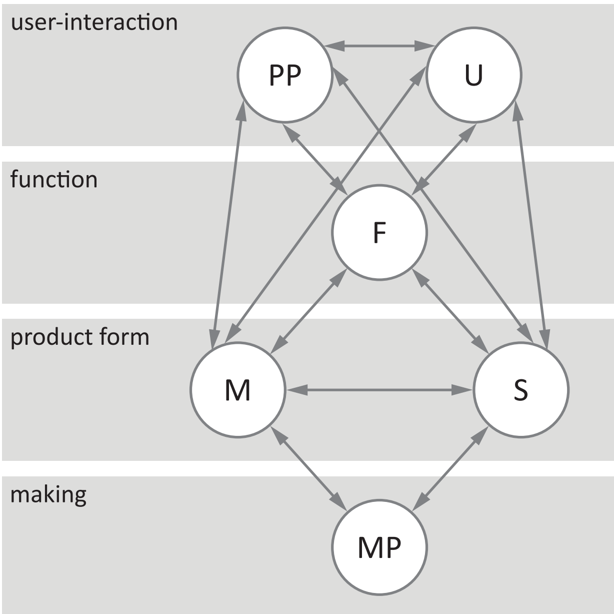
The following elements were derived from the above relations: product personality (PP), function (F), use (U), material characteristics (M), shape (S) and manufacturing process (MP). These elements are taken as the main elements for the decisions in the materials selection process in product design.

Combined model of considerations in materials selection

In figure 2.2, the interactions between the design elements that were found in the studied methodologies are summarized in a model termed the Materials Selection Considerations (MSC) model. This model shows the different topics that are considered within the project boundaries in a materials selection process. The result of these considerations is a material choice for a new product.

The interaction of function, materials, shape and manufacturing processes was adapted from Asbhy (1999). The interaction of function, product personality and use was taken from Ashby & Johnson (2002), as was the interaction of materials, product personality and use. From Roozenburg & Eekels (1995), the interaction of use, function, materials and shape was adapted.

The MSC model shows that almost all decisions are influenced by other decisions. The only exception is the manufacturing process, which interacts with product form (materials and shape) which in turn interacts with function and the user-interaction considerations. The product form thus has an intermediate role between manufacturing and the elements in function and user-interaction in this model. This implicates that the creation of a product form includes the consideration of all the other elements in the model, which makes it the most complex task of the design process.



considerations in the materials selection process on:

PP product personality
F function
U use
M material characteristics
S shape
MP manufacturing processes

Figure 2.2
The Materials Selection Considerations (MSC) model. This model shows the relations between the considerations made in the materials selection process.

Table 2.3
Examples in the Materials Selection Considerations (MSC) model. For every relation between two elements a product example is given (No. 1 to 12). Pictures were taken from various Internet catalogues.

1. Product Personality & Function

Party shoes have a festive look while running shoes look sportive and comfortable

2. Product Personality & Use

Serious cassette players have another use and interface than funny and childlike ones

3. Use & Function

Use and interface differ for a basic calculator and an advanced calculator with graph-function

4. Product Personality & Materials

Transparent and rubbery materials for a sportive look and metallic for a classy

5. Use & Materials

ABS gives hard keys in contrast to the soft flexible keys of a keyboard made of ElekTex™

6. Product Personality & Shape

A luxurious watch has a different shape to a novelty watch

7. Use & Shape

The shape of these volume controls require another way of using it (pressing or rotating)

8. Function & Materials

Packaging for microwave ovens needs other materials (polyethylene) than for salads (polystyrene)

9. Function & Shape

A bottle with all-purpose cleaner requires another shape than a bottle with toilet cleaner

10. Materials & Manufacturing Processes

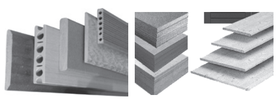
Plastics are processed here by injection moulding and metals by sheet forming

11. Materials & Shape

Materials (plastic, metal) cause a different shape of this dish drainer

12. Shape & Manufacturing Processes

Extrusion of wood gives another shape than sawing and milling of wood



In order to clarify the relation between the materials selection decisions an illustration of each interaction is given in table 2.3. The comparison of two products that differ on the elements in the specific interaction, and are similar on the other elements, illustrates these interactions. For example, for the products that illustrate the interaction of use and shape, the other elements were kept the same, by choosing two volume control buttons (same function) that are made of the same materials (plastics), made by similar manufacturing processes and have a similar personality (table 2.3, No. 7). It was not always possible to find examples that differed in two elements only, simply, because the elements interact, not with just one other element, but with several. As a consequence, some of the examples illustrate the interaction of two elements, but also differ on the other elements e.g. the dish drainers which are not only different in shape and materials, but also in manufacturing (table 2.3, No. 11). Not finding examples that differed on only two aspects illustrates that the elements interact and that creating these products requires balancing the materials selection decisions within these interactions.

Discussion

The many relations between design considerations, makes the materials selection process very complex. This model can therefore aid product designers, especially those who are learning the skills of designing, to gain insight in their considerations in the materials selection process and how these considerations interact. The product examples contribute to understanding the complexity, by helping to visualise the results of the interaction between two elements. In addition, these examples show the impact of playing with the elements, for example how playing with material characteristics can contribute to product personality.

It may be argued that representing only six elements that are considered in materials selection is too limited. For example, costs, marketing and sustainability, to name a few, are additional important elements in a design project and influence the decisions on materials. For that reason, Pugh (1991) explains a larger number of design aspects. However, visualizing the interaction of the decisions about these aspects would result in a very complicated model. Besides, as illustrated with the comparison of Ashby's model (1999) and Pugh's aspects of the product design specifications (1991) in table 2.2, one view does not exclude the other. The costs aspect, for example, can be explained within the MSC model as follows. Firstly, costs can be considered as a project boundary, e.g. the marketing value that the product should have. This means that the considerations in a materials selection process are made within these boundaries. Hence, a material choice resulting from the considerations on the six topics is evaluated on the consequences for the objectives on costs and value. A concrete example is the LG Chocolate phone[3], which derives its marketing value from the considerations about how the materials create the 'chocolate personality'. Secondly,

3 Chocolate by LG, Bluetooth music phone (us.lge.com/chocolate).

the costs of a product is determined by its material costs, manufacturing costs, handling costs, retail costs, and so on. These different costs aspects are considered within the different topics. For example, the material costs are considered as one of the material characteristics and hence considered within the 'material characteristics' element. Likewise, the manufacturing costs are considered, within the 'manufacturing processes' element, in relation with the 'product form' elements.

Ashby (1999) uses his model, showing the relations between materials, process, shape and function, as a starting point for materials selection. Dependent on the design project, the materials selection process starts with one or more elements, e.g. a combination of materials and shape. The MSC model can also be used in this way: the product designer can pick a few elements to start with and then fill in the others. For example, Muller (2001) describes how the appearance of the designed product is based on the product designer's knowledge about possibilities and restrictions of materials and processes and the knowledge about spatial characteristics of shapes in relation to the intention for use. Designing is thus in a way combining the knowledge about different design elements. How product designers gain this knowledge is explained in the following section, which explores the information needs of product designers.

2.3 Information for the materials selection decisions

Only recently, the materials information society ASM International (www.asminternational.org) acknowledged that industrial product designers are a new audience for the materials information society. They recognize that product designers have special information needs regarding tactile and aesthetic values of materials (in: Abbaschian & Marshall, 2006).

Product designers use various ways to access information and use different information sources to acquaint themselves with the material characteristics of candidate materials (Beiter *et al.*, 1993; Fidel & Green, 2004; Karana *et al.*, 2008; Ferrante *et al.*, 2000). Information seeking is a part of decision making and problem solving and used to reduce uncertainty about a relevant topic for the problem (Rouse & Rouse, 1984). Product designers can fully apply the extensive possibilities of current and new materials to improve the qualities of their designs if these sources suit their information needs (Baya & Leifer, 1996; Young, 2003; Martini-Vvedensky, 1985).

In order to explore what sources product designers use to support the decisions they need to make in the materials selection process, they were interviewed. The purpose was to understand their information needs concerning the content of the information and its accessibility. An overview of the information sources that product designers currently use and their information needs based on these interviews are given in this section.

Table 2.4
Information sources used in materials selection. The complete table is presented in appendix 1.

1 Material applications	2 Independent sources	3 Materials on supply
Experience Knowledge of the client, colleagues and experts, experience from former projects	**Databases, search engines** In-company databases, general available databases (e.g. CAMPUS Plastics), commercial databases (e.g. IDEMAT, Cambridge Engineering Selector), search engines (e.g. Google), trade guides (e.g. yellow pages)	**In person** Customer advisor of material supplier or manufacturer, company visits
Testing Knowledge institutions (e.g. Universities), finite elements calculations, experimenting for choosing materials, testing for verifying choice	**Sample collections** Samples from former projects (e.g. Tech Box www.ideo.com), commercial sample collections (e.g. Material ConneXion www.materialconnexion.com, Materia www.materia.nl)	**On-line** Internet information of supplier, databases, data sheets
Example products Inspiration from shopping, competition products, proven technology, tradeshows (e.g. Milan international furniture show), magazines about design topics (e.g. i-D Magazine: www.idonline.com)	**Books, exhibitions** Books for inspiration (e.g. Lefteri series (2001-2004)), Exhibitions (e.g. Materials Skills www.materia.nl), seminars organized by material federations	**Samples, brochures** Send on request or as advertisements (e.g. a sample box www.plexiglas-magic.com, newsletters)
		Tradeshows, magazines Presentation of materials suppliers on plastic fairs, magazines (e.g. Materials Today from Elsevier www.materialstoday.com)

Currently used information sources

A series of interviews with product designers lead to a list of currently used information sources. Thirteen product designers from design agencies, production companies and engineering agencies were interviewed[4]. Their design experience ranged from 1 to 13 years with a mean of 5 years of experience. The reason for selecting these interviewees was to maximize the input of commonly used information sources. The information sources mentioned in an interview were discussed in the next interview to verify whether the next interviewee also used this source. Therefore, it was possible to make a complete list of mostly used sources. Therefore, appointing a frequency of use was not possible. However, it is recognized that product designers, with differences in experiences and differences in working situation, may use some sources more frequently than others.

The information related topics discussed in the interviews were: What information sources are used during materials selection? How satisfying and useful is the information provided about materials and how is the information found? At the end of the interviews, we discussed how the interviewees keep up with new developments in the material and process technology areas.

The interviewees mentioned dozens of information sources, which are categorized in the different source types shown in table 2.4 and appendix 1. The categorization

4 The thirteen product designers were interviewed both for this study and the one presented in chapter 4.

into types was based on the source from which the information originated, e.g. from example products or from Internet. An important distinction was made between information about materials applied in a product and information about characteristics of raw materials or semi-finished products. Broadly speaking, information in the ‘general materials application’ category is gained by assessing materials in existing products or models. In the other categories, information obtained from standardized materials tests and experiments. Information about materials characteristics derives from independent sources, such as handbooks in the ‘independent sources’ category or from suppliers in the ‘materials on supply’ category.

General materials application
The interviewees stressed that, although materials are tested for their properties, it is hard to predict how materials will react when processed into a designed shape. The same holds for the circumstances to which a product is subjected in during its life cycle. However, for guaranteeing the reliability and durability of the product, product designers need to be able to predict the behaviour of the materials in their design. Therefore, product designers use information about applied materials from different sources, such as company experience, testing and example products.

In the majority of the design projects it is sufficient to utilize existing materials that are used in other products. Especially the product designers that are working in a production company are to work with the materials available in the company. In these companies the information about the standard used materials is largely available. Product designers from design agencies need to access more sources to get the same information. They use both the knowledge about materials gained during previous projects as the knowledge from their client’s former projects when available.

Independent sources
The independent sources are helpful for the first rough selections. Soon after this, product designers switch over to information that includes the availability of materials. The younger interviewees used more general information sources that the more experienced product designers. More complicated decisions, especially during the embodied and details design stages, were made by more experienced colleagues. Young product designers remembered that they used general material selection software during their education, but in the visited companies, this software was not available. Most product designers, regardless of their working environment or experience, mentioned to use general information beyond the concrete question in a project, for example, for educational purposes or for inspiring current and future projects.

Materials on supply
Instead of starting with all options, such is the case when using a database with materials, the interviewees start their materials selection with a small number of options that is selected based on experience and thereby limiting their options.

Materials suppliers and representatives are contacted to asses these options on availability, costs and properties. Design offices often have a few suppliers they work with, but also the client has often contacts with a selection of suppliers. Material suppliers are related to businesses that provide information for their own commercial interests. In some cases, the interviewees found this a drawback because the suppliers did not want to advice about materials other than their own. However, in other cases product designers and suppliers or manufacturers combined their interests and developed parts together.

In summary, there exist many types of information sources related to materials that are used by product designers. In every design project, several of these sources were used. The sources reflect on what is important in information about materials, namely information about availability, about application in products and for inspiration.

Product designers' information needs

The discussions with the product designers resulted in four themes that represent the way they require to access information and the content of the information they need. These are 'compare', 'multiple detail levels', 'product related aspects' and 'material samples' themes (figure 2.3).

Compare

Product designers compare different materials to find optimal candidate materials for their products. In order to be able to make comparisons, they need information about several materials and they need this information to be presented in similar formats. In general databases and in databases from a single company, materials are presented in a similar format. However, comparing materials from different companies is more complicated. The material data that companies present differ. An interviewee

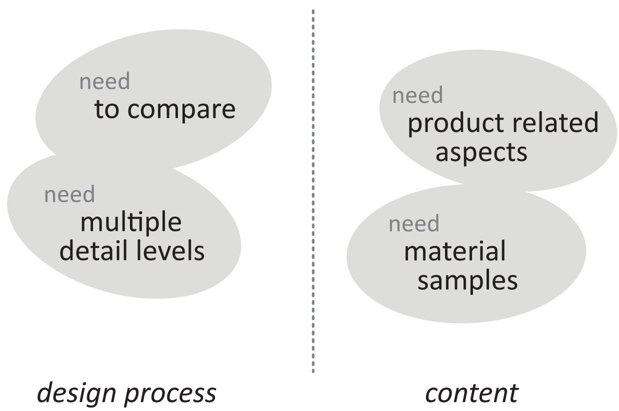


Figure 2.3
Four themes on product designers' needs for information about materials.

explained that some suppliers show their best test results. Therefore, their materials come out best in comparisons. Showing the best results however, has drawbacks. If the materials perform slightly less well than predicted by the best test results, they may cause reliability problems. Therefore, other companies are more moderate and show mean test results. A concrete example mentioned during the interviews was the influence of shrinkage of materials on the mould geometry. If shrinkage is different than expected, the moulds need to be adjusted. Due to the different test results that are presented by the materials suppliers, product designers have difficulties with interpreting comparisons of materials. As a consequence, product designers have frequent contact with different suppliers, which is cost consuming for both parties.

Multiple detail levels

In the design process, materials information is needed in each phase and the nature of the information differs greatly in the different phases. This is described by Ashby & Johnson (2002) and Fidel & Green (2004) and equally found during the interviews. In early phases, product designers make preliminary decisions about materials based on just a few parameters. In the detailed design phases they assess the suitability of these materials in depth to be able to make the final decisions. The material objectives and constraints are formulated in different terminology and details by the product designers. For example, in early phases they use general and qualitative search parameters like stiff and transparent. Books with pictures of materials can be very inspiring during this phase, but these are unsuitable for later phases if more detail is required. Later product designers use more specific and quantitative search parameters like a stiffness value and a transparency percentage. Data sheets that present all material properties of specific material types are suitable in this phase. However, these data sheets are unusable in early design phases. Hence, information about materials should be presented in a way that suits the level of detail that is required in different phases (Baya and Leifer, 1996).

Tech Box

The international design agency IDEO has a well-known collection of material samples and technologies named Tech Box (Kelley, 2002). The Tech Box is a large cupboard with drawers full of samples that is placed in a central place in the companies. Every sample (about 360 in total) has a name, a place to store and a number, which is used to search a database from a computer on top of the cupboard or on the agency’s intranet. For every item the specifications are listed including manufacturer, prize and an anecdote by the designers that used the sample in a project. “The Tech Box is mostly used as a spark for brainstorms when designers bring the demo samples into a group meeting”. The samples increase the flow during a brainstorm. They show the strength of a material and what its look and feel is.

Information gathered during a visit of the London department of IDEO on August 31st, 2004
Information about the Tech Box on: www.ideo.com/portfolio/re.asp?x=50035, accessed 18-07-2007

Product related aspects

Product designers need to assess how the materials perform in a product throughout all aspects of a life cycle. However, they mention problems related to product issues with current information sources. Materials are tested with standard experiments to identify their parameters. In these tests, temperature, humidity and stress are standardized, but in real life these factors change during the lifespan of the product, which influences material performances. Products are manufactured, transported, stored, sold, used, disposed and recycled and all processes have specific influences on materials. As a result, for a reliable selection, product designers need information about how materials perform under these circumstances. Data sheets that only provide information based on standard tests are therefore not sufficient. Product designers, together with manufacturers and suppliers, try to predict how materials behave during the lifespan by lab experiments and finite elements calculations of the concept products. Furthermore, they seek for information in existing products. The materials used in these products have proven their performance or show the limitations of materials if they show imperfections. Product designers use this information to focus their materials searches. Furthermore, they use experience from former projects, test materials in products and assess existing products to deal with the lack of product related information about materials.

Material samples

Product designers use material samples to consider how materials of a product will influence the senses of the user. They therefore explore material samples with their own senses. Product designers come across samples via material suppliers or via organized collections. Material suppliers produce customized samples to demonstrate, for example, different colours, shapes and visual effects, but also offer standard combinations. Samples are not only useful for visual aspects, but also for tactile perceptions such as the roughness or flexibility, and even for auditory aspects such as the sound materials make. The product designers mentioned that the problem with material samples is that they have high production costs. Materials suppliers are not eager to send samples to people that are not a potential client for them. Small design agencies have trouble with ordering samples because they do not order large numbers of materials. These are mostly ordered by the client of the design agency.

There are initiatives of collections where designers can browse through material samples such as Material ConneXion (www.materialconnexion.com) or Materia (www.materia.nl) and some design agencies have a material collection in house. Product designers thus rely on material samples for inspiration and communication, especially about non-technology parameters such as sensorial and personality aspects.

The themes that were found in the interviews indicate what is needed in materials selection. Literature sources that discuss materials selection issues also raise these themes. For example, Ashby *et al.* (2004, page 53) recommend that selection tools should ‘allow this iterative procedure and accommodate a range of databases appropriate to the various stages of the design' (multiple detail levels-theme). Furthermore, Ullman (2002) explains that a support system should communicate information in the format, level of abstraction, and level of detail needed. Martini-Vvedensky (1985) mentions that product designers compare data taken from different sources (comparison theme). Many sources mention the relation between materials and manufacturing aspects[5]. However, other product related aspects are not mentioned extensively. In addition, only a few sources mention that product designers need material samples to find information about sensorial properties (e.g. Ashby & Johnson, 2002).

In conclusion, product designers need information about materials that is adjusted to their design approaches. Information about materials that can be compared to other materials, is usable in different design phases (multiple detail levels), contains information about materials related to product issues and, in addition, shows a material sample, is expected to be best adjusted to the selection process and considerations of product designers.

2.4 Conclusions

The role of materials in the user-product interaction is via the interface it gives to products. This interface is perceived by the senses and thereafter translated into actions of use and experiences such as associations and emotions. The sensorial properties of materials influence this sensorial interaction and thereby partly create the use possibilities and personality of a product. Product designers can use materials to increase the user-interaction qualities of products by considering how the sensorial properties influence the use and personality of a product; however, other aspects need to be considered too. Considerations on these aspects, which are shape, function and manufacturing process, and the before mentioned materials, use and personality, interact, which makes materials selection a complex task. To make decisions about these aspects product designers use various information sources, mainly to inform about the way materials can be applied, which materials are available and to get inspiration from independent sources, such as materials samples collections. Product designers have specific needs for the information sources to be able to compare material options on the different design aspects they need to consider. Furthermore, they need information that is adequate in different design phases and is physical, such as material samples.

5 E.g. Ashby, 1999; Ashby and Johnson, 2002; Ashby *et al.* 2004; Beiter *et al.*, 1993; Dobrazanski, 2001; Martini-Vvedensky, 1985; Shercliff and Lovatt, 2001; Ullman 2002.

Chapter 3 A user-centred approach for improving materials selection

In the previous chapter the role of materials in the user-product interaction and the complexity of the materials decisions have been explained. Understanding the relations between materials, products and end-users helps to increase the positioning of user-interaction aspects in the materials selection process, but does not explain how to deal with it. Therefore, it is needed to understand the process of creating products and the process of materials selection in this. This chapter describes design and materials selection methodologies and the techniques and tools that are available for product designers.

Although the fields of product design and materials selection explain their angles to the other field, hardly any techniques are available for the integration of user-interaction aspects in materials selection. However, as will be explained at the end of this chapter, it is expected that improvements can be made in this. Therefore, this chapter continues with outlining the approach that is followed in this thesis to develop such a user-centred materials selection technique.

3.1 Design process, techniques and tools

The user's role in designing has increased. Sanders (2001) states that experts from biological and social sciences have infiltrated to serve the design process to enlarge product designers' understanding of the user's interactions with products. The practice of design started to include physical and cognitive ergonomics, shifted towards social aspects and emotions and might even include the dreams of users in the future (Sanders, 2001). To understand the people who will interact with the new products, it is crucial to include all these aspects. Sleeswijk Visser *et al.* (2005) stress that especially in the creative phases of the design process, understanding the end-user's experiences is of great value for product designers. Likewise, Janhager (2005) points out that there is a need for design methods that support the synthesis activity in early product development phases and take end-user aspects into consideration.

Design approach, techniques and tools

An ***approach*** describes the means to reach a goal on the highest level. For example, the aim is to make successful products. A particular approach can be to make many different products and hope that one is successful. Alternatively, one could follow a user-centred design approach to understand the user's needs in successful products and by that means try to predict the success of the product.

A ***technique*** describes the sequence of possible steps taken in an approach. For example, in a user-centred design approach, a technique can be to involve end-users in the design phase (e.g. using a focus group technique or brainstorming) or to do usability testing. More techniques can be followed in an approach.

A ***tool*** is an aid in a certain technique. For example, a pencil is a tool for sketching, a checklist is a tool for interviews and a database is a tool for information storage and retrieval. More tools can be useful in a technique.

This section explains the product design process and the means that are available to understand the future users of products.

Product design process

The product design process does not start from scratch, but is guided by a rough idea or requirements for a new product. Especially when product designers work for clients, this rough idea is communicated at the start of a project, in a textual document, by phone or during a first meeting with a client. This rough idea is termed a design brief, and contains the requirements, intentions and wishes for a new product and the needs this product will fulfil, what the intended end-users are and how it will be used (Pasman, 2003).

Based on the design briefs, product designers develop new products, taking several aspects into account (such as for example explained in section 2.2). Because of the variety of aspects, a systematic approach is indispensable (Roozenburg & Eekels, 1995). In product design methodology, systematic approaches are proposed for engineering and product design[1]. These approaches prescribe design tasks and steps to achieve optimal product specifications in which materials are also specified. Most approaches have an iterative character.

According to Roozenburg & Eekels (1995), products are designed to fulfil a certain need e.g. an end-user or a salesman. Product designers translate these needs into functions, for which they make a product form (characterized by its shape and its materials). Hence, product designers thus reason from function to product form in a sequence of design phases. A frequently used sequence is shown in figure 3.1 (left)

1 E.g. Cross, 2000; Hubka and Eder, 1992; Pahl and Beitz, 1996; Pugh, 1991; Roozenburg and Eekels, 1995; Wright, 1998.

and consists of 'clarification of the task', 'concept', 'embodiment' and 'detail' phases as described by Pahl & Beitz (1996).

During the clarification of a task, designers define the task as fully and clearly as possible although not to a full end. Lawson (1994) explains that product designers come to understand their design problems through their attempts to solve them. Important questions, for both product designers and clients, in the clarifying phase are: what is the problem really about, what wishes and expectations are involved and what paths are open for developments. In the concept phase, product designers create the principle of a solution. One of the interviewed product designers explained that a concept design specification does not contain unsolvable difficulties; for every sub-problem a solution is given. During the embodiment phase more and more detail is given to more and more characteristics of the product (Roozenburg & Eekels, 1995). While during the concept phase, rough choices in the material and manufacturing technologies can be made, during the embodiment phase the materials and technologies are chosen for all parts of the product with a much higher precision. In the detailed design phase the final choices are made. All arrangements, forms, dimensions, materials and surface properties of all the parts are laid down in the 'specification of production' (Pahl & Beitz, 1996).

The three design phases - concept, embodiment and detail - organize the design activities according to the number of design problems that are solved and the details are known about the solution. The solution space decreases and changes in the course of action become more drastic once entering the detailing phases.

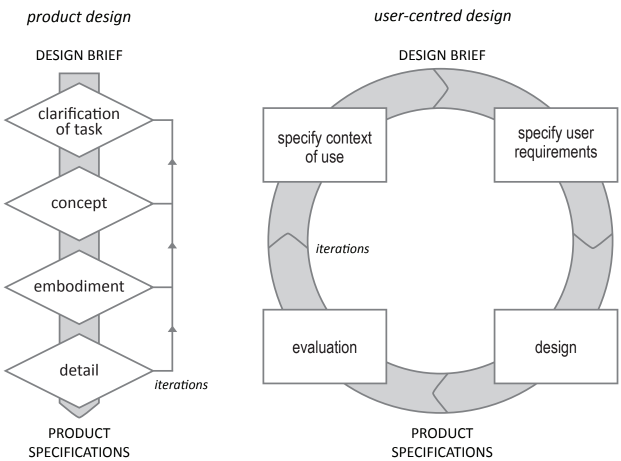


Figure 3.1
Examples of the design sequences performed by product designers in a design project as described in design methodologies (e.g. Pahl & Beitz, 1996, left) and user-centred design (e.g. iso13407:1999, right).

In user-centred design, the phases are organized slightly different, namely in ‘design’ phases, in which designs and prototypes are produced, and in ‘evaluation’ phases, in which user-based assessment of the designs are carried out (ISO 13407, 1999). Furthermore, user-centred design specifies the ‘clarification of the task’ phase more explicitly as ‘understanding and specifying the context of use’ and the ‘requirements of the user’. These phases occur on different detail levels in a cyclic manner (figure 3.1, right).

In user-centred design, the end-user is involved when needed and possible. Bonapace (2002) explains that focusing attention on user issues in the user-centred design cycle is critical to the quality of the product. User tests produce fresh information that helps to define the design and the needs for the next development stage. Popular techniques to involve the users are focus groups (for understanding the context of use), questionnaires and interviews (for requirements and evaluations), usability testing (in the design and evaluation activities) and participatory design (in the design activity) (Webcredible, 2006).

Design techniques and tools

To facilitate their designing, product designers utilize a wide variety of design tools, ranging from sophisticated computerized information support systems such as CAD systems to inexpensive memory aids such as pencil and paper (Love, 2003). Design tools enable product designers to structure and formalize parts of their design steps (Jangager, 2005). Fulton Suri & Marsh (2000) state that product designers want to have as much inspiration about the user as possible in the conceptual design phases of a project, to ensure that their efforts are directed appropriately. It is no longer acceptable to simply evaluate what others design and produce, but product designers need tools that support the exploring, prototyping and communicating of user-interaction aspects of new products.

Many generative design tools exist, for example, for co-designing. To understand the user’s experiences with product use, they are stimulated to make drawings and collages to express experiences and to discuss them together (Sanders, 2000; Sleeswijk Visser *et al.*, 2005). The results of these sessions are often presented to a research audience instead of a designer audience and Sleeswijk Visser is developing tools to involve product designers in the user-experiences data. They argue that in order to make such tools successful, it should engage the product designer in the user studies. Furthermore, the tool should inspire the designer to actually use the data.

Other design techniques encourage the communication between different persons involved in the product development process. For example, Kleinsmann (2006) explains that adding a moderator that focuses the decision process to a conversation can prevent leaps and loops. Task of such a moderator are to structure the design process (to fill the need for a structural approach) and structuring the content (by creating shared mental models). She explains that product designers use mood boards after and during these conversations.

Mood boards support communication and expression beyond linguistic restrictions about e.g. emotions (McDonagh *et al.*, 2002). Mood boards consist of a collection of abstract or literal visual images. They are typically made after a design brief meeting to make a personal interpretation about the discussed product requirements. Drawbacks of mood boards are that they rely on subjective interpretation and are often misunderstood by inexperienced users (McDonagh *et al.*, 2002).

Another approach to enhance the design process is to offer product designers examples from previously designed products. Subsystems and parts that have been proved to be successful in past designs can improve the quality of new products and the effectiveness in product design (Amen & Vomacka, 2001). For example, Shahin *et al.* (1999) developed such a reuse system in which product concepts, solution concepts, embodiment and detailed designs are stored. Pasman & Stappers (2001) focus on the concept phase with 'ProductWorld', a system that helps product designers to form and apply a collection of product samples. The input module of this system is primarily based on visual assessments to enable product designers to have a loose and exploratory dialogue between them and the system.

More and more tools are developed and used to understand the end-user's needs and to integrate these needs in the design process, however, only a few examples could be presented in this thesis. Understanding the end-user is becoming more important in these techniques. The existence of the wide variety of techniques and tools, expresses that the design process is characterised by the creative use of these.

3.2 Materials selection process, techniques and tools

Gutteridge & Waterman (1986) use an illustrative description of the aim of materials selection: 'the identification of materials, which after appropriate manufacturing operations, will have the dimensions, shape and properties necessary for the product or component to demonstrate its required function at the lowest costs' (in: Sapuan, 2001, page 687). The description shows that it is necessary to have a foresight about how a material will behave once processed into a product when selecting materials. Before ending up in a product, materials are undergoing many processes, that all influence the behaviour, such as shaping, joining, hardening or surfacing. Selecting materials is thus more than just picking a material from a catalogue and requires a thoughtful approach.

Materials selection process

Many researchers in the field of materials selection focus on analytical approaches toward selecting materials and are mainly based on materials selection in mechanical engineering (e.g. Ashby, 1999; Farag, 1989; Cornish, 1987). An analytical approach generally uses a set of objectives and constraints that are compared with the properties of a set of existing materials. Materials that match are then selected. For example, Dobrzanski (2001) explains that after defining the requirements for a new product, these requirements are compared with extensive materials databases for a preliminary selection of a number of materials that might be applicable. These materials, acquired from a trade network, are then tested in the particular product. These materials selection approaches are suitable for the majority of the design projects in which it is sufficient to select materials from the materials available on the market.

Selecting materials is more than matching requirements with candidate materials. Doordan (2003) explains that materials are not just a given to be incorporated in the design process, but are part of the design problem. The analytical approaches are therefore less suitable to describe the materials selection process of product designers. Furthermore, they do not often include user-interaction aspects. One example of a description of the materials selection process in product design is that of Ashby & Johnson (2002).

Ashby & Johnson (2002) identify four materials selection methods, all using different strategies and all having their own information needs. These are the 'analysis', 'synthesis', 'similarity' and 'inspiration' method. These methods can be used separately, but 'the most effective path exploits the most useful features of each' (Ashby & Johnson, 2002, page 130). In the 'analysis' method, a list of product requirements is

Strategies for designing a sensorial interaction

Designing a sensorial interaction involves selecting adequate sensorial properties of materials. Understanding which manipulations of the senses contribute to experiences is important to be able to create this experience (van Kesteren & Ludden, 2005). A possible strategy for product designers to design experiences for a product is to see how every single sense can be stimulated in such a way that the perception contributes to the desired experiences (Ludden & van Kesteren, 2006). In this, they should be aware that selecting a material based on its tactile value has consequences for the visual appearance of a product.

When interacting with a product, the different senses get input signals that are used to form a product experience. Hekkert (2006) explains that people tend to prefer products that convey similar messages through the different senses. In line with this, he argues that the sensorial impressions should also be appropriate for the particular product. Product designers could thus try to make the sensorial interaction through the different senses matching the intended product experiences.

The experience can be influenced by creating a similar input per sense or by deliberately giving the senses different inputs. For example, in the cosmetic industry the packaging of the product tries to give the same message through all senses (Ludden & van Kesteren, 2006). Colour, roughness, softness and smell are all harmonized. Different inputs through the senses, for example a high gloss transparent ball (looks like glass) which is flexible might elicit a surprise effect that makes the product more interesting to interact with (Ludden, 2008).

translated into material objectives and constraints and then a database of materials is screened. This method requires information about characteristics of available materials. In the 'synthesis' method, product requirements are translated into required features and then a database of products is explored. The method exploits the knowledge of other solved problems. The method requires information about previous materials solutions.

If product requirements are not a starting point for selecting materials, the 'similarity' method can be used. For an established material, an attribute profile is generated that is used to find materials solutions closely related to the established one. Like the analysis method, information is needed about characteristics of available materials. Creative thinking fuels the last method identified by Ashby & Johnson: 'inspiration'. A database with materials is combined with a database of products and new matches are generated almost by a random walk.

Materials selection techniques and tools

Literature sources presenting tools for materials selection mainly focus on computerized materials databases (e.g. Beiter *et al.*, 1993; Martini-Vvedensky, 1985). Databases can provide quick and appropriate access to state-of-the-art materials and enable the compatibility of candidate materials to be evaluated when adequately designed (Beiter *et al.*, 1993). The advantages of databases are that the same data can be accessed via multiple ways and that data can be presented on different detail levels. For example, CAMPUS (www.campusplastics.com) combines general information with information from suppliers.

Cambridge Engineering Selector (CES) is a well known computer system developed by Ashby and co-workers at both Granta Design and Cambridge University Engineering Department. Ashby and Cebon (2007) explain that the selection of materials has four basic steps 1) translating the design requirements as constraints and objectives, 2) screen the material world to find materials that cannot do the job, 3) rank the materials that can do the job best and 4) explore the top rated materials. CES supports the second and third step herein by presenting the material world in a comparable way, showing property charts containing all materials and enable finding optimal materials for certain property combinations.

The databases that are developed differ in the kind of information they present and the intelligence of the search options they provide. In some databases, sensorial properties are presented (e.g. www.materialexplorer.com), some provide good practices guide (e.g. McMahon & Pitt, 1995), while other databases focus on manufacturing aspects (e.g. CES). Intelligent databases enable its user to combine different requirements for example, via a dialogue with the system (e.g. Smith *et al.* 2003), via a decision matrix (Shanian & Savadogo, 2006) or with a case base reasoning system with flexible retrieval of its content (Mejasson, 2001).

A large disadvantage of databases is that you need to know what you are looking for.

They require search entries that are in the worst case the exact properties needed of the materials in the end product. Especially in the early phases of the design project, this information is irrelevant and designers need other tools than databases to support their materials selection process such as physical materials or example products such is outlined in section 2.3.

To support product designers with physical materials, several initiatives organize exhibitions, collections and libraries of materials. For example, the agency Inventables helps companies to innovate by showing the newest technology and materials in an inspiring manner (www.inventables.com). Another commercial example of collections of materials are 'Material ConneXion', being the world's leading knowledge base for information about new and innovative materials (www.materialconnection.com). They combine a physical database in several places in the world with a database accessible for members and consulting services. The number of local material inspiration centres is increasing, such as 'Materia', in Enter and the 'Materialenbibliotheek' in Eindhoven, both in the Netherlands (www.materia.com, www.materialenbibliotheek.nl) and in Paris, France, 'Innovatheque' is situated (www.innovathequectba.com). Furthermore, universities and academies offer material collections and support to designers. Examples are the 'Technotheek' of Poelman (2005) or the 'Material biblioteket' in Stockholm, Sweden (www.materialbiblioteket.se).

Above examples of tools and techniques in materials selection are mainly about providing information in a useful and inspiring way. Information is important in the materials selection process as it supports the product designer to make well-informed choices (Cornish, 1987). However, these tools enable an individual search, while in the design activity, more people are involved in the selection process. A materials selection tool that makes it possible to explore material ideas in teams is Skin, being developed by Saakes (2007)

The purpose of Skin is to explore whether it is possible to bring considerations of colour and texture of materials earlier in the design process to enhance a richer idea generation (Saakes, 2007). Skin is a prototype that projects materials, colours and textures on white or light coloured objects. These objects can be foam models created to evaluate the shape of a new product. Skin enables product designers to digitally explore materials, colours and graphics on physical models. The tool proved to foster creativity and sharing ideas when it was used in a workshop with packaging designers (Saakes, 2007).

3.3 Development approach for an improved technique

There are plenty of materials selection techniques available that are meant to increase the effectiveness in the process, however, there is little effort spent on supporting the identification of materials in the early stages of design (Deng & Edwards, 2005). In these early stages the user-interaction qualities can be determined, but product

Table 3.1
Products can be new in function, use or personality.

New function	New use	New personality	Combination of all
			
Dolphin saver by Cuckoo company. A floater that makes scary noises to be put on a fishing net to chase dolphins	iPod by Apple. All the input for the interaction is given by the thumb on one multifunctional button	Bathroom products by N|P|K for HEMA. The transparent blue and semi-transparent white plastics give these products its personality	Wireless hand-held device by IDEO for Lufthansa. New function, new use and new personality (and even newly used materials: Corian™)

designers are not well supported in the complex material decisions they have to make in these stages. In addition, the decision to include new materials in the selection process, and thereby including the opportunity to increase the interaction qualities of the new product, can be made in the early stages. New materials selection techniques, specifically developed to integrate user-interaction aspects in materials selection in the early design stages, are expected to optimize this process. In the rest of this thesis, such a technique will be developed.

The approach in this development resembles user-centred design, which means that understanding the materials selection context and critical factors in the current materials selection process are key steps in the development. This understanding is created via the studies presented in the analysis section of this thesis. In the synthesis section thereafter, the technique will be designed and evaluated.

Analyze part: clarifying the context and requirements

The first step in the user-centred design approach is to clarify the context in which improvements are aimed for, thereafter, the critical factors in this context can be identified and the requirements for the improvements identified.

Clarifying the materials selection context

The target group for the technique are product designers working in design agencies, being the persons that bring the functionality and user-product interaction into a new product. They combine their engineering knowledge with their knowledge about industrial design in different projects. These product designers work for ‘clients’ that have a certain need for a new product for which a materials search is needed (table

3.1). These product designers are expected to have the possibility to implement the improved techniques that are developed in this project, because they benefit from the possible time savings, structure and improved communication provided by these techniques.

Wood (1997) states, that when the understanding of the potential users' work and context is transferred into a descriptive model, this model can be used to guide further design activities. Several materials selection models were explained from a theoretical point of view in this chapter, however, to fully understand the context in which product designers select materials, a new descriptive model, based on design practice is necessary. The creation of such a model was therefore the first step in clarifying the context. This descriptive model was to match the materials selection activities that product designers perform and its creation is based on interviews with 13 product designers (chapter 4). The model is thereafter evaluated in 15 design projects outlined by the product designers that performed the materials selection steps in the projects (chapter 5).

Understanding the requirements of product designers

The descriptive model explains the context in which improvements are aimed for and forms a structure for the exploration of the problems that product designers are experiencing when including user-interaction aspects in their materials selection activities. Fifteen product designers explained the materials selection techniques they use and the problems they experience (chapter 6). Based on these problems, critical factors can be identified that decrease the effectiveness in the materials selection process. These critical factors form the requirements for the improved technique.

The requirements for the techniques are not only based on the result of design practice, but include some general objectives. Pasman (2003) formulated several considerations for designing an environment to support early phases in the design process, based on a contextual inquiry of the form-creation phase of product designers. According to him, such an environment should support the rapid and rough capturing of ideas such as done with sketches in the early phases. The environment of the product designer is scattered with information such as newspaper articles, material samples, sketches, and is highly personalized. This information is mainly visual and Pasman explains that these precedent designs embody the design knowledge which the designer seems to transfer to his own unique design solution. Further considerations are the designers' activity of communicating ideas to other people, and easily shifting between activities and projects in a highly individualistic style. Furthermore, Baya & Leifer (1996) explain that there is a need for developing tools, methods and technology which integrates smoothly with the design process and supports information managements without being cumbersome to use. Therefore, general starting points for the technique are that they fit well in the current approaches of product designers as described above.

Synthesis part: designing and evaluating techniques and tools

The technique developed in this thesis tries to give an answer on the critical factors that were found in the analysis phase. In chapter 7, the critical factors are summarized and the outline for the improved technique is given. The technique is accompanied by tools that aim at supporting product designers to use the technique. These tools are designed and evaluated in the steps explained hereafter.

Design

The tools were designed in several iterative steps of which the main considerations and results are explained in chapter 8. The sequence of these steps was 1) idea generation, 2) conceptualization, 3) evaluation of the usability and 4) detailing. In the idea generation step ideas for tools were generated that were expected to fulfil the aims in the improved technique and harmonize with the current techniques and tools of product designers. The ideas were developed together with design students into the concept versions of the tools. These versions were tested by product designers and students in a fictitious situation to be able to improve them on usability issues (achievements, ease of use). In the detailing step these improvements were made.

After the evaluation study, which is explained hereafter, the last revisions for the tools were made (chapter 10). Furthermore, the technique is fine-tuned in this chapter.

Evaluation

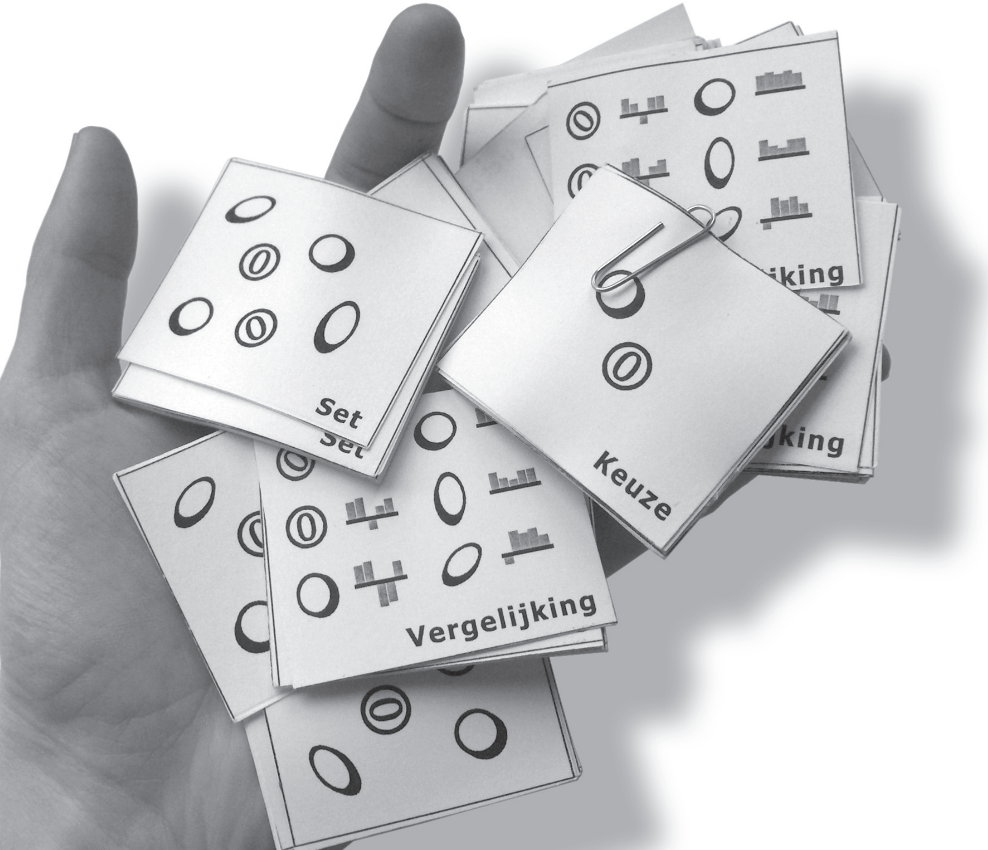
A thorough exploration of the materials selection context, and the critical factors in the process, helps to predict how the effectiveness can be improved in this process. However, evaluation of the assumptions made in the creation of these improvements is necessary to verify whether they indeed increase the effectiveness. Hence, the aim of the evaluation step in this thesis is to see whether the tools function as designed and what influence they have on the effectiveness in materials selection. In this step, four product designers used the tools in their own ongoing projects. They were therefore able to evaluate the effect of the tools compared to projects in which they did not use the tools. These results are valuable for the fine-tuning of the proposed technique.

3.4 Conclusions

The product design and materials selection processes are well studied and various techniques are being developed to support product designers. However, for the specific aims in this project, which is the inclusion of user-interaction aspects in the materials selection process, hardly any examples were found. As a consequence, product designers are not supported in their complex decision making in the materials selection process for high quality products. Therefore, the challenge is to improve this by analysing product designers' problems and develop new techniques and tools for user-centred materials selection.

Analysis of materials selection practice

Part 2



Chapter 4 is based on:
I.E.H. van Kesteren, P.V. Kandachar and P.J. Stappers (2007) **Activities in Selecting Materials from the Perspective of Product Designers.** International Journal of Design Engineering. Vol. 1 (1) page 83-103

And:
I.E.H. van Kesteren, P.V. Kandachar, P.J. Stappers (2006) **Activities in selecting materials by product designers.** In: Su, D, Zhu, S (eds.) Proceedings of the International Conference on Advanced Design and Manufacture 8th-10th January 2006, Harbin, China, ADMEC, UK, page 145-150

Chapter 4 | Creating a model for materials selection activities

The first step in the development of an improved materials selection technique is to understand the current approaches and the difficulties experienced by product designers when using these approaches. Several models exist to describe the materials selection process. However, in the previous chapter is explained that, to find difficulties in the materials selection activities of product designers, a model that describes these activities is needed. Existing models do not include user-interaction aspects or emphasise the results of the activities, rather than the activities themselves. Therefore, this chapter describes the empirical study that resulted in a new materials selection model. This model is validated in chapter 5 and used to find critical factors in the materials selection process in chapter 6.

The objectives of this study were to systematically describe materials selection approaches of product designers and to organize them into a model of materials selection activities. Although the literature covers both product development and materials selection, Stempfle & Badke-Schaub (2002, page 474) state that the systematic approaches of methodologists '...often neglected to look at what people actually do – simply prescribing a methodology may not meet the needs of a designer 'out there'.' An empirical approach was used instead, to be able to describe the activities as realistically as possible.

4.1 Interview method

Thirteen product designers were interviewed to create the model[1]. The interviews were semi-structured, using a list of key questions that covered the main topics of interest. This approach left room for discussions and more focused questions from both the researcher and the product designer (Wood, 1997). The following topics were discussed: the design process in practice with a focus on materials and the materials selection process and the role of information sources in the materials selection process

1 The thirteen product designers were interviewed both for this study and the one presented in section 2.3.

Table 4.1
Topics and questions used in the interviews.

Topics	Key questions
Design process	What are the design phases you normally follow? What aspects are mentioned in the design assignment? What is the role of requirements in the design project?
Materials in the design process	In which of the design phases are material decisions involved? How do you make a material selection? How are materials defined in the different phases?
Information in the materials selection process	Which information sources do you use? How available is the information, what can be changed?

(table 4.1). Recording devices were not used to encourage the product designers to speak freely about their projects and about product examples. Each interview session took between one and one and half hours.

Participants

The product designers were selected as participants based on their educational background in product development and jobs as professional designers. Three had studied at a design academy, two had studied product development in professional institutes and eight had studied industrial design engineering at a university of technology.

The respondents all held different kinds of jobs, although all were involved in product development at the company at which they worked. This was done to get input from different working situations and to maximize the references to materials selection activities. Although the aim was not to compare different working situations, it was expected that selecting these participants would result in a more complete overview of materials selection activities than when interviewing product designers who were all roughly engaged in the same type of work.

The participants worked for design agencies (#=6), production companies (#=3), one-man studios (#=2), a multinational (#=1) and an engineering office (#=1). The participant's working experience ranged from 1 to 13 years, with a mean of 5 years. They were all Dutch. Examples of products they worked on ranged from: business gifts, paint dispensers, a chair lift and a tanning bed, to packaging, bicycles, baby buggies, bathroom accessories, a mail box, beer crates, photocopiers and furniture.

Interviewing product designers with a wide range of design experience was expected to lead to a broad overview of materials selection activities. Young product designers were expected to be knowledgeable about their activities and therefore able to discuss them during an interview. Experienced product designers were expected to be familiar with activities that the younger designers could or did not yet perform (such as the examples found by Ahmed *et al.* (2003) e.g. being aware of the reasons for selecting options or being able to question data from a source).

Data analysis

The notes made during the interviews were screened for occasions in which the participants mentioned a task or a piece of work (e.g. drawing, consulting a colleague, negotiating with a client). All instances were written down on small cards to make a set of unique activities cards. These cards contained a short description of the activity, how often this activity was mentioned in the interviews and, when applicable, how materials were involved in this activity. The cards were grouped into categories of similar product development activities and ordered based on our experience in design methodologies. For those categories in which aspects of materials selection were mentioned a category of materials selection activities was formed.

4.2 Activities in materials selection

The product designers brought up a total of 134 activities resulting in 109 unique activity cards (table 4.2). Only a small number of the activities was found identical throughout the interviews, indicating that every project has its own activities. Out of these 109 cards, 63 explicitly mentioned materials. The cards that did not mention materials described activities in general terms, e.g. 'defining the project', 'making visual models'. Although the product designers may be expected to consider materials during these activities, they were not explicitly doing so. For the model, only the 63 cards that explicitly mentioned materials were used.

The variety of the activities indicates that choosing materials is not a purely analytical process, but rather an iterative design cycle in itself. The materials selection approaches of product designers seem to resemble iterative design approaches. The results were grouped into 'basic', 'supportive', 'general' and 'detailed' activities. In the following, the basic and supportive activities in materials selection are discussed as they are related to a design project. The other explanations can be found in van Kesteren *et al.* (2006)

Four basic activities

Activity 1: formulating material objectives and constraints (criteria activity)
At the start of a design project the emphasis is on setting the solution boundaries or requirements for the product that is to be designed. These requirements are translated into materials objectives and constraints or criteria. Formulating material criteria is an activity that is performed during all design phases and they become clearer and more complete throughout the project. Hence, they do not come about at once, but are often changed and detailed. As a consequence, formulating criteria holds a central place in the iterative design process.

Table 4.2
Activities that were derived from the interviews and the number of cards that were found per activity.
N_D Number of design activity cards
N_U Number of unique design activity cards
N_M Number of material activity cards

			N_D	N_U	N_M
Basic activities					
1	setting solution boundaries formulating material objectives and constraints	*criteria activity*	12	8	6
2	creating solutions making a set of candidate materials	*set activity*	27	24	13
3	comparing solutions comparing candidate materials	*comparing activity*	4	3	2
4	choosing solutions choosing candidate materials	*choosing activity*	8	8	6
Supportive activities					
5	testing solutions testing materials	*testing activity*	18	13	17
6	gathering information gathering material information	*information activity*	16	14	6
7	cooperating and consulting material cooperating and consulting	*consulting activity*	12	8	5
General activities					
8	giving advice		1	1	1
9	keeping informed		11	8	7
10	controlling business processes		7	7	2
Detailed activity					
11	designing parts		18	15	8
		Total	**134**	**109**	**63**

The objectives and constraints are used as a starting point for creating a set of candidate materials, to compare and choose materials, but also to find information about materials.

Activity 2: making a set of candidate materials (set activity)

During this activity product designers obtain a set of candidate materials from all available materials that fit the design objectives and constraints. Although thousands of materials are available, a set of candidate materials do not contain thousands of options, not even in the early design phases. The sets made by the product designers often contained some 3 to 4 options, a number considered adequate by the product designers to make efficient comparisons. As a consequence, a set contains general labels of materials, such as plastic, wood or metal in the early design phases, and these subsequently become more refined, specifying alloys or types of plastics. During this activity, the number of candidate materials is increased.

Activity 3: comparing candidate materials (comparing activity)
Product designers use two subsequent activities to narrow down the number of candidate materials. During the comparing activity, product designers establish the suitability of different candidate materials. During the choosing activity product designers decide, based on the evaluated materials, to continue with a reduced number of candidate materials.

Candidate materials are compared with two aims. The first aim is to evaluate the materials within the context of other aspects such as shape and usability. For example, evaluating the appearance of a product includes evaluating the materials. The second aim is to evaluate whether the materials fulfil a particular criterion, e.g. impact-resistance or adhesion of a coating.

Note that the result of the comparing activity is not always visible. Although comparing methods are available (e.g. Pugh, 1981; Harris, 1961), the product designers did not mention using them when selecting materials. They relied on their experiences.

Activity 4: choosing candidate materials (choosing activity)
After the different candidate materials have been evaluated, a choice of candidates qualifying for further investigation or a choice for a new investigation can be made. The decision to continue with particular candidate materials is often taken together with the client of the project. This activity thus reduces the number of candidate materials and clarifies whether the material objectives and constraints are still accurate enough for the next steps in the materials selection process.

Three supportive activities

In addition to the basic activities, three supporting activities were found. These are ‘testing materials’ (testing activity), ‘gathering material information’ (information activity) and ‘material cooperating and consulting’ (consulting activity) (table 4.2). The supportive activities are performed when product designers need additional knowledge to carry out a basic materials selection activity. For example, product designers may not know the current price of raw materials and request this information in order to be able to compare the costs of candidate materials.

During the parts of the interviews where the product development process was discussed, only the client was mentioned as an external party. During the discussions about materials selection more stakeholders came forward, namely material suppliers, manufacturers, engineers and materials experts (see section 1.2 for an explanation of these stakeholders). These information providers are involved in the design process, providing up-to-date knowledge about the availability of materials, their price and whether or not the materials offer what is needed in the product.

Consulting information providers about materials is therefore an essential step in the materials selection process. Product designers can fully assess the appropriateness of the candidate materials in respect of function, manufacturing and user-product interaction, only after consultation has taken place.

Activity 5: testing materials (testing activity)
Prototypes are made at various design stages to test the product as a whole or to test parts of the product. Testing is carried out with the help of simulations (e.g. with finite element calculations), physically with three-dimensional prototypes, or with two-dimensional presentations. Some product designers mentioned that making prototypes is a fixed part of the design process they offer to clients. At one design agency, they make a sequence of models starting with visual models in which the appearance and consumer preferences are tested. It is followed by functional models in which working principles are tested and technical models in which details for production are considered.

Although materials developers test their materials on performances (e.g. chemical resistance, durability and yield strength), information about specific performance during the life cycle of the product is lacking. Therefore, product designers, together with manufacturers, use prototypes to test candidate materials in the product. They verify whether the materials perform as expected when processed and shaped in the specified geometry. The product designers also test material samples ordered from suppliers.

In visual models, materials are evaluated in combination with colour, form and shape details. Therefore, this materials selection activity is termed as 'testing materials' rather than testing candidate materials. This definition includes the separate testing of candidate materials, which seem to refer only to functional aspects of materials, as well as the integrated testing of materials in relation to form, colour and shape details.

Activity 6: gathering information about materials (information activity)
Product designers frequently mentioned the role of information in their design process. The activity of gathering information is performed on various topics, but always to reduce uncertainty about a specific aspect of the product. During the first steps of the design process, information is gathered about rival products and existing solutions (reversed engineering). Some product designers mentioned that they literally 'shopped' to find products featuring similar facets of the design problem they are facing.

At the start of a design project, the client prepares a design brief together with the product designer. During the project, however, the objectives and constraints gradually become more specified. To do this, product designers need additional information about the client's project requirements. Furthermore, product designers gather information about topics such as legal issues, toxic materials and other environmental aspects.

To make a set of candidate materials from the numerous available materials, product designers gather information about materials. The clients provide information about aspects such as manufacturing aspects or legal issues. Other information sources that are used when selecting materials are the Internet, supplier manuals, catalogues or experts. Materials suppliers are an important source for materials information in several phases of the design phase (see also section 2.3).

In the first phases, product designers use information that materials suppliers have available on Internet or in databases. Later, when more specific information is required, data sheets are used. These are sometimes directly available on-line, but more often need to be requested from the supplier. In the last phases, product designers need information about candidate materials that is specific for the proposed geometry and manufacturing. Product designers visit materials suppliers or manufacturers to gather this information. Even after the design phase has finished, material choices can be made, for example by manufacturers who propose cheaper materials than the ones selected by the product designers.

The above information needs are mainly about technical performances and manufacturability of materials. In addition, product designers need information about the visual and tactile aspects of materials. Therefore, they order material samples from suppliers, or find examples of materials in existing products. The product designers indicated that they value product examples in which materials are used to the extreme, e.g. silicon baking forms, very highly.

Activity 7: cooperating and consulting about materials (consulting activity)
An activity closely related to gathering information is the activity of cooperating with and consulting experts. There are two main differences. This last activity always involves a number of people, compared to the information activity, in which no personal contact is required. Another difference is that consulting means that the other party must find answers to a multifaceted problem with integrated design considerations. Often, an optimal solution has to be found within conflicting objectives and constraints. In this sense, the other parties think along with the product designers. Mainly, the difference between information and the consulting activities is how many people understand the design problem and whether or not there is a shared interest (Kleinsmann, 2006). In consulting, the information provider understands the design problem and has an interest in providing the information, while in the information activity, the understanding and interest is solely the concern of the product designer.

In materials selection, the consulting activity is performed together with material related parties such as suppliers, experts and manufacturers. In the later design, these material parties are consulted to determine the value of candidate materials based on the set of objectives and constraints. Not only materials objectives and constraints are considered, but also aspects of costs, manufacturability and user related aspects. Product designers, together with materials experts, make an integral evaluation of candidate materials.

4.3 Description of the model

The materials selection activities are not performed randomly. Some activities are always followed by others (these are the basic activities) and some activities are performed during other activities (these are the supportive activities). For example, the supportive information activity is performed during the basic criteria activity. The basic activities are performed a single to several times in a design phase before the required materials are specified. The model is organized in four types of cycles that represent the relation of the design activities, namely the *basic materials selection cycle*, the *testing materials cycle*, the *information* and the *consulting cycles*.

Iterations

Basic materials selection cycle

The basic materials selection cycle connects the basic activities (No. 1-4 in figure 4.1). The activities are performed in this order and the results of an activity are used in the subsequent activity. The results of the choosing activity (No. 4) lead to selected materials. Although basic activities might follow each other quickly and might therefore not be recognized as separate activities, all four activities are needed to select a number of adequate candidate materials. Subsequent basic materials selection cycles narrow down the number of candidate materials.

Especially in the early design phases, it is not necessary to fully know all the details of the selected materials. Therefore, the results of basic materials selection cycles change in detail during the design phases. The first basic cycles result in selected

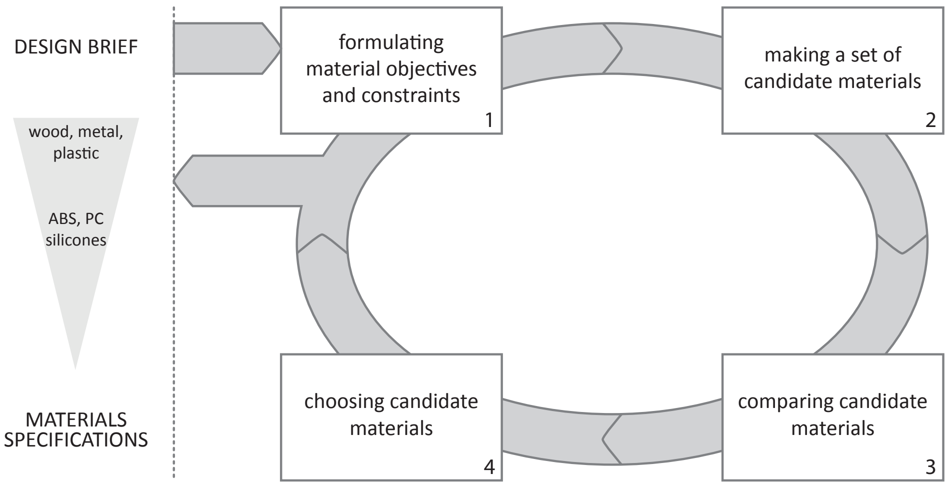


Figure 4.1
Basic materials selection cycle.

material families (e.g. wood, metal or plastic). The next cycles result in material classes (e.g. the plastics ABS and PC or silicones) and the last cycles result in full materials specifications. This classification is similar to the one proposed by Johnson *et al.* (2002). They classify the kingdom of materials from family and class (e.g. polymers, metals, composites; e.g., steels, Al- alloys, Pb- alloys), to sub-class and member (e.g. 4000, 5000, 6000; e.g. 6060, 6061, 6062) to attributes (e.g. density, price, modulus of the specific member). The basic materials selection cycle is repeated until the materials are specified to the required detail.

The selected candidate materials may lead to new design requirements, e.g. on aspects of costs or manufacturability. Furthermore, choices on other aspects in the design project can lead to new material objectives and constraints. In every basic materials selection cycle, the material objectives and constraints are therefore reconsidered, if necessary resulting in more extensive criteria. The activity of formulating material objectives and constraints (No. 1) is for that reason positioned in the basic materials selection cycle.

Testing cycle

Figure 4.2 shows that the testing cycle connects the testing activity (No. 5) with the basic materials selection cycle at the comparing activity (No. 3). Materials are tested when product designers need information that is not yet available but that is needed to evaluate the candidate materials. To obtain this information product designers plan and perform a test or simulation, whether or not together with materials experts.

Information and consulting cycles

The information cycles and the consulting cycles represent the relations between the information activity (No. 6), the consulting activity (No. 7) and the basic materials selection cycle (figure 4.3). Although both types of cycles are used during the basic four

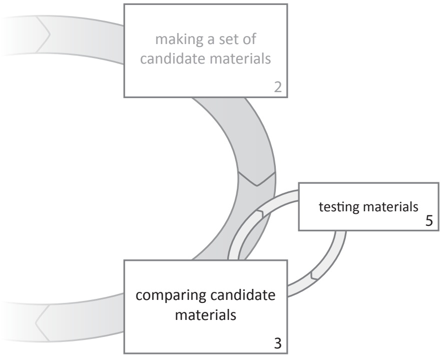


Figure 4.2
Testing materials cycle.

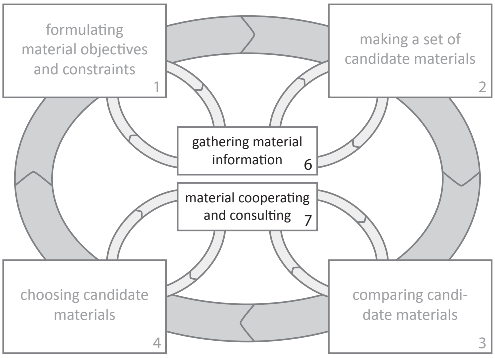


Figure 4.3
Information and consulting cycles.

activities, the information activity is mainly performed during the criteria activity (No. 1) and the making a set activity (No. 2). Equally, the consulting activity is mainly used during the comparing and choosing activities (No. 3 and 4).

The Materials Selection Activities model

The above described iterations are combined in a model. This model is named the Materials Selection Activities (MSA) model (figure 4.4). The model shows one cycle of materials selection activities, but represents the many cycles performed during the materials selection process.

The time spent on a single cycle differs from moment to moment. When supportive activities are needed, cycles obviously take longer, than when not. Based on the findings, we assume that the time spent in one cycle depends on the consequences of the decisions made. For example, in the concept phase, materials have a large influence on manufacturing and costs and are therefore considered thoroughly, but not in full detail. A relatively large amount of time is therefore spent on one cycle. When arriving at full materials specifications, materials are considered on the basis of more detailed information, but the decisions have fewer consequences. The activities and cycles follow each other very quickly. During one or two consultations with materials experts, many cycles are carried out.

The contribution of the MSA model can be found in the way this model explicitly describes the information and consulting activities. Fidel & Green (2004) state that especially human sources are not often recognized in studies trying to understand the information behaviour of engineers, although they are one of the main sources

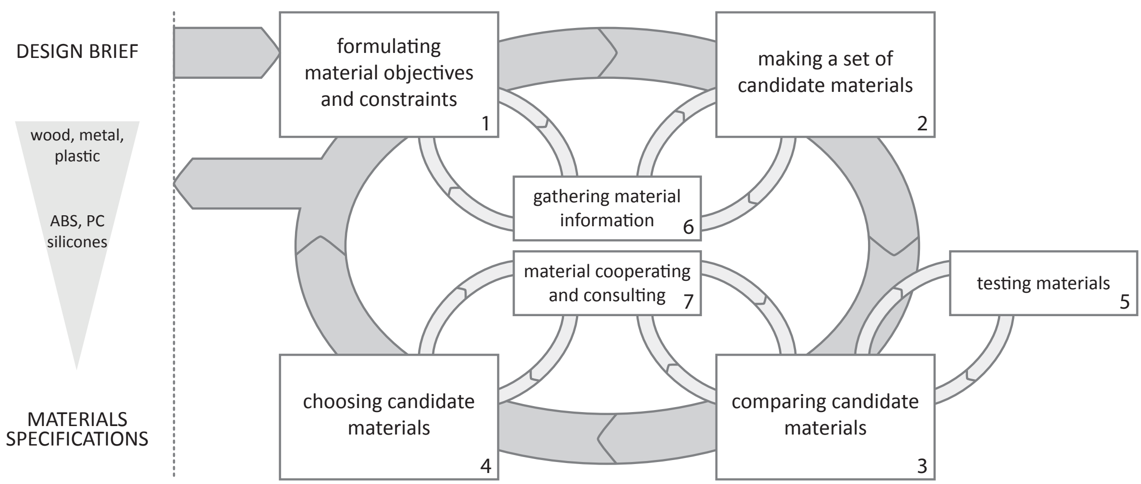


Figure 4.4
Materials Selection Activities model (MSA model).

in engineering. The MSA model explicitly specifies the role of human information providers in the materials selection process and could therefore be more accurate.

Discussions with young designers learned that they often do not recognize information activities as work, although they are necessary to select materials. Besides, this model shows that these activities occur from the early phases in product development throughout the whole product development phase and not only at the end. The MSA model can thus be used to train young designers and can contribute to more realistic insight into product designers' materials selection approaches. This aspect is further explored in section 5.4.

MSA model compared to existing models

The MSA model resembles, to some extent, product development models such as, Hall's problem solving steps (Hall, 1962), the last four problem solving phases of Ullman (2002) and the basic design cycle (Roozenburg & Eekels, 1995) in which the steps are: analysis (resembles the criteria activity), synthesis (resembles the set activity), simulation (resembles the testing activity), evaluation (resembles the comparing activity) and decision (resembles the choosing activity). However, there are some differences.

One of the main contributions of the MSA model is the illustration of two additional activities, to the general problem solving steps, namely the information and consulting activities. Explicitly showing these activities acknowledges the fact that product designers do not carry out the selection process on their own, but depend on others in their materials selection activities. Although, for example Ullman (2002) places a 'document and communicate' task in his mechanical design model, it is limited to this task and not so extensively described as in the MSA model. Placing these activities in a central position of the model enhances the communication about these activities and the relevance of them. Note that information retrieval can in itself have many phases. For example, Poltrock *et al.* (2003, page) explain information retrieval as that it 'involves identifying an information need, formulating a query, retrieving information, evaluating it, and applying it to address the need'.

The criteria activity and the revision of the criteria is one of the basic materials selection activities. This activity is performed throughout the project and not just at the analysis phase. The MSA model, therefore, differs both from design methods and analytical materials selection strategies that position the criteria activity mainly at the beginning of the materials selection process.

Product designers break down the problem because of limitations of the short term memory (Ullman, 2002). This is visualised in the MSA model. It shows that the activities are performed one to several times per product development phase, for example in the embodiment design phase. The materials are thus not determined at once, but in increasingly detailed steps and with different attention points. The number of candidate materials that is considered simultaneously is about three. The model distinguishes itself from the analytical approaches that speak of materials selection as a selection moment.

This materials selection model is organized as a sequence of materials selection activities instead of in product development phases, such as concept design, embodiment design and detail design (Ashby, 1999). An advantage is that materials selection is described in the MSA model on execution level and not on the level of physical outcomes such as sketches or lists of materials. As mentioned before, the MSA model serves as a framework to identify during which activities materials selection can be improved. Identifying only the outcomes that can be improved provides no instruments with which to reach these outcomes. However, identifying possible improvements on execution level helps to improve what product designers actually do.

4.4 Conclusions

Empirical data was obtained to create a model that systematically describes and organizes the materials selection activities of product designers. This data was formed into the MSA model, which follows an iterative problem solving approach that is made specific for selecting materials. It shows four basic materials selection activities, which are the criteria, set, comparing and choosing activities. The formulation of material criteria and the revision of them (the criteria activity) occupy a central role in the iterations. Additional to existing models, it adds activities that show that product designers depend on information sources for their basic materials selection activities. These are the supportive activities in the model and include gathering information, consulting specialists and testing materials. The model is expected to improve the communication about the materials selection process and is assumed to form an effective basis to evaluate and structure the needs of product designers throughout the user-centred materials selection process.

Chapter 5 and 6 are based on:
I.E.H. van Kesteren, J.C.M. de Bruijn, P.J. Stappers (2007, in press) **Evaluation of materials selection activities in user-centred design cases.** Journal of Engineering Design

And:
I.E.H. van Kesteren, P.J. Stappers, J.C.M. de Bruijn (submitted) **Product designers' approaches of integrating user-interaction aspects in materials selection.** Design Studies

Chapter 5 Validating the Materials Selection Activities model

The Materials Selection Activities (MSA) model, of which the creation is described in chapter 4, shows the activities that product designers perform to select materials. This model forms the basis for two studies in which 15 finished design projects are analysed. This chapter describes the first study. This study validates the model by analysing the specific characteristics of it (the order of activities and the role of information in the model). The second study aims to identify the critical factors in an effective materials selection process (chapter 6). This chapter explains the method for obtaining and analysing the case studies and the study performed to validate the model. The applicability of the reworked model for teaching students the materials selection process is discussed at the end of this chapter.

5.1 Objectives of the study

The MSA model can be used to describe the materials selection process of product designers when the model represents the materials selection activities in different projects, as well as the user-product interaction considerations herein. This information is relevant, not only for evaluating design projects, but also for providing design students an materials selection structure based on practise.

The MSA model was formed based on interviews with product designers, who spoke about their materials selection process in general (section 4.1). The activities found in these interviews are organized by a reasoning process into the sequences and relations shown in the model, but not discussed again with product designers. The next step is to validate the model based on its particular characteristics in single design projects.

The particular characteristics of the MSA model are threefold: 1) the selection of materials is performed in a sequence of iterative activities, 2) the activity of formulating material objectives and constraints is centrally placed in these iterations and 3) the activities of gathering information and consulting information providers are specifically included in the MSA model. In section 4.3 was argued, that these activities are important to make decisions about the criteria and the best material options. The relevance of showing the information activities in the model is dependent on the number of activities in which information is used.

The aim of the study was to validate the MSA model by exploring the particular characteristics of it via the following research questions:

> ***Question 1*** *Is there a similar sequential order of activities in the MSA model and in design projects?*

> ***Question 2*** *How often do product designers use information in their materials selection process and does this justify for the central role assigned to the information activities in the model?*

The study, performed in the framework of this project by Holper *et al.* (2006), showed that in design projects, requirements come forward that deal with product personality. However, function, shape and use aspects were found more frequently in the projects. Product personality aspects were not communicated solely by requirements but also through visual means such as collages. When materials are not predefined in a project, product designers have greater freedom in the materials' selection activities. In these cases, product personality aspects were among the dominant requirements in materials selection. In other projects, where materials were predefined or selected by an external party, product personality aspects were among the least dominant requirements.

Besides studying the characteristics of the model in the design projects, the projects were used to observe whether it is possible to predict the moments where user-interaction aspects are considered in the materials selection process. If no user-interaction aspects are considered at all, the MSA model cannot be used to describe materials selection in user-centred design projects. However, in particular activities, where user-interaction aspects are considered this can be added to the model. The last question studied is therefore:

> ***Question 3*** *Are there materials selection activities where product designers pay more attention to the user-interaction aspects of materials than during other activities?*

5.2 Case study method

To validate the characteristics of the model, a case study approach was used. This approach differs from the previous technique to create the model although in both studies product designers were involved. During the interviews, performed to create the model, we discussed the materials selection process in general and not related to a specific project. These results were formed into the MSA model by a reasoning process.

It therefore does not assure that the model represents single projects. To assess the outcomes of this reasoning process, the materials selection steps taken in a particular project were identified and compared with the model.

The heterogeneity of the studied cases is important in this study. The more the projects differ, the more discrepancy might exist between the MSA model and the design practice. This means that when the model is similar to the projects the model will be more robust. Participants were therefore selected from a wide range of design offices.

Fourteen Dutch design offices participated in this study, ranging in size from 1 to 40 employees. One product designer of each office agreed to outline a case about the materials selection process of one of their design projects. From one office, two cases have been constructed, resulting in 15 cases in total. The product designers' experience ranged from 1 to 35 years with a mean of 10 years. All were involved in the materials selection process in the projects.

Procedure

The product designers were asked to select a user-centred design project, i.e. a project in which emotional, sensorial and ergonomic considerations are key factors in the design choices besides the technology choices (table 5.1). The projects concerned a new product or design, released in the period spanning from two years before to one year after the interview. The product designers were visited in their design studio for the interview.

The interviews were performed in three steps.

Step 1 Outlining the case

The product designers were asked to explain the materials selection steps they took to design the product. Besides an oral explanation, the product designers were asked to make an outline of their materials selection steps with cards representing the outcomes of the basic activities of the MSA model (figure 5.1). A total of eight cards could be used to indicate the following: product criteria, material criteria, making a set (2 cards), comparing (2 cards) and choosing (2 cards). Each card represented a different detail level, for example a set of materials groups (e.g. wood, plastic or metal represented by different symbols) or a set of materials variations (e.g. Al4000, Al3000 represented by similar symbols). Product designers were free to add or adjust cards and were encouraged to make notes and decisions on the paper they used to make the outline.

Step 2 Marking data points

After the representation was made, the product designers indicated the design aspects that they considered during different materials selection steps. They did that for the moments at which we expected the product designers to be aware of the design aspects considered. The first moment was when product designers used the formulated criteria in an activity, for example to make a set of candidate materials or

Table 5.1
Projects discussed in the cases.

Case	Project	Objectives	Examples
1	Ankle brace	Redesign of an existing product with a complex manufacturing process	
2	Shaver stand	A new additional product for existing shavers to enhance their appearance	
3	Children's car seat	New series of products based on existing designs, new appearances	
4	Relax chair	New product to change the appearance of the chair and make it usable in public spaces	
5	Blister lock	New product for protecting goods from stealing that hang on rods in a shop	
6	Medical hand-held	New product for the medical treatment of patients	
7	Lighting for rural people	New product on solar energy, to be manufactured in rural areas	
8	Stairs elevator	New product, focus on arm rest and user-interface	
9	Global family gear	New family of products for hiking with small children, child carrier	
10	Braille terminal	Redesign of a product for Braille reading to include a mouse control	
11	Public letter-box	Redesign of an 20 year old version of the mail box	
12	Cutting tray	New product to replace the disposable version with a durable version	
13	Hospital bed communication	New products for the patient alert system that enable interaction with patients and nurses	
14	Sample folder	New product and manufacturing process for the display of material samples	
15	Colour spectrum (only step 1)	New products and interaction for the colour selection of paints	


2


9


10


11


13

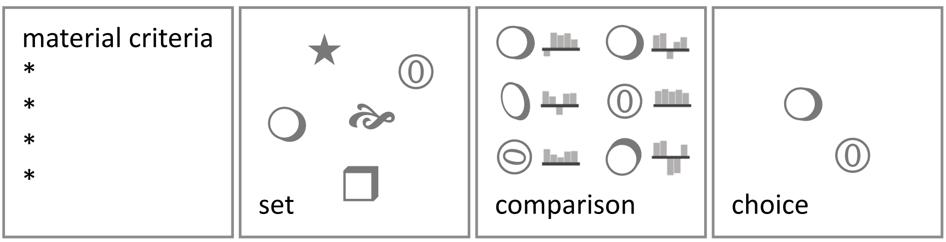


Figure 5.1
Examples of activity cards used for reconstructing materials selection steps. Symbols were used to represent different materials (different symbols) or variations on the same material (variations on a symbol).

Table 5.2
List of the ten design aspects that were used in the questionnaires.

Technology aspects		User-interaction aspects	
Function	F	Product Personality	PP
Materials	M	Use	U
Shape	S		
Manufacturing	MP		
Marketing/ Sales	Sa		
Durability	D		
Costs	C	Other	O

to choose materials. The second moment was when the product designers gathered information. The product designers marked these moments as data points using coloured stickers and tagged them with a number.

Step 3 Design aspects considered

For each data point indicated in step 2, the product designers picked the design aspects that they considered at that point from a list (table 5.2). The list is based on the MSC model (section 2.2) and the study of Holper *et al.* (2006). In their study, they found three additional aspects that are considered during the process of materials selection (marketing/ sales, durability and costs). Product personality and use are the two user-interaction aspects in this list.

Data processing

To distinguish between the marked data points which included user-interaction aspects and the data points which did not, these were grouped into two categories, namely 1) the user-product interaction (UI) category (a combination including use, product personality or both) and 2) the none user-product interaction (NUI) category (a combination of function, materials, shape and manufacturing without product personality or use).

The cases were processed into diagrams by combining two kinds of data: 1) the outlines of the materials selection steps and 2) the design aspects that the product designers selected in the questionnaires. The diagrams represent the materials selection steps taken in a project. The results of the case of the cutting tray (case 12) are now used to explain how these diagrams were made (figure 5.2). The full set of diagrams is presented in appendix 2.

Every activity card used in the outline made by the product designer is represented by a rectangle in the diagram (figure 5.2). The rectangles show letters referring to the activities of the MSA model. For example, ‘oc’ refers to the activity of ‘formulating materials **o**bjectives and **c**onstraints’. The activities that were marked as a data point show a number and a matrix with six boxes (e.g. point E, G and H in figure 5.2). The *top line* shows the data points marked at the moments that the product designer indicated having used the formulated *criteria*. The *bottom line* shows the moments the product designers indicated having gathered *information* and marked that as a data point. The numbers refer to the case number and the sequence number of the data point. The six boxes represent the design aspects from the MSC model (as introduced in section 2.2) that the product designers could select in the questionnaires. The legend of the figure shows which aspect refers to which box. A black or grey box indicates that this aspect was considered at the data point. The technology aspects are shown in grey, the user-interaction aspects are shown in black.

Figure 5.2 shows that the first materials selection activity in the case of the cutting tray (case 12) was 'formulating materials objectives and constraints' (A, oc) followed by choosing candidate materials (B, ch). For the chosen candidate materials a set of variations was made (C, s), which were compared in the next activity (D, cp). Based on this comparison a new set was made (E, s), which contains candidate materials on a more detailed level than the first set. The product designer indicated that he had used criteria and gathered information here (data points 12.1). He considered the

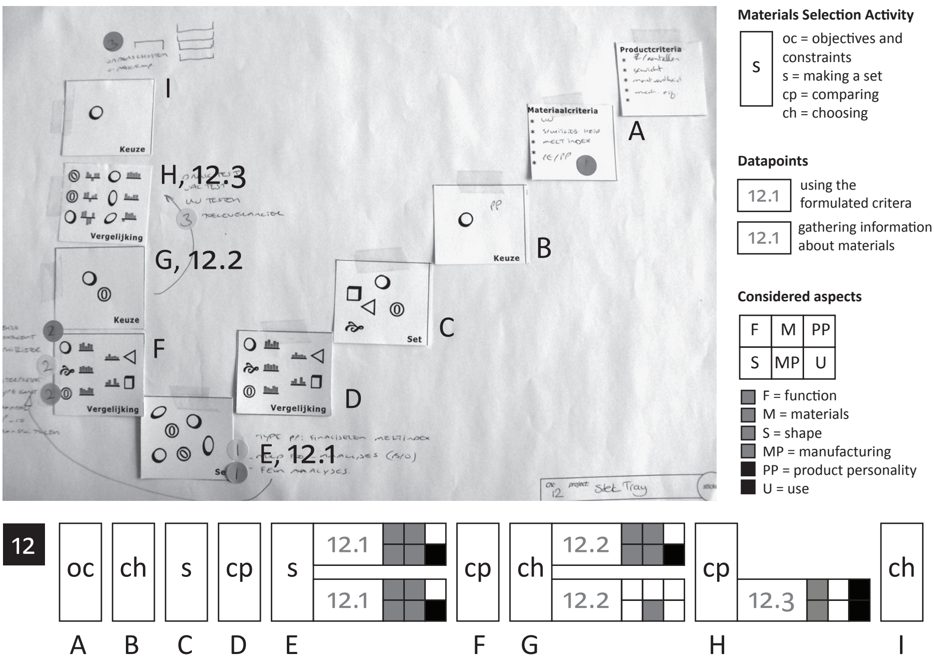


Figure 5.2
Example of the materials selection steps reconstructed from the cutting tray project (case 12) and the diagram created about it.

following aspects: function, materials, shape, manufacturing and use. After making this detailed set, the product designer compared the candidates (F, cp) and chose them (G, ch). During the choosing activity, he indicated that he had used criteria and gathered information for the second time (data points 12.2). The design aspects considered while using criteria were: function, materials, shape, manufacturing and use. The aspect considered while gathering information was the manufacturing process. After choosing the candidate materials, a third comparison took place (H, cp). Here several tests were performed and information was gathered (data point 12.3). The design aspects included in this information were: function, shape, product personality and use. The last activity was the choosing activity (I, ch).

5.3 Results

The diagrams that were made are presented in appendix 2. The results discussed here are based on these diagrams. The data point numbers refer to the numbers given in these diagrams.

Question 1, the MSA model compared to the sequence of activities

The first research question compares the order of activities represented in the MSA model and found in the project cases. The iterations are discussed first, followed by the position of the criteria activity in the cycle, and finish with the order of the basic activities.

Iterations

The MSA model shows a single cycle of activities, but represents the iterations needed in the materials selection process. The studied cases indeed show that materials are selected by performing more than one cycle. However, the product designers outlined just a few cycles for the whole project, from initiation to product specification. This might indicate that the materials selection process indeed has three or four cycles per project. On the other hand, product designers can also have performed a number of cycles unconsciously, which was not revealed in the cases. The fact that the projects were discussed after finishing them makes it difficult to validate this. However, the results clearly show that at least more than one cycle is needed to select materials and that materials selection is indeed an iterative process.

The product designers used all the activity cards in their projects, indicating that all activities are needed in the model. Activities not present in the MSA model were not used by the product designers. However, some participants used a blank card to indicate a quick follow up of the set, comparing and choosing activities. Furthermore, extra cards were used to indicate information and testing activities.

Criteria activity

The outlined cases show that the projects start with an analysis phase in which the project objectives and constraints are set. Most product designers used more than one card to indicate their formulating criteria. Product designers perform the criteria activity also later in the project, such is predicted by the MSA model. In many cases, just after the criteria activity, the choosing activity was performed. Especially in the beginning of a project, the product designers do not make a set of materials and compare them, but directly choose options based on experience. These materials are for example generally used in a product category or are determined by the production facilities of the product designers' client. With the predefined choices, they limit their materials searches to certain materials families early in the project. However, when later in the project these pre-choices need to be reconsidered because they appear insufficient, the product designers will do so.

Order of activities

The MSA model shows an order of basic activities that are needed to be performed to be able to select materials, namely first the criteria activity, followed by the set and comparing activities and finally the choosing activity. The case projects do not always show this order. For example, cases 3, 7, 8, 12 and 14 show the activity of formulating objectives and constraints directly being followed by the choosing activity (appendix 2).

The set activity is not always present in the later design phases of the outlined projects, although a sequence of comparing and choosing is present. Product designers might see selecting a variation of one material not as a sequence of making a set, comparing and choosing but just as comparing. The results provide no information about this issue.

The comparing activity is sometimes indicated by more than one card and the design aspects compared per card differ. This means that the product designer did not compare all the design aspects of the materials simultaneously, but sequentially. The same situation was found to hold for the choosing activity.

Product designers skip some of the activities of the model in their projects especially in the later design phases. Proceeding studies should assess why the steps are skipped and what the consequences are for the effectiveness in the materials selection process. The design projects should for this purpose not be studied in retrospect, but during the process. Only then it is possible to be sure that the activities are skipped, and not just forgotten by the participant.

In conclusion, a similar order of activities was found in the design projects and the MSA model. The projects followed an iterative materials selection process, as predicted in the MSA model and not just a single material choice moment. The criteria activity is found at different stages in the projects, which justifies the position of the criteria activity in the model. All the activities of the MSA model are found in the projects, although, not always in the exact sequence as described in the MSA model. Especially, at the beginning of a project, the sequence is a choosing activity directly after a criteria activity. This choosing activity closes the analysis phase and results in a selection of materials families that form the basis for the materials selection searches in the design phase.

Question 2, the relevance of information activities in the MSA model

The relevance of describing information activities in the MSA model is investigated by analysing the percentage of the materials selection steps in which information was used. This was done per information provider and per activity in which the information was used. Mapping these sources gives insight in the role of the different information providers in e.g. supporting the criteria activity or the choosing activity.

Method

The transcriptions from the product designers' descriptions of their materials selection process were transformed into quotes representing a single step in the process. These quotes were categorised in the materials selection activities of the MSA model. The information activities were not used as a category because these activities are performed during other activities. Quotes that could be categorized as two or more activities, or did not represent an activity of the MSA model, were categorized as 'other activities'.

For every quote the following two aspects were indicated: 1) whether or not the product designer searched for information in this step, and 2) what his or her main information source was. If more than one human information provider was mentioned in a quote, it is categorized as 'group'. If it was clear that the product designer had searched for information in a materials selection step, but did not indicate which source, it is categorized as 'other source'.

Results

The number of quotes in the different categories is presented in appendix 3. A total number of 459 quotes was found in the 15 case descriptions. In 70 percent of all quotes, information was used.

The percentages in figure 5.3 illustrate in how many of the materials selection steps information was used. The pictures indicate the main information sources. In more than half of the materials selection steps, information was used. For the activities, represented at the right of the MSA model (set, comparing and testing activities), this percentage climbed to 75%, 86% and 94%. The results clearly show that product designers gather and use information frequently in materials selection.

The main information sources were the client, the supplier, the manufacturer, the user, models and a group of people (figure 5.4). The group of people often consisted of the designer, an expert, the client and/or a manufacturer or supplier. These information providers were used in 19 to 7 percent of the steps respectively, which indicates that product designers rely on different sources in the project (appendix 3). The materials selection activities for which the sources are consulted differ from activity to activity.

The *client* is mainly used as an information source when formulating objectives and constraints and during choosing. The rest of the activities are left to the designer, which is logical because the client appoints the product designer to do this job. However, during the set activity, the client provides the commonly used materials in some occasions.

Suppliers and *manufacturers* are consulted during all activities except for that of formulating objectives and constraints. However, they can indirectly influence objectives and constraints as these are sometimes adjusted during other activities.

Users are an information source for formulating objectives and constraints, for example in the analysing design phases. They are also used in the testing materials activity.

Models are used as sources during the testing materials activity.

Making a set of candidate materials and comparing activities are sometimes performed with a *group of people*, using information from different sources in a discussion. The results, however, show that the choice is left to the designer, client and manufacturer.

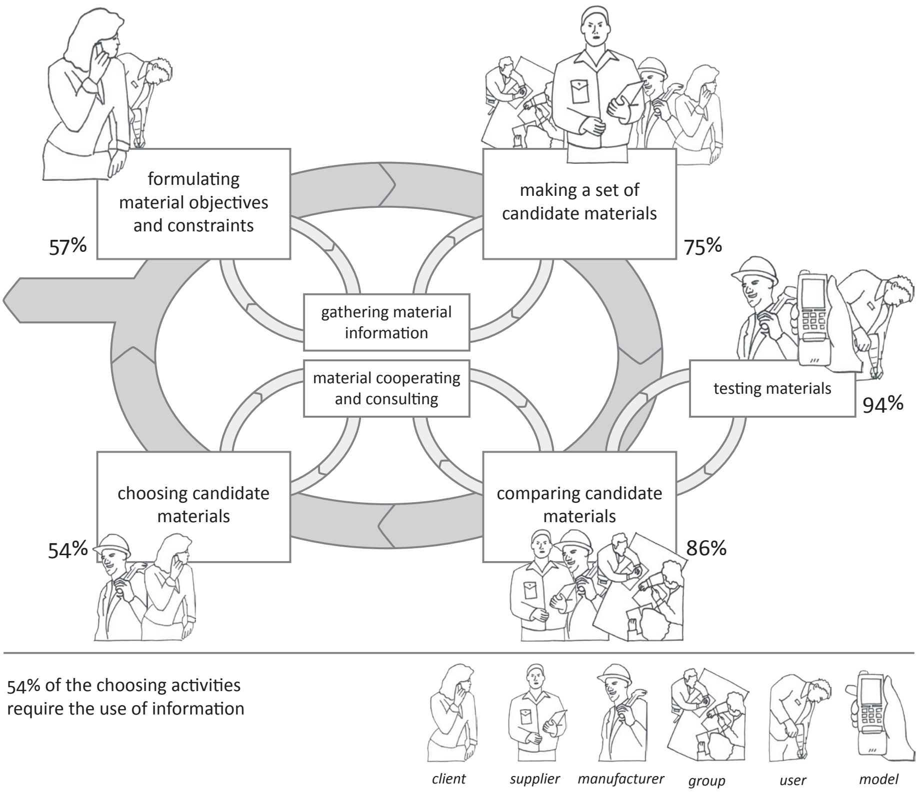


Figure 5.3
Main information sources in materials selection. Percentages represent in how many of the steps, the usage of information was found, categorized per materials selection activity (appendix 3).

*Materials supplier*s are not involved in the choosing activity.

Although both Fidel & Green (2004) and Hertzum & Pejtersen (2000) found that colleagues are among the main information sources in engineering, the product designers did not mention colleagues as a frequently used source. The product designers mostly worked as teams and explained their materials selection steps from a team point of view and thus not mentioned colleagues as a source. Furthermore, the expertise needed to make material decisions was often found outside the team.

In conclusion, the results clearly indicate a large frequency of the information activities in the materials selection process and in almost equal contributions of the different information sources. These sources are mainly people. It is therefore justified to assign a central role to the information activities in materials selection models, which is the case in the MSA model.

Question 3, user-interaction aspects in the MSA model

The last question studied is whether it is possible to point out activities in the MSA model where user-interaction aspects of materials are more frequently considered than during other activities.

Generally, it differs per project at what phase user-interaction aspects are considered in the materials selection process (appendix 2). Nevertheless, in most projects, user-interaction aspects played a role in the first criteria activities. Furthermore, user-interaction aspects played a role towards the final phases of the projects.

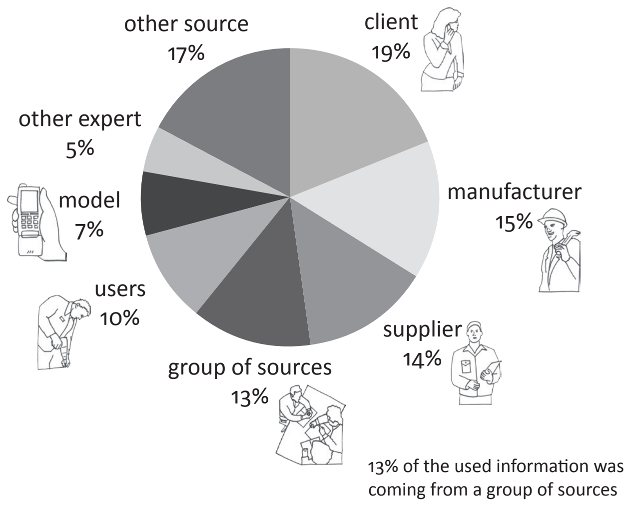


Figure 5.4
The information sources consulted by the product designers. Percentages represent in how many of the steps, the usage of a specific information source was found.

Table 5.3
Moments where product designers used criteria (criteria data points) and gathered information (information data points) organized in the activities of the MSA model.

Activity		**Criteria data points**			**Information data points**			
	Code	UI	NUI	Total	UI	NUI	Total	
Criteria activity	oc	12	0	**12**	9	6	**15**	
Set activity	s	9	4	**13**	8	7	**15**	
Comparing activity	cp	3	4	**7**	4	2	**6**	
Choosing activity	ch	9	3	**12**	3	2	**5**	
Testing activity	t	0	0	**0**	3	0	**3**	
Information activities	i	0	0	**0**	1	0	**1**	
Other activities	o	1	1	**2**	1	1	**2**	
Total		**34**	**12**	**46**	**29**	**18**	**47**	***93***

In every project, user-interaction criteria were formulated and used (appendix 2, top line). In two projects this were only use criteria and they were considered only once: in the ankle brace case (case 1, data point 1.1) and in the case of the public letter-box (case 11, data point 11.3). In the other projects user-interaction criteria were used several times.

In all projects, information was gathered about user-interaction aspects (appendix 2, bottom line). The only exception is the shaver stand project (case 2), in which the product designer was able to formulate objectives and constraints about user-interaction aspects without additional information (data points 2.1-3). In the blister lock project (case 5), the product designer only once considered user-interaction aspects during information activities (data point 5.2), at which he specifically searched for information about this topic. In the lightning and stairs elevator projects (case 7 and 8) information was required about user-interaction aspects for one part of the product only (data points 7.1-2 and 8.2).

The product designers marked data points at the moment they used earlier formulated criteria or when they gathered and used information. These data points were divided in two categories based on whether or not user-interaction aspects were involved (UI and NUI category). In table 5.3, the number of found data points per category is presented per materials selection activity.

Product designers used their user-interaction criteria for the criteria, set, comparing and choosing activities (table 5.3). Criteria data points during the criteria activity illustrate the moments were product designers revised their criteria and during these moments only the UI category was found. At these data points, user-interaction and technology criteria were used simultaneously, for example, in the ankle brace, children's car seat and blister lock projects (e.g. data points 1.1, 3.1-3 and 5.1-4). In other cases, only user-interaction criteria were used, for example, in the braille terminal project (e.g. data points 10.1-2).

During the activities other than the criteria activity, both the UI and NUI categories were found. During these activities, product designers used user-interaction criteria, technology criteria or a combination to make a set of candidate materials. The same holds for the comparing and choosing of candidate materials.

About the information data points, table 5.3 shows that the product designers consider user-interaction aspects when they gather and use information. However, in two-fifths of the moments they do not consider user-interaction aspects. Information is mainly gathered during the criteria and set activities.

The results demonstrate that, during the activities of the MSA model, there are materials selection activities where product designers pay more attention to the user-interaction aspects of materials than during other activities. During most criteria activities user-interaction aspects are considered. Product designers define the objectives and constraints about user-interaction aspects in the beginning of a project and use these towards the end in the other activities. The product designers gather information on a combination of user-interaction aspects and other design aspects or solely about some of the aspects. Information providers should thus be able to provide combined information. Especially the information providers in the activity of formulating material objectives and constraints (clients) need to be able to information about user-interaction and technology aspects.

5.4 Reworked MSA model

The MSA model successfully indicates the iterative nature of the materials selection process in product design. In addition, it shows the importance of user-interaction aspects in the materials selection process and when these aspects are considered. However, with some additions to the model it is expected to illustrate the materials selection process more accurate.

Additions

The first addition concerns the analysis phase of a design project. In this phase, not only the objectives and constrains are formulated for the project, but also a pre-selection of candidate materials is made. Based on these candidate materials, the product designer starts the synthesis phase. The previous version of the MSA model does not make a distinction between the different design phases. The model would thus be more accurate in describing design practice when two activities are added in the analysis phase before the materials selection cycles start. These activities would be the formulation of material objectives and constraints and thereafter choosing some candidate materials based on experience with former projects (figure 5.5). It then

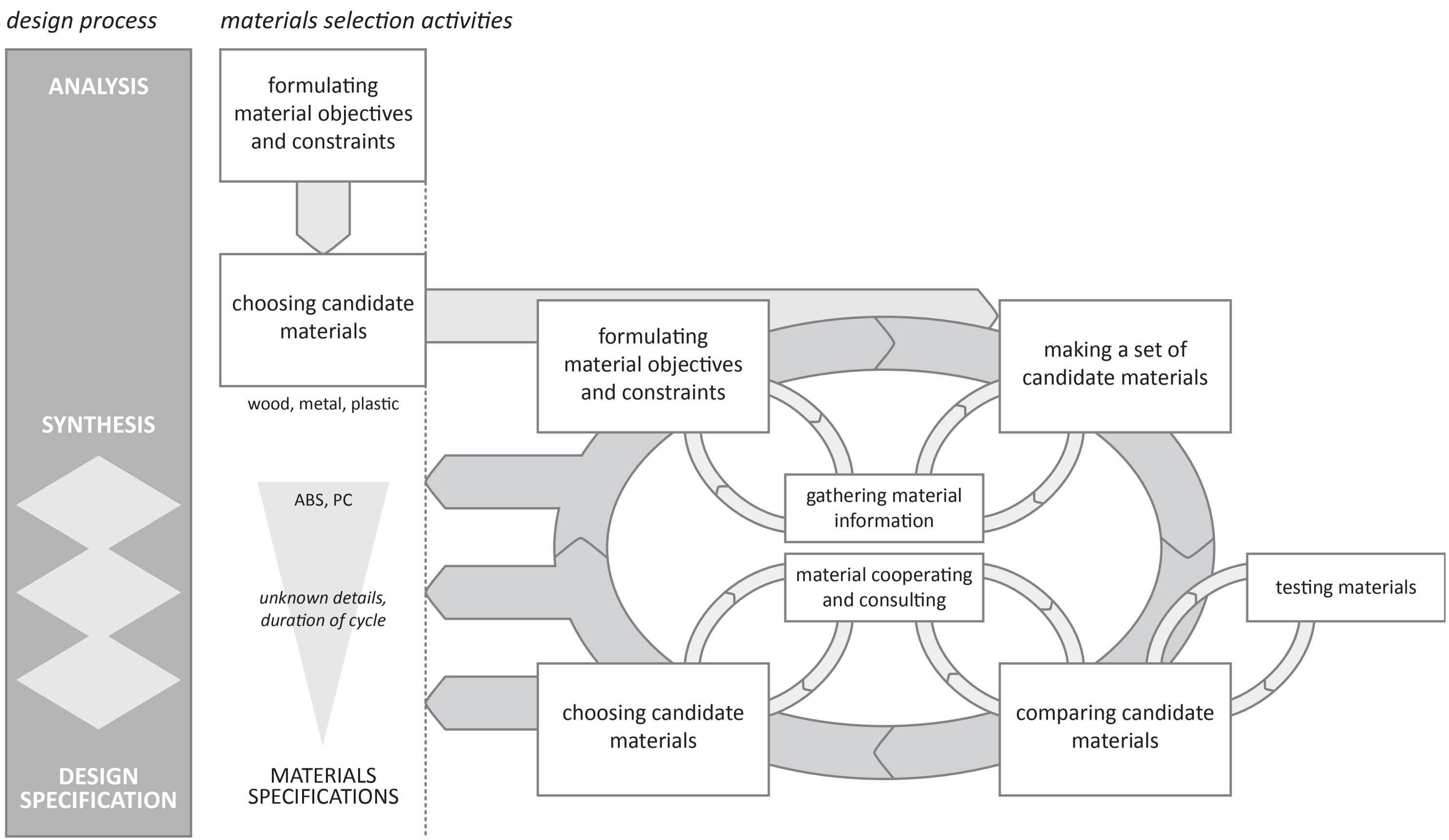


Figure 5.5
Materials Selection Activities model in combination with the design process. Adjustments are made in the initial model to include the preliminary selection of candidate materials in the analysis phase of the design process.

shows that product designers in current practice regularly start the synthesis phase with a predefined idea about the materials that will form the product based on what they know.

Product designers were found to consider user-interaction aspects during most of the criteria activities in every project. Furthermore, they consider user-interaction aspects during the information activities, but not at every moment. At some moments the product designers focused on technology aspects. A possible addition to the model therefore involves showing the considerations of a combination of user-interaction and technology aspects at the criteria activities. Furthermore, considerations of either user-interaction aspects or technology aspects or a combination of both can be added to the information activities.

How to use the model

The new MSA model can be used, together with the model in which the information providers are included (figure 5.3), to teach young product designers a structure for making considered material choices for a new design. Young product designers could learn from the relation between the design process and the materials selection process as shown in the MSA model that materials selection starts at the beginning of a project and that the efforts in selecting materials are needed throughout the project. The model can help to cut the materials selection process in understandable pieces. The structure can in addition be used by design teachers to evaluate the argumentation in the materials selection process of students. Reports can be scanned for descriptions of the different activities.

Cross (2000) states that design students tend to become bogged down in attempts to understand the problem before they start generating solutions. The MSA model helps students to realize that not all material criteria need to be known at the beginning of a project, but that it evolves along the way. It shows that by following the cycles in which the activity of formulating of material criteria is present, the problem is also better formulated. Moreover, the MSA model explains that materials selection is a selection process in which several solutions are searched for and compared. Considering more solutions can increase the quality of products.

Students tend to stick to one solution, due to limited knowledge about materials, especially in the early years of their education (Wright, 1988). The MSA model shows that limited knowledge and experience is normal in the materials selection process, even with more experienced product designers. The activities of gathering information and consulting material experts in the model show that students need to be actively concerned with looking for information and that the model can help to plan this in their design process.

The model shows that the materials selection process does not simply stop at indicating the material families like wood or plastics, but that it has barely started here. Students need to be encouraged to find information based on their pre-selections and use this information to make more detailed choices. In the mean time, they expand their materials selection experience, to be able to make better pre-selections in future projects.

Although the MSA model can show the activities and significant role of information, it does not show where to obtain the information and how to adequately process it in the design decisions. Students however frequently asked for this. Using the model in a course should thus be accompanied with a considerable number of examples of where to find information about materials, for example the ones identified in this thesis. Indicating the information providers in the model can stimulate students to not only look for information in databases and on the Internet, but also to talk to suppliers and manufacturers. The advantage of getting information from these specialists is that students learn new possibilities and start making a material information network. The model can be extended by providing some interesting sources to find information in the different phases and for the purpose of different activities to put them on their way.

5.5 Conclusions

The MSA model succeeds to describe the materials selection activities in user-centred design projects. The model is complete in describing all activities that are performed in iteration. As in 70% of the activities information was used in the projects, we feel confident that the information activities are relevant in the model. User-interaction aspects of materials are considered during the materials selection activities, especially in most criteria activities. The information sources used during these activities thus need to be able to communicate about these aspects. These information providers are mainly the client and users. Users, obviously, can provide information about their interaction requirements via the user studies they participate in. For an effective formulation of criteria, clients should also be able to communicate about user-interaction aspects.

The only discrepancy between the model and practice is that the order of activities followed in practice does not always follow the same order as described in the MSA model. For that reason, the model was reworked by adding two activities before the basic selection cycles start. These two activities, criteria and choosing, are performed in the analysis design phase and result in chosen material families like wood or plastics. Adding this to the model emphasises that product designers in practice often start their materials selection process with a set of commonly used materials in their mind.

Chapter 6 Exploring the critical factors in materials selection

In the previous chapter, the MSA model was validated by studying 15 design projects. The same projects are used in this chapter to find the critical factors in an effective materials selection process. The study focused on the moments where product designers needed extra steps in the process and the factors that accelerate the materials selection process. The relation between these critical factors and the involvement of user-interaction aspects in the activities was of special interest. Exploring these critical factors helps to find the requirements to improve the materials selection process. The findings of this study form the basis for a new materials selection approach that is described in broad outline in chapter 7.

6.1 Objectives and expectations of the study

The explanations about user-interaction aspects in materials selection in chapter 2 bring in that selecting materials in user-centred design project is not easy. Several aspects were seen that influence the effectiveness in the materials selection process. For example, not finding information about materials that combines the considered design aspects can lead to not finding the optimal materials that match the objectives and constraints. This study aims at finding the critical factors that product designers experience in design practice. Critical factors are those factors that influence the effectiveness in the materials selection process by leading to extra steps or by not finding the required materials. Hence, not only the problems are interesting, but also the activities that go smooth. Understanding why these activities go smooth help to improve the process.

Expectations

The MSA model shows that the specification and satisfaction of criteria is the most critical phase in the materials selection process. For example, Brechet *et al.* (2001) highlighted the problems of not finding expected solutions based on the requirements, finding no solutions at all, finding solutions that are obviously wrong, or finding too many solutions. When the outcomes of the criteria activity are not usable as input for the other activities, the criteria need to be adjusted. Adjusting criteria is a regular ingredient of the iterative design process and is included in the MSA model, but it is inefficient when carried out after a search for specific candidate materials has started. The chance that a search is unnecessary, and hence time is wasted, is always present. Critical factors in the criteria activity are therefore expected when criteria are adjusted during search activities (set and comparing activities).

When product designers cannot use the outcomes of previous steps, extra materials selection steps are needed (figure 6.1). When the outcomes of a basic activity are not sufficient, the work for creating these outcomes needs to be extended (left figure). A special situation occurs when the criteria are insufficient for comparing or choosing (right figure). The criteria then need to be reformulated. These extra steps decrease the effectiveness in the materials selection process.

It was shown in the previous chapter that user-interaction aspects are considered during the criteria and information activities. Different information sources are used during these activities and to be effective, these information sources should include the user-interaction aspects of materials. Brechet *et al.* (2001) explain that product designers have trouble with the use of information, especially when presented in databases, when the design involves several objectives and constraints or when it involves simultaneous optimization of more than one design element. Furthermore, Poelman (2005) explains that the people involved in the materials domain have different education backgrounds e.g. chemistry or engineering, which makes it difficult to communicate between fields.

The information activities are the second activity during which critical factors are expected. The activeness of an information provider is expected to influence the acceleration in a materials selection step. Furthermore, an activity can be accelerated

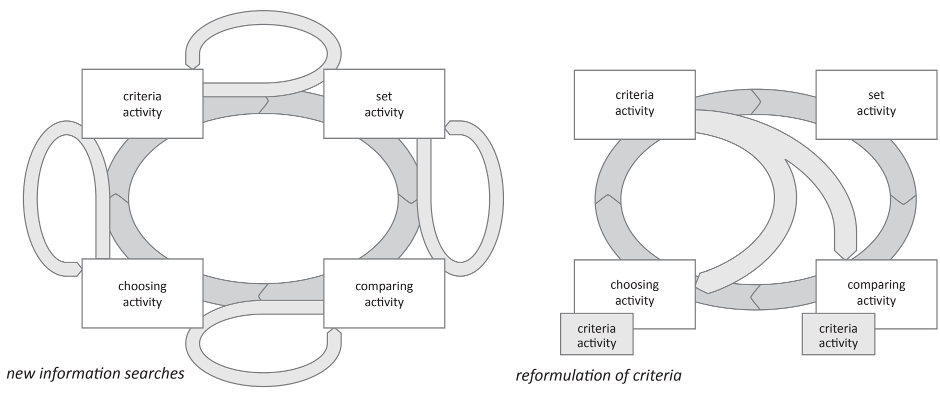


Figure 6.1
Steps needed when outcomes are not usable in the next activity. In the left figure, only an iteration is necessary, in the right figure, extra activities are needed.

when the advice given is specific to the problem. Product designers depend on information in their materials selection activities as clearly found in section 5.3 on page 73. Especially the fact that most information providers are consulted when product designers consider user-interaction aspects makes it likely that problems occur in this activity. People involved in the design process tend to discuss the problem in different vocabularies, e.g. about attributes related to use, in engineering dimensions or as properties (Cross, 2000). Material experts, who have been trained to advice on the technology aspects, could therefore have difficulty in recommending about the user-interaction aspects of materials.

Research questions

The aim of the study is to provide insight into the critical factors in the materials selection process, especially when user-interaction aspects are involved. The questions posed were:

> ***Question 1*** *During which activities do product designers indicate most critical factors in user-centred materials selection and what are the main reasons?*
>
> ***Question 2*** *Do the expected critical factors in the criteria activity lead to critical adjustments in the materials selection process?*
>
> ***Question 3*** *Which information sources are able to give adequate information about the combination of user-interaction and technology aspects?*

Question 2 and 3 compare the situations in which user-interaction aspects are considered to the situation where none user-interaction aspects are considered.

6.2 Case study method

The same projects as in chapter 5 are used in this study. During the interviews about these projects, the product designers outlined their materials selection steps and the design aspects they considered during the steps (section 5.2). For the purpose of this study, they performed one additional task, namely they marked the moments at which the materials selection process was accelerated or slowed down. These moments identify the product designer’s critical factors in the process (critical data points). The other data points that were indicated were the moments at which the product designers used their formulated criteria (criteria data points) and those at which they used information (information data points). The product designers indicated the design aspects considered at the activities during which the two latter types of data points occurred.

Table 6.1
Questions for the critical, criteria and information data points.

Data points	Open questions	5-point scale questions
Critical		
	Why did the critical situation occur?	How did the formulated criteria and available information affected this data point (from not to totally)?
	What would you do different next time?	
Criteria		
	Which criteria were used at this point?	To what extent were criteria adjusted at this point (from not to totally adjusted)?
Information		
	What kind of information did you need at this point?	How actively was the information provider involved (from not at all to very active)?
	Who was the main information provider here?	How specified was the information (from 'raw information from a book' to 'a specialised advice')?
		How useful was the information (from not at all to very useful)?

A short questionnaire was used to discuss the materials selection step at each data point in more detail and to be able to gather the information needed to answer the research questions (table 6.1).

The data derived from the case descriptions and outlines were processed as explained in section 5.2. The data points for which the considered design aspects were indicated (criteria and information data points) were divided into two categories: 1) the user-product interaction (UI) category (a combination including use, product personality or both) and 2) the none user-product interaction (NUI) category (a combination of function, materials, shape and manufacturing without product personality or use). The answers of the questionnaires were processed as explained in the results sections.

6.3 Results

Table 6.2 shows that a mean number of 2 critical data points and 3 criteria and information data points were indicated per project. The product designer of the colour spectrum project (case 15) did not make an outline of his materials selection steps. He was therefore not able to indicate the data points. The results are based on the other 14 projects.

Table 6.2
Number of data points indicated in the outlines made per case. The product designer of the colour spectrum project (case 15) did not make an outline of his materials selection steps. He was therefore not able to indicate the data points. The results are based on the other 14 projects.

Case	Project	Number of Critical moments	Critera moments	Information moments
1	Ankle brace	2	3	5
2	Shaver stand	3	3	3
3	Children's car seat	1	3	3
4	Relax chair	3	3	4
5	Blister lock	2	4	3
6	Medical hand-held	2	3	4
7	Lighting for rural people	3	4	4
8	Stairs elevator	2	5	3
9	Global family wear	3	2	1
10	Braille terminal	2	2	4
11	Public letter-box	1	4	6
12	Cutting tray	3	2	3
13	Hospital bed communication	1	4	2
14	Sample folder	2	4	2
	Total	**30**	**46**	**47**

Question 1, critical factors

The first question explores the moments at which the materials selection process was accelerated or where the materials selection process was slowed down. The product designers marked these moments as critical data points. The critical data points are organized according to the activities in the MSA model. The reasons that the product designers gave for the occurrences of these data points are discussed here.

In all projects, the product designers experienced critical factors. In about half of the projects these moments accelerated the materials selection process (successes), at the other moments, extra steps turned out to be needed in the process (problems). The critical data points were indicated during all activities of the MSA model (table 6.3). The only exception is the testing activity, which was added by some product designers as an activity card, yielded no data points. During the criteria activity, 35% of all critical factors are indicated.

We expected to find critical factors during the activities in which product designers search for information and used their formulated criteria. Table 6.4 indeed shows that clear restrictions in the materials searches and the availability of information facilitate

Table 6.3
Activities in which critical factors were found (successes and problems).

Activity	Successes	Problems	
Criteria activity	5	6	
Set activity	3	1	
Comparing activity	3	2	
Choosing activity	2	3	
Information activities	2	3	
Testing activities	0	0	
Other activities	0	1	
Total	**15**	**16**	**31**

the materials selection process. However, besides these factors, another factor was critical in five of the projects, namely, a change in the project objectives. These changes did not result from material related aspects, but from other design aspects such as the manufacturing process, costs or target group. However, these changes proved critical for an effective materials selection process, as they led to extra steps in reformulating the material criteria and extra steps in the materials searches in the projects. Extra steps were especially needed when the information gathered before the change did not provide enough details to re-evaluate the selected materials for the new objectives. The first was to ask the information provider whether the materials still fulfilled the criteria and the second, to search for new materials if this was not the case.

Clear restrictions on the material search accelerated the set activity. For example, a restriction in technology, finished products in the portfolio or the number of products to be produced resulted in a smaller set of adequate materials. However, in the cutting tray project (case 12), restrictions led to extra steps in the materials selection process. The client did not want to use a certain plastic in this project, although this later turned out to be the best option. In two other projects, materials decisions were made by an external party. These materials were thus a starting point for the project. However, these materials were not always the best solution for the objectives of the product and therefore caused unwanted delays. For example, in the shaver stand project (case 2) the client had made an agreement with a manufacturer, however, it later became evident that other materials were more cost effective, making it necessary to change the manufacturing process. A similar problem occurred in the hospital bed communication project (case 13). Others had selected a specific thermoplastic elastomer (TPE), but printing on the material was required, which was not possible with the selected TPE. In short, restrictions can speed up the process as long as is clear what the basis is for the restrictions.

The availability of information was indicated as a critical factor in the materials selection process. If the information was available, for example within the databases

Table 6.4
Reasons why materials selection went smooth or why difficulties arose.

Reasons why materials selection went smooth	Times found
Clear restrictions for the materials search	6
Information is available	5
Synergy between information providers	3
Materials were found that fulfilled the criteria	1
Reasons why difficulties arose in the materials selection steps	
Information is not available	5
Change of project objectives or scope	5
Materials did not fulfil criteria	3
Biased client	1
Time pressure	1
Wrong estimation of criteria	1
Total	**31**

of the design agencies, this was shown as having accelerated the materials searches. However, both during the set and comparing activities, product designers indicated difficulties with finding information. Information was not available or insufficiently in-depth to specify details. The product designers needed to optimize their decisions about user-interaction and technology aspects in separate steps. For example, at one point in the mail box project (case 11) another material was chosen to adjust the strength of a product part. However, after testing these materials in a prototype, it was discovered that this material did not match aesthetic criteria. In the children's car seat project (case 3), materials were selected based on aesthetic qualities, but needed to be eliminated later in the process because they did not match the technical requirements. In the medical hand-held project (case 6), there was not even an adequate match between user-interaction and technology aspects of materials.

Successes were furthermore indicated during different activities at the moments where a group of people (client, product designer, materials experts) came together to discuss the project. The form of information influenced the activity the information was used in. If there was synergy between the information providers and they were able to form a specialized advice, this accelerated decisions in the set and comparing activities enormously.

In three projects, the product designers could, at one point, not find adequate materials for the project. In these cases, the criteria were too restricting, or unclear. In two projects, this was solved by putting more effort into the tests and fine-tuning of the materials. In one project, the criteria for the test were unclear and as a result the materials were evaluated on other criteria than initially agreed upon.

In conclusion, product designers experience most critical factors in their materials selection process during the criteria activity. The availability of information in this activity influences the accuracy with which criteria can be formulated. These restrictions affect other activities, such as creating and comparing a set of candidate materials. Critical in these activities is the availability of information about user-interaction aspects of materials. Specialized advice speeds up the activity regarding where the information is needed.

An unexpected critical factor leading to extra steps in the materials selection process are changes in the project scopes. After a change, product designers needed to adjust the material criteria and start a new search for information about materials. The product designers therefore indicated not only preferring a specialized advice, but also the considerations of the information provider to formulate this advice. When changes are needed, the product designer can then easily re-evaluate the selected materials.

Question 2, adjustments of criteria

The previous section shows that, during the activity of formulating criteria, relatively often critical factors are found. Whether these factors also lead to extra steps in the materials selection process, is studied here. The focus is on the moments where criteria are adjusted when a material search has started, thus during the set and

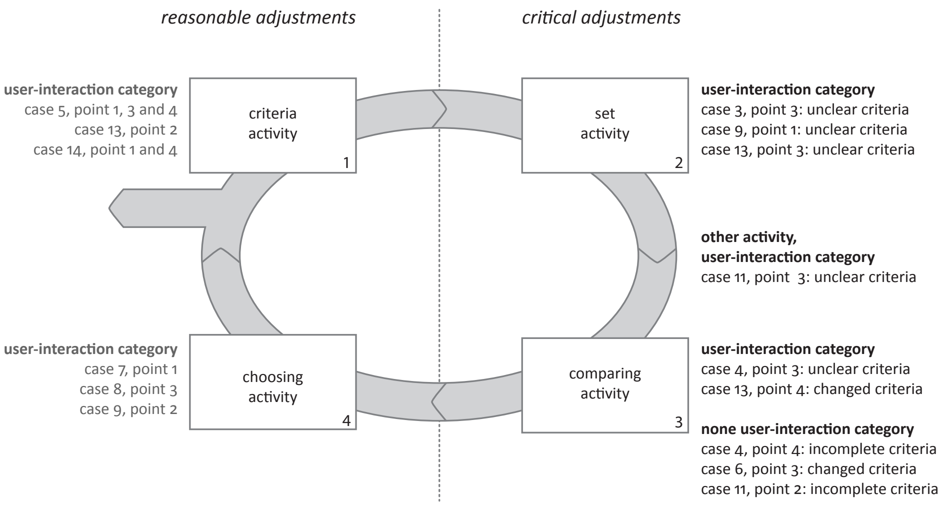


Figure 6.2
Adjustments of criteria. Adjusted criteria during the set and comparing activities, presented in black, are more critical than during the other activities. For these activities, the reasons why criteria were adjusted are given.

comparing activities, and on whether user-interaction aspects were involved at this moment.

The product designers indicated 46 criteria data points in total (table 6.2). In 18 of these points the formulated criteria were adjusted and these points are organized in the MSA model in figure 6.2. The numbers in this figure refer to the case number and data point number, which can be found in the diagrams of the cases in appendix 2.

The product designers of 10 of the 14 projects adjusted criteria. This could be during one of the four basic activities of the MSA model. In most cases criteria were adjusted that included criteria on user-interaction aspects. Only at three data points only none user-interaction criteria were adjusted. At these data points, the product designers made adjustments during the comparing activity. In the UI category, adjustments were made during all basic materials selection activities.

The reasons whether or not adjustments had been made during the criteria and choosing activities are a consequence of the iterative nature of the materials selection process and fit in the criteria activity in the MSA model. A distinction was made between these activities, in which it is reasonable that adjustments are made, and other activities. Adjustments during other activities are extra steps and may slow down the set activity when instead of finding candidate materials closely related to the ones found earlier, entirely or partly new set needs to be made.

These results lead to three main reasons why criteria were adjusted during the critical activities: 1) the formulated criteria were unclear, 2) they were incomplete, or 3) criteria were adjusted after changes in the project objectives.

Unclear criteria

In the car seat, global family wear and hospital bed communication projects (case 3, 9 and 13), criteria were adjusted during the set activity. The criteria were unclear in a sense that there were many design aspects included in the criteria but not specified (data points 3.3, 9.1 and 13.3). Finding a solution that matched criteria on both the technical and user-interaction aspects was therefore difficult. Hence, the consequences of the unclear criteria in these projects were that no adequate materials were found and criteria needed to be adjusted to focus a new search. This increased the time spent in the subsequent set activity.

In the relax chair project (case 4), unclear criteria were adjusted during the comparing activity. At this point, the product designer compared the consequences of a considered material on the aesthetics and shape. The adjustments did not only lead to specification of the material criteria, but also of the shape criteria. This was a crucial step in the project for focusing the project.

The client of the public letter-box project (case 11) was involved in different steps in the materials selection process, such as comparing and testing. This client was not able to make himself clear regarding the criteria about user-interaction aspects. As a result, the product designer made many iterative changes and new searches to select the materials the client wanted (data point 11.3).

Incomplete criteria
In the relax chair project (case 4), the criteria regarding technology aspects were not well formulated and therefore needed reformulation and detailing before the product designer was able to compare the materials (data point 4.2). Although the requirements were specified enough for making a set of candidates, comparing them was not possible. The consequence was that an extra step was needed to reformulate the criteria, thus causing the comparing activity to take longer than needed.

In the public letter-box case, material tests showed an unwanted reliability problem (data point 11.2). In the searches that followed, the material characteristics that caused this effect were added as criteria. The consequences were that extra materials searches were needed.

Changed criteria
In the medical hand-held case, a new manufacturing process was chosen (data point 6.3), leading to adjustments in the criteria and making a new set of candidate materials necessary. The client changed criteria late in the hospital bed communication project due to strategic changes in the project (data point 13.4). The material criteria were more demanding after this change. The product designers of both projects indicated a critical moment at these changes. As a consequence, extra steps were needed to formulate the criteria and to search for materials.

In conclusion, criteria are adjusted during the set activity when they are not clearly enough formulated to make a set. The many design aspects included in the criteria, relating to both user-product interaction and technology, caused the lack of clarity of these criteria. An extra step during the set or comparing activity is needed to clarify the criteria before a set of candidate materials can be selected.

Comparing the selected materials based on the formulated criteria, can lead to the discovery that the criteria are incomplete, rendering comparisons impossible and an extra step is necessary to find discriminating criteria for comparisons. Examples of incomplete criteria were found in the category where none user-interaction aspects were considered.

Question 3, abilities of information providers

Successes in the materials selection steps depend on the availability of information about materials (question 1). This section outlines how the different information providers contribute to these successes. The information sources that provided information about user-interaction aspects (UI category) are compared with the ones informing about other aspects (NUI category).

In general, specialized advice accelerated the materials selection activities. However, these recommendations could also slow down the process when not accompanied by background information. For example, a product designer indicated that some materials parameters, such as the melt flow index of plastics, are only one of the data points in the viscosity curve. This information cannot be used to predict the true processing conditions of the material (case 12). Without interpretation, an information source is not valuable (case 4). On the other hand, wholly pre-processed information is not what product designers are seeking for either. Product designers question the reliability of the information provided (case 6, 7, and 13) or keep searching for new candidates as they do not know which aspects have been included in the choice of the information source (case 8). Besides, motivating choices is a way to add to the design company's experience (case 8).

Active and specialized

Figure 6.3, in which the bubble size represents the number of participants giving a specific score, shows that the information providers that were used in the UI-category vary more in their activeness than in the NUI-category. The sources were reasonably active in the NUI-category except for 3 information providers. Some information providers in the UI-category were judged as active and some as not active. The specification level charts in figure 6.3 show a similar difference between the two

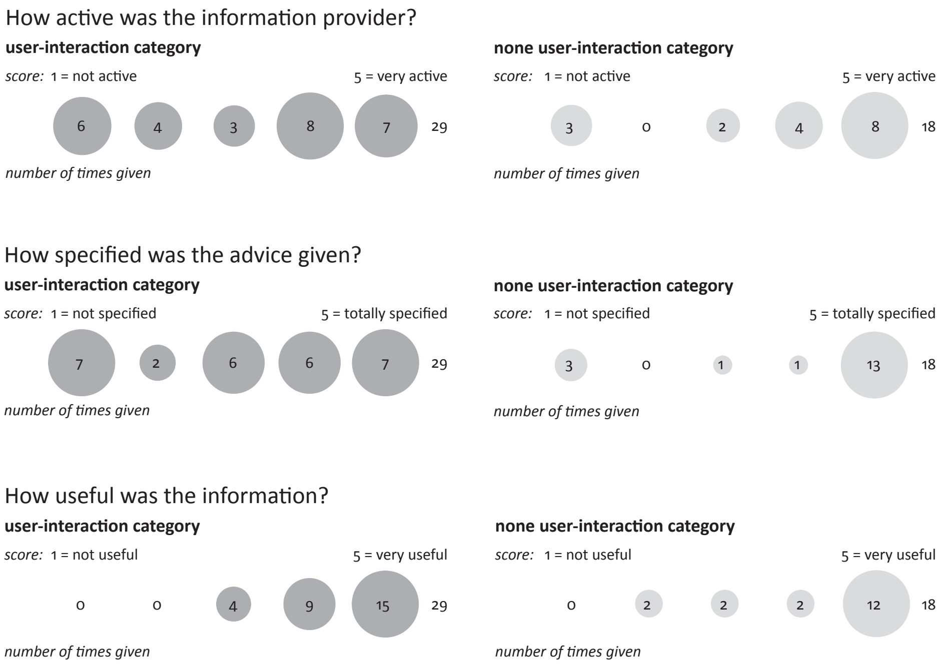


Figure 6.3

Distribution of answers given in the information questionnaires. 1) How active was the information source? 2) How specified was the advice given? 3) How useful was the information?

Table 6.5
Information providers used in the UI and NUI category including the scores on the activeness of the source and the level of specification of the advice given.
$N_{\#}$ number of data point — 5 active or specialized
M_A mean score on Active — 1 not active or specialized
M_S mean score on Specified

Information provider	UI category			NUI category		
	$N_{\#}$	M_A	M_S	$N_{\#}$	M_A	M_S
Client	3	3,33	4,00	3	5,00	5,00
User	6	1,83	2,17	0	-	-
Supplier	6	4,00	3,60	5	3,80	5,00
Manufacturer	0	-	-	4	4,25	4,50
Group of people	5	3,80	3,40	2	4,50	4,50
Other	9	3,13	3,13	4	2,50	2,60
Total	**29**			**18**		

categories. The information that is used in the NUI category is judged as specialized in more than 72% of the data points compared to 25% in the UI category. Product designers can use specialized advices without interpreting the information. They thus need to interpret the data or parts of the data in the UI category more often than in the NUI category.

Both categories score high on usefulness. Afterwards, the question that was asked seemed to aim at how well the product designer was able to search for and use information. It thus evaluates the product designer instead of the information provider. Most product designers judged their own capabilities as good.

The results show that the information activities in the UI category take more effort from the product designers. The information coming from the sources in the UI category is less specified for the criteria in the project. The activities in which the information is needed thus take longer in the UI category than in the NUI category.

Information sources

The client, supplier and a group, consisting of a combination of sources, were found as information providers in both the UI and NUI category (table 6.5). The user was, obviously, found as a source only in the UI category, but provided no information about technical aspects. The manufacturer is shown as information provider only in the NUI category. Although the product designers considered user-interaction aspects in the moments categorized as UI, they explained that not every source provided information about user-interaction aspects, and clients in particular did not do so. The product designers needed to interpret the client's information for defining and assessing the user-interaction aspects of the materials.

Table 6.5 summarized the scores on activeness of the information providers and how specified their recommendations were. The results show that the clients are less active and specified in the UI category than in the NUI category. The supplier is similarly active in both categories but less specifying in the UI category. The group of people is equally active and specialized in the two categories and it depends on the composition of the group whether there were people able to provide information about the user-interaction aspects of materials. The 'other' sources score relatively low in both categories although slightly higher in the UI categories. This category includes non-personal information sources such as books, so the mean scores are influenced by that. The users are not active or specified. They are often observed in user-tests and their information is transferred by the product designers into usable information.

In conclusion, the results teach us that product designers put more effort in the information activities when considering user-interaction aspects than when considering other aspects. The information providers are less active and specialized in the UI category. Material experts were not expected to be able to provide information about user-interaction aspects of materials, although the materials suppliers were frequently consulted on this. Manufacturers and clients however, tended not to be involved in providing information about the user-interaction aspects of materials. Consequently, product designers can not specify their criteria regarding these aspects or can evaluate the materials based on user-interaction and manufacturing criteria together.

6.4 Discussion

The MSA model was used in this study as a framework to find critical factors in the materials selection steps of 15 design projects. This section discusses the results and evaluates how effective the model was in structuring the steps and the difficulties that the product designers encountered.

Discussion of the results

Material suppliers and a group of people, such as a combination of client, supplier and manufacturer, are consulted to provide information both on user-interaction aspects and technical aspects. However, the client and manufacturer are mainly experts on technology aspects. This is a problem because the client is involved in formulating material criteria and these are determinative for the materials searches (section 5.3). Furthermore, clients are involved in choosing. Different concepts of the criteria can thus lead to disagreements in the choosing activity, which might in turn lead to extra steps in the materials selection process. Currently, therefore, product designers cannot start with clear objectives and constraints about user-interaction aspects.

Identifying difficulties with finding information about user-interaction aspects of materials was expected. Additionally, the results revealed the more specific problem of product designers not getting specified advice about these aspects. Such recommendations are desired by them to speed up the decisions in a materials selection step. Product designers only get ‘raw’ information about user-interaction aspects that they need to interpret themselves. Product designers can use this information to re-evaluate candidate materials when project objectives change. However, it offers no certainty about their choices. For an effective materials selection process, information providers should be able to include user-interaction aspects in their recommendations.

Although adjustments in the criteria were made during the set and comparing activities, the product designers did not always mention that this influenced the effectiveness of the process. They see it as a normal part of the designing process and are accustomed to taking a step back when needed. The question is, however, whether it is possible to reduce the chance of having to take such a step back. If the criteria are well clarified in advance, the number of extra steps needed when searching for materials can in many cases be reduced.

Fifteen design projects were evaluated in this study. In every project, critical factors were indicated, as were the moments at which product designers used their formulated criteria or information. The total number of data points on which the results are based seems limited: for example, just 9 data points were identified at which critical adjustments were made in the formulated criteria. However, finding these data points justifies that there is indeed an interesting moment in the materials selection process that merits attention. There are two arguments in favour of this. First, the projects were discussed in retrospect. That means that the product designers needed to recall their processes. They may reasonably be expected to recall the most critical factors in this process, as the everyday difficulties have disappeared into the background. The results are thus based on these most critical aspects in the process. The second argument is that, contrary to the expectations, the results revealed extra critical factors in the cases. These were, for example, the effect of project changes on the materials selection process and the need for specialized advice as well as background information about this advice.

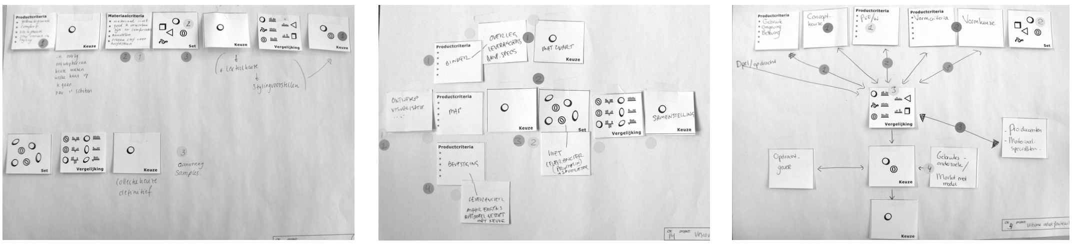


Figure 6.4
Examples of the outlined cases of the study. The product designers made linear representations (left example), hierarchical representations about different product parts (middle example) or relational representations (right example).

Use of the MSA model for structuring a project

The basic activities of the MSA model were used in this study as elements to structure the materials selection steps taken in a design project (criteria, set, compare and choose activities). These activities were set down on cards in two forms to represent different detail levels (see the outlined steps of the case study mentioned in section 5.2). The product designers who described the projects were free to adjust or add cards. The supportive activities (information and testing activities) were not shown on cards, in order to be able to discuss the supportive activities a step later than the basic activities. This enabled the product designer first to describe the whole picture of the process and then focus on the aids to the process.

The product designers were eager to talk about their projects and started off without using the cards. After probing, they felt free to use the cards and to adjust them. Working with two cards per activity clarified matters, as product designers understood that they could indicate the different steps they took and did not need to stick to one selection step.

The outlined case made with the activity cards appeared to be valuable as a memory aid when going deeper into the critical factors and information use in the materials selection process. The two step approach helped the designers to oversee the whole process and indicate the most relevant issues herein. This makes the interview technique effective. This not only worked for structuring the case in an effective way, but it also helped with the data analysis.

In some occasions, the activity that the product designer described could not be represented by any of the given activity cards. It appeared to be extremely difficult for the product designers to formulate an activity on the same abstraction level as the given cards. The researcher often gave an idea which the product designers agreed with or not. This means that the activity cards are only useful to describe the materials selection steps in a generalized way. Using the cards to go deeper into the separate actions is difficult since the researcher might influence the representation of the actions too much. Furthermore, the fact that the activity was performed in the past makes it complicated to make detailed descriptions of the actions.

In some of the cases the product designers felt limited in their descriptions because of the systematic interviewing approach that did not match their creative materials selection approach, which involved letting people to talk about their projects and experiences. Although unstructured interviews can generate an enormous amount of valuable information, it is more complicated to process the data than with some structure as with the cards. The product designers were therefore stimulated to use the cards, which resulted in different approaches to outline the projects from linear in time to combined activities that are performed simultaneously (figure 6.4). One out of the 15 product designers did not outline a case with the structure provided.

Another effect of using the cards to describe a case was that the product designers were very careful about selecting the right card for a step in the project. They thought aloud about the considerations to select one and sometimes made changes after describing some of the preceding steps. The product designer thus verifies whether his descriptions are indeed representing the steps he took. This might indicate that fewer mistakes are made in the outlining of the case.

Summarizing, the MSA model is effective in structuring a case, although only on activities level. This level is sufficient for finding the critical factors and information use in a materials selection project, but does not provide enough details to analyse the separate actions the product designer performs.

6.5 Conclusions

Several critical factors were found in the studied projects. These critical factors lead to extra steps in the materials selection process or not finding the optimal solutions for a project. The factors thus influence the effectiveness in the materials selection process.

The overall problem was that project objectives sometimes change after a material search has started. As a consequence, some of the materials selection activities already performed were no longer useful for the new objectives. These changes thus meant unnecessary extra steps and led to ineffective materials selection. Three other critical factors were found that were part of the materials selection process.

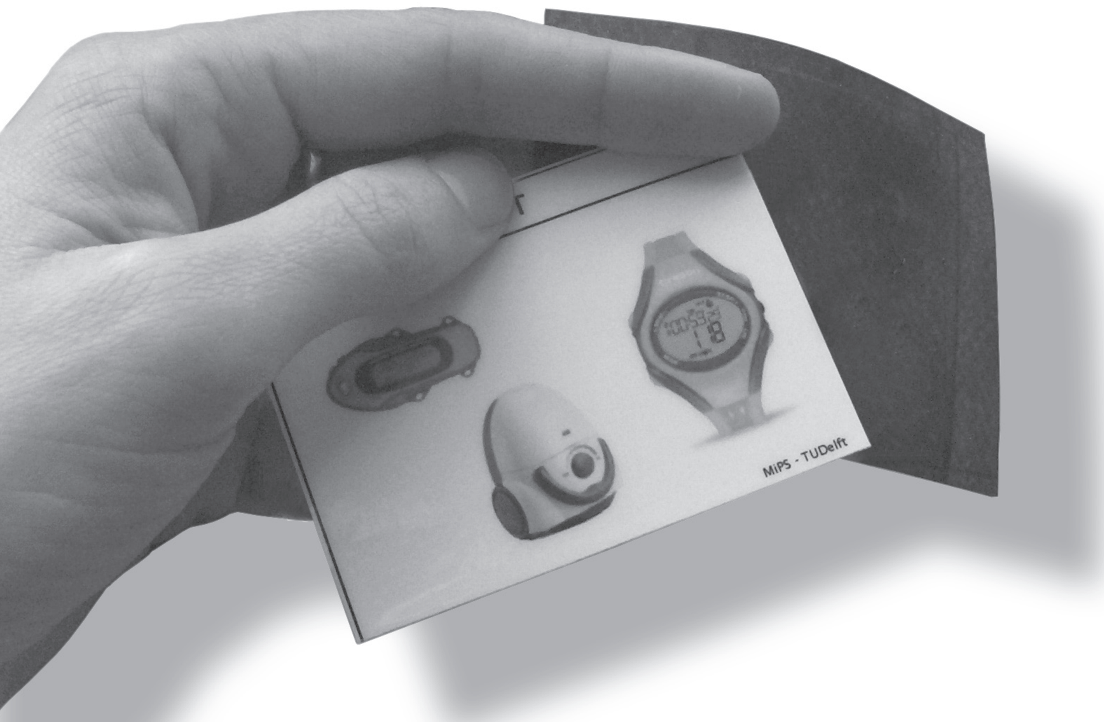
1 The first critical factor is the formulation of a clear set of material criteria. The clarity of criteria is influenced by the degree to which criteria are specified and agreed upon between people involved in the project. Unclear criteria, especially about user-interaction aspects, made it difficult for product designers to make a set of candidate materials or to compare them. The client, who is an important information provider in the criteria activity, is not always supportive here. The problem is that this results in extra steps in the materials selection process to clarify the criteria.

2 The second critical factor concerned the availability of information about materials that combines different design aspects, such as user-interaction and technology aspects. The problem is that product designers cannot make an integral decision about these aspects, leading to longer searches to find the best available material options.

3 As a third critical factor, product designers indicated the following: They prefer a combination of specialized advice and background information on the considerations leading to this advice. Knowing the basis for a particular recommendation is helpful when modifications to the product are required. This background information was not always provided in respect to user-interaction aspects of materials, leading to extra steps to verify whether the materials can still meet the changed requirements.

Synthesis of new materials selection technique and tools

Part 3



Chapter 7

Proposal for a new materials selection technique

In the analysis part of this thesis, the materials selection activities of product designers were explored to increase the understanding about an effective materials selection process. The materials selection steps were processed into an activity model and based on this model the critical factors that influence the effectiveness in materials selection were identified. These results are used in this chapter to formulate directions for improvements in the process. Thereby, not only the findings based on current practice are used, but also the trends and opportunities found in the background part of this thesis are included.

The chapter presents a vision for an improved approach in materials selection. Generally, the approach is to postpone the thinking about materials solutions in the analysis phase until a clear set of materials objectives and constraints are formulated. This approach can be stimulated with a new materials selection technique and tools to support it. The outline for this technique is presented in section 7.3 and the design and evaluation of the tools for this technique is presented in chapter 8 and 9. The final designs are presented in chapter 10.

7.1 Directions for an improved materials selection process

The following discusses the three areas for improvements in the effectiveness of the materials selection process and how product designers could improve this. These areas are 'the clarity of materials criteria' and 'the accessibility of adequate information about materials'. Furthermore, the area of improving the user-interaction quality of products with new materials is discussed.

Starting a materials search with clear objectives

The quality of a design is influenced by the shared understanding about the objectives for a design (Valkenburg, 2000). To avoid expensive changes and delays, it is rewarding to get things right form the beginning (Janhager, 2005). This is important for the design objectives and includes the material objectives and constraints. As shown in the Materials Selection Activities (MSA) model in figure 5.5 on page 78, product designers put effort in formulating the material objectives and constraints in the analysis phase of a project. Theoretically, this would lead to an effective process and high quality products. However, several critical factors decrease the effectiveness in practice as discussed in chapter 6.

Critical factors

An overall problem found was, although project objectives are discussed at the beginning of a project, they sometimes change after a materials search had started. The new objectives often require new materials criteria and thus extra steps in the materials selection process. The fact that product designers often, already in the analysis phase, select a set of candidate materials to start with, increases the risk that these do not suit the new objectives. Hence, choosing materials early in the design process decreases the effectiveness of the process.

The active parties involved, in the formulation of material objectives and constraints, are the product designer and the client. They need to discuss the objectives and constraints to generate a mutual view about the aimed for interaction qualities. However, clients find it difficult to express their ideas for the user-product interaction on a material level. The mutual view is therefore minimal. As a result, product designers do not have a clear starting point for the materials searches. Furthermore, when choosing materials, the client and product designer can have different perceptions of the formulated criteria, which complicates the choosing activity. Hence, the lack of clarity of the criteria on user-interaction aspects decreases the efficiency to find materials that both client and product designers agree upon.

Improvements

Overall, to increase the effectiveness of the process, product designers should try to avoid the chance of changes in the project. Furthermore, increasing the clarification of material criteria about the user-interaction aspects, should lead to lesser steps to clarify the criteria during the materials searches. Since the objectives and constraints come about together with the client, the suggested improvement necessary to start a materials search with clear objectives is:

> ***Improvement 1*** *Formulating clear criteria on the user-interaction aspects of materials with the clients of the project*

Using the available information about (new) materials

Chapter 2 explained that product designers use various ways to access information and use different information sources to acquaint themselves with the materials characteristics of candidate materials. The availability of adequate information influences the time needed to find the information and the quality of the solution found. The critical factors study in chapter 6 revealed that there are several critical factors that diminish the adequate use of information in the materials selection process.

Critical factors

Product designers indicated two critical factors in their information activities. Firstly, regarding the lack of specialized advice about candidate materials: product designers have a preference for advice from the specialists they consult in the materials selection process. Secondly, regarding the availability of information about the combination of user-interaction aspects and technology aspects. The main problem experienced was, that there is hardly any information available that includes both kinds of aspects of a material. This leads to longer searches to find the best available candidate materials for both aspects. Furthermore, it could result in not finding the best available options for creating the user-interaction qualities of the product.

The information that is used during the searches is mainly coming from suppliers, manufacturers and the client. The interviewed product designers explained that the last two have difficulties with informing about the user-interaction aspects of materials. This can partly be explained by the different backgrounds and focus that they have related to the product, such as the budget requirements or manufacturability.

Product designers do not only indicate to prefer a specialized advice, they also need to understand why the advice was given. This background information, accompanying an advice, is necessary for considering the consequences of the advice for the project. When this background information is not available, product designers need to ask for a new advice when material criteria are fine-tuned in the project. This makes the materials selection process unnecessary longer.

Improvements

The search for materials that meet the user-interaction criteria as well as the other criteria is a long process as it is difficult to get recommendations about the user-interaction aspect of materials. However, there is plenty of information available about the technology aspects of materials (see for example the overview in: Karana *et al.*, 2008). The process of finding adequate information about the user-interaction aspects of materials could thus be improved when the technology information is adequate for the user-interaction aspects as well. The suggested improvement is therefore:

> ***Improvement 2*** *Reducing the difficulties for information providers to give an advice accompanied by its backgrounds about user-interaction aspects of materials*

Using the user-interaction qualities of new materials

In the introduction of this thesis was explained that new materials can have better user-interaction qualities than the conventional ones and therefore have the potential to increase the user-interaction qualities of products. However, as found in chapter 5, product designers define, for the most part, the materials for a new product in the analysis phase. For example, they choose materials that are conventional in a certain product category. Thereafter, they start the materials searches with this predefined direction. As a consequence, new materials are hardly considered in the synthesis phase and product designers and their clients do not grasp the opportunities to apply new materials with enhanced user-interaction qualities. To be able to increase the user-interaction qualities of product the following improvement is therefore necessary:

> ***Improvement 3*** *Including new materials in the considerations in the materials selection process*

7.2 Tactics for achieving the suggested improvements

In the current materials selection practice, product designers experience problems with the effectiveness of their process. Adjustments in their approach could diminish these problems. The alternative approach should aim at accomplishing above described improvements as illustrated in the following:

Tactic 1

A practical tactic for achieving improvement 1 is, for product designers, improving the formulation of material criteria in the analysis phase of the selection process, together with the client. The client should be helped to formulate his objectives and constraints in a clear manner. The analysis phase can then result in a material profile that forms the basis for the materials selection searches in the synthesis phase. The main benefit in this approach is that the discussion about the requirements is not stopped by thinking about solutions. This discussion is crucial to increase the clarity of the material criteria especially about the user-interaction aspects of materials. The presumptions in this tactic are:

1 The involvement of the client in the discussion about the objectives and constraints diminishes the need to clarify the criteria once a material search has started and could reduce the changes later in the project. When a change is indispensable in the synthesis phase, the knowledge about the material profile helps to identify the changes needed in the material criteria and the already chosen candidate materials.

2 Discussing the user-interaction aspects of material in the analysis phase has the advantage that a lot of target decisions are made in this phase and the required user-interaction aspects of the materials can be formed here. Results of user-studies can be directly translated into material criteria. Hence, not only can the effectiveness in the materials selection process be improved with this approach, but also the user-interaction qualities of products.

3 When the client is involved in the formulation of the profile, he knows what to expect from the outcomes of the materials searches and might indicate fewer changes. Furthermore, the client is better able to consider the consequences of the decisions for the qualities of the product.

Tactic 2
Clarifying the objectives for a material search theoretically eases up the materials searches in the synthesis phase including the information activities; however, the profile for the needed materials should be understandable for the information providers. A practical tactic for the achievement of the second improvement can thus be found in the content of the material profile. The material profile should be written in a language understandable for technology-oriented information providers. The presumption in this is that when a mutual vocabulary is used, this enables specialists to include the user-interaction aspects in their specialized advice.

Tactic 3
The tactic for achieving the third improvement follows from the first and second one, which suggest making a material profile as an end result of the analysis phase. The presumption here is that when, in the analysis phase, no materials are chosen yet, and the synthesis phase can start with clear objectives and constraints instead of certain materials, it is easier for product designers to include new materials.

The improvements for including user-interaction aspects in the materials selection process can thus be found in the product designers' effort in the formulation of a material profile. When this profile includes the required user-interaction aspects of the new product, they can effectively include these aspects in their materials selection process. Furthermore, when the material profile is understandable for manufacturers and suppliers, who are the important sources for new materials, they can better inform product designers about the superior qualities of new materials. An approach in which a clear material profile is made in the analysis phase is expected to lead to this.

7.3 A technique for the analysis phase in materials selection

As argued, making a material profile in the analysis phase, should lead to increased effectiveness in the materials selection process. However, product designers need new techniques to make such a profile as they currently follow a different approach. In this approach, two criteria are important:

> ***Criterion 1*** *The client is involved in the creation of the material profile with required user-interaction aspects for the new product*

> ***Criterion 2*** *The profile is understandable for the information providers in the materials selection process*

In this section, the outline for such a new technique is explained as well as a theoretical answer on the question about which terminology could be effective in the material profile to enable technology-oriented information providers to advice about the required user-interaction aspects.

Outline for the new materials selection technique

The materials selection technique aims at describing a material profile that includes the required user-interaction aspects of the new product. Making a profile requires first to define what is needed for the interaction qualities of the product and then to

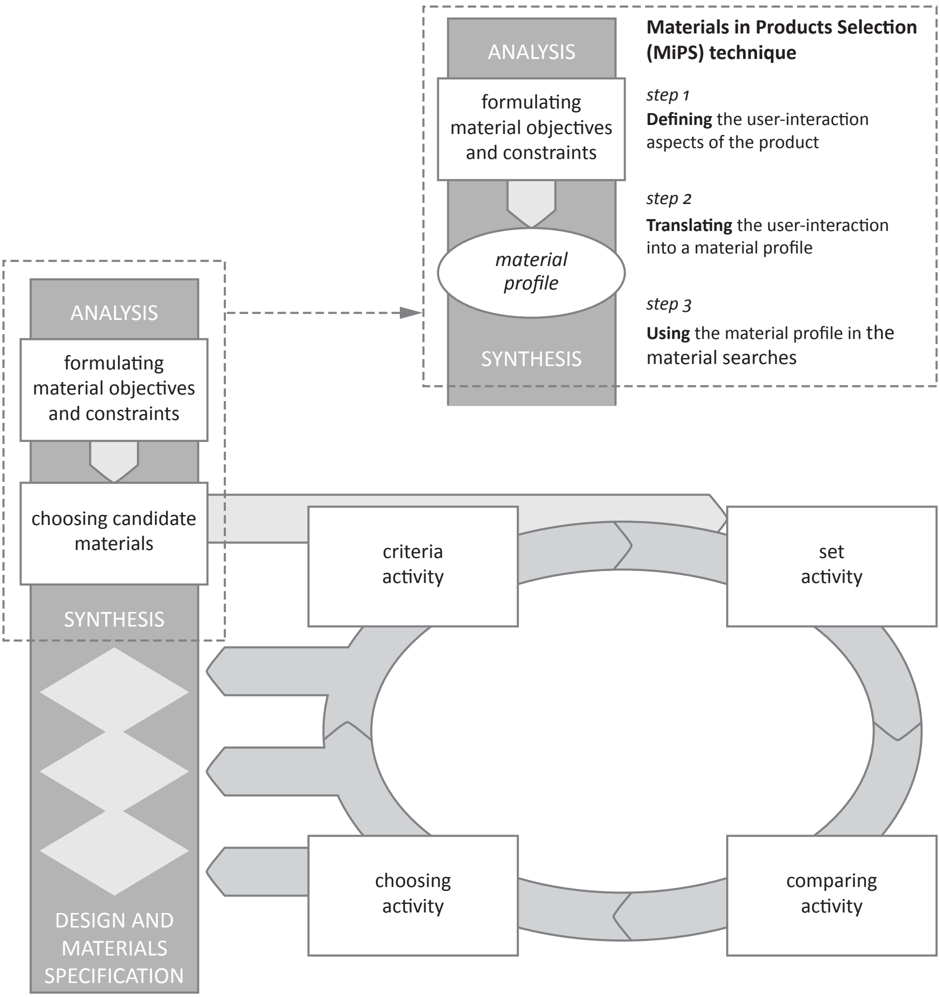


Figure 7.1
General steps in the Materials in Products Selection (MiPS) technique. The technique is placed in a simplified MSA model as explained in section 5.4.

put those needs in the profile in an orderly and understandable way. Thereafter, the material profile can be used in the materials searches. Hence, a technique to write such a profile overall consists of steps for these three activities (figure 7.1). This technique is named the Materials in Products Selection (MiPS) technique.

In the defining step in the technique, the user-interaction aspects of the new product are discussed by the product designer and client. Thereafter, the results of the discussions are put in a material profile in the translation step. In this step the user-interaction criteria are made understandable for the technology oriented information providers. In the usage step, the material profile is used in the synthesis phase to search for adequate materials. In the usage step, the profile forms a basis for finding candidate materials, comparing them and choosing them. Furthermore, the profile forms, when necessary, the basis for the reformulation of criteria.

The defining step is performed together with the client to meet the first criterion and should result in a clear mutual view about the material objectives and constraints regarding the user-interaction aspects. This mutual view can be accomplished by using new tools that will be described in the next chapter.

The second criterion is that the material profile is usable in the materials searches and thus that it is usable by the technology oriented information providers to base their advice on. Cross (2000) explains that in some cases, there is a very close relation between different views on a product, such as, how to sell it, how to make it or how to use it. He explains that the physical properties of a product create the technology characteristics. These characteristics form the product attributes, which in turn satisfy the user needs. This vision provides opportunities to find a common language to bridge the communication difficulties caused by the different views. The material profile could thus be documented in a language that is both suitable to describe user-interaction aspects of a product and is understandable for information providers with a technology background. In the following is discussed how the sensorial properties of materials can be sufficient for this.

A material profile in sensorial properties

Sensible language to discuss user-interaction aspects

Clarifying the user-interaction requirements for the materials searches means that there should be a minimum of interpretation steps needed to find the materials that fit the requirements. The most interpretation is needed when the user-product interaction is discussed in use or personality terms, for example about the ease of handling, or about the perception of the quality of the product. People can have different interpretations of these terms and therefore translate them differently, leading to different sets of candidate materials for a new product. This can influence the effectiveness of the selection process when the proposed candidate materials do not match the expectations of the client. A significant part of the interpretation steps should therefore take place during the discussions for the material profile.

Discussing the sensorial interaction of an end-user with the product could be used for reducing the interpretation steps needed in the materials searches. In another study, we found that non-designers are able to describe materials in terms of sensorial aspects (Karana & van Kesteren, 2006). The sensorial interaction with the product is a key aspect in the using and experiencing of a product as outlined in section 2.1. The sensorial perceptions are furthermore closely connected with the materials of which a product is made. Our senses are the first point of contact with the physical product and Adank & Warall (2006) argue that the senses should be a valuable source of information in the development of products. Defining the user-interaction aspects in sensorial terms is therefore expected to lead to a minimum of interpretations steps in the materials searches. Consequently, it is expected that finding candidate materials based on sensorial terms leads to materials that better match the mutual understanding of the required user-product interaction. For example, it is much clearer to look for high gloss and white materials (sensorial terms) than for material that express a high quality (perception term).

A small study provided insight into the assumption that formulating the required user-interaction aspects as sensorial properties leads to a uniform selection of materials (appendix 4). People with different backgrounds selected materials based on two different material profiles. The first profile was written in perception terms and the second in sensorial terms (table 7.1). The aim was to find out which profile leads to a higher consistency of selected materials. When a profile is formulated in sensorial terms, it was expected that people more often selected the same materials than when you formulate a profile in terms of perceptions. The results of the study show that it is likely that a profile described in sensorial terms requires less interpretation during the materials searches and thus leads to a clear set of criteria about the required user-interaction aspects of the product.

Understandable language for technology-oriented information providers

As outlined in section 2.1, the user-interaction aspects of materials are perceived by the human senses to enable usage and experiences of the product. The specific material properties that influence the senses are the sensorial properties, such as gloss, colour, texture, smell, flexibility. Sensorial properties are defined in this thesis as being a material characteristic that can be measured (table 2.1 on page 25) and Zuo *et al.* (2004b) explains that these properties have direct relations to the physical properties of materials. For example, the sensorial property glossiness or scattering is connected with the physical properties: reflection coefficient, surface roughness, orientation of pigments and the index of refraction. Hence, the sensorial properties and the related physical properties are expected to act as a sufficient language for technology-oriented information providers to advice about the user-interaction aspects of materials.

Manufacturers of materials develop materials with special sensorial properties. In the plastics industry, the continuous development of new pigments results in almost

Table 7.1
Material profiles on the basis of which the participants selected three materials from a set.

Profile	Instruction
Perception terms	The appearance of the materials should fit the modern camper; high tech, comfortable, durable and sturdily
Sensorial terms	The materials should be opaque and glossy, do not scatter or be flexible, but do contain a texture

infinitive possibilities to create visual effects. To structure the realm of possibilities, manufacturers offer special aesthetic portfolios, such as VisualFX of GE Plastics (www.geaesthetics.com). These portfolios are specially developed based on trends in colours and technological developments in pigments. Other examples resulting from materials developments are high gravity compounds that help to influence the weight of a material, and odour compounds that mask or add a specific odour.

Summarizing, the presumption is that a profile described in sensorial properties could be sufficient to enable technology oriented information providers to advice about the best material options to create a required user-product interaction. Furthermore, describing the user-interaction aspects in sensorial terms could help to reduce the interpretation steps needed and thereby clarify the criteria.

7.4 Conclusions

The current materials selection approaches of product designers lead to problems when user-interaction aspects of material are involved. Improvements are expected when clients are involved in the formulation of clear criteria on the user-interaction aspects of materials and when technology-oriented information providers can give advice based on these criteria. Furthermore, the user-interaction qualities of products can be improved when a new approach increases the opportunity for applying new materials. A new technique is proposed in this chapter to improve the integration of user-interaction aspects in the formulation of material criteria. The technique is expected to result in better formulation of criteria and an improved definition of a material profile and a more efficient material search process.

With the Materials in Products Selection (MiPS) technique, product designers and clients are to discuss the required user-interaction aspects for the new product based on the sensorial interaction. These discussions result in a material profile formulated as sensorial properties. Sensorial properties are related to physical properties of materials, which enables technology-oriented information providers to recommend the best material options for the desired user-product interaction. Furthermore, a profile in sensorial properties is expected to lead to a clear profile that needs a minimum of interpretations during the materials searches.

Section 8.2 is based on:
Ilse van Kesteren, Pieter Jan Stappers and Sjef de Bruijn (2007) **Defining user-interaction aspects for materials selection: three tools**. Proceedings of the Nordic Design Research Society, May 27-30th 2007, Stockholm, Sweden. www.nordes.org

Section 8.4 is based on:
I.E.H. van Kesteren, P.J. Stappers, J.C.M. de Bruijn (2007, in press) **Materials in Products Selection: a tool for including user-interaction in materials selection.** International Journal of Design. December issue

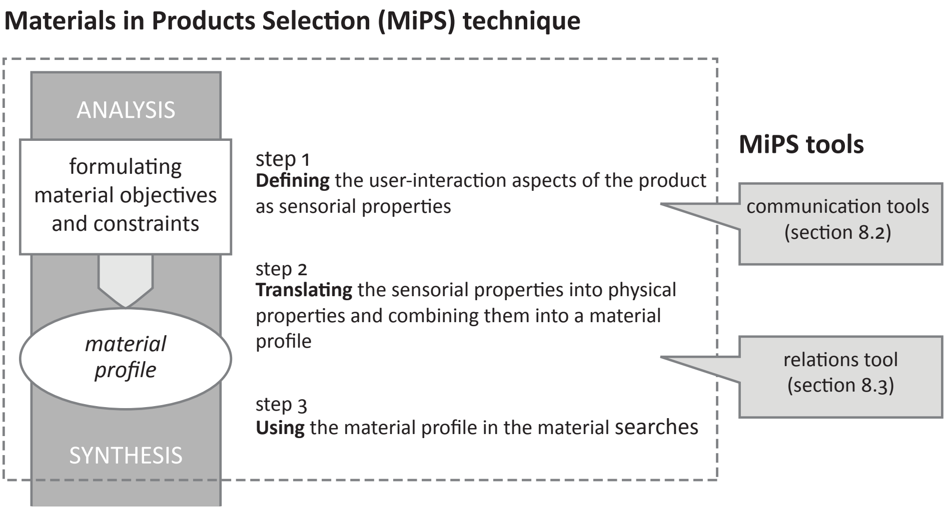


Figure 8.1
Materials in Product - Selection technique and the position of the tools.

Chapter 8 Designing tools for user-centred materials selection

The previous chapter outlined a technique that is expected to improve the materials selection process. For making this technique effective, several tools are developed. These tools, in broad outlines, help clients to express what kind of user-product interaction they want to create with the product and its materials. Furthermore, the tools help product designers to translate these required user-interactions into the material profile. This profile is then used in the information searches about possible materials. This chapter describes the design steps taken to create these tools and the considerations made herein. Product designers were involved in several steps, for example in a study that evaluates the tools in a fictive design brief meeting. After this study, the tools were adjusted and detailed as presented at the end of this chapter. Chapter 9 and 10 continue with the development of the tools of which the final design is presented in section 10.1.

8.1 Tools for the Materials in Products Selection technique

The Materials in Products Selection (MiPS) technique exists of three steps (figure 8.1) and for two of these steps tools are developed. The tools for step one, defining the user-interaction aspects of the product, are needed to facilitate the client-discussions. For describing the material profile in an understandable manner for technology-oriented information providers, which is step 2 in the technique, a tool is necessary that relates the user-interaction aspects with the physical properties of materials.

Defining step

The client and the product designer start with defining the requirements for a material search. This step results in a material profile that contains the required sensorial properties of materials. New communication tools need to be developed to help the client to talk in terms of user-interaction aspects. In addition, it should help to decide what the key user-interaction aspects are that the product designer needs to focus on in his materials searches. Requirements for such tools are that it uses a practical medium to bring to client meetings, uses a structure that is appealing for both the client and product designer and that it enables to make choices about the directions to follow in the materials searches.

Translating step
This step is performed by the product designers. In this step, they translate the sensorial properties into physical materials properties to make an understandable material profile for the client and himself and for the technology-oriented information providers. This profile contains the sensorial properties and the related physical properties. Product designers can use tools in this step that help to translate the properties and present them in an orderly way. Requirements for such a tool are that it provides the physical equivalents of the sensorial properties in a simple interface, usable from both sides.

Using step
The final step is the using step. The product designer uses the material profile with sensorial and physical properties to find and compare candidate materials and to choose materials. In the search step all materials selection activities as presented in the MSA model (chapter 4) are performed, including the information and testing activities. The tools should thus take the materials selection activities in mind, such as the refinement of criteria. Product designers refine their criteria in the synthesis phase, based on requirements relevant for the created concept designs. Therefore, the material profile should be adjustable. The profile should only direct the materials searches without being too specific. For example, a profile could include a requirement for transparent, light materials, but is too specific when it includes a requirement for a material Shore value of 15.

8.2 Three communication tools

Several tools for materials selection are being developed such as outlined in section 3.2. A considerable number of these tools aim at providing information about materials. These tools are thus effective in the synthesis phase of the materials selection process. A lot of effort is performed for the later stages in this process, although more tools are being developed for the concept design phases such as Skin (Saakes, 2007). A materials selection tool for the analysis phase is rare, although several design tools exist for this phase, such as brainstorming, user studies, and structured ways to formulate the requirements for a project. The knowledge about these tools helped to formulate three ideas for the communication tools.

Three ideas

The three tools in the defining phase in the MiPS technique focus on different aspects of the user- product interaction (figure 8.2). The first idea was to define the user-product interaction via pictures of example products (picture tool). Using pictures of product examples can bridge the desired product personality and the required material properties. The second idea focuses on the materials that represent a wide range of sensorial properties (sample tool). The properties of the selected samples can then direct the materials search. The last tool proposed, uses questions that help to structure a conversation based on the sensorial interaction with a product (questions tool). It focuses on the sensorial experiences of the user. The origin of these ideas is discussed hereafter.

Idea 1: Pictures

Product designers live in their private world of images (Athavankar, 1997). They use tools to communicate their thoughts to other people involved in the design process. Example products are an important frame of reference in the early phases of product development (Pasman & Stappers, 2001). Product designers use visual material (although not only of products) in mood boards and collages for presentations to their clients (Kolli *et al.*, 1993).

The idea for the picture tool is that when product designers want to create a certain personality, they can use existing products and the materials these products are made of as examples. Together with a client, they can select those pictures that represent the personality for the new product and discuss the properties of the example products which they think create the desired personality. Stappers *et al.* (2000) explain that judging samples and their overall similarity is a task that people do well when many attributes are judged simultaneously. Hence, it is expected that clients in particular will benefit, as they can more easily point to example products for what they want, rather than attempting to describe this directly in terms of material characteristics.

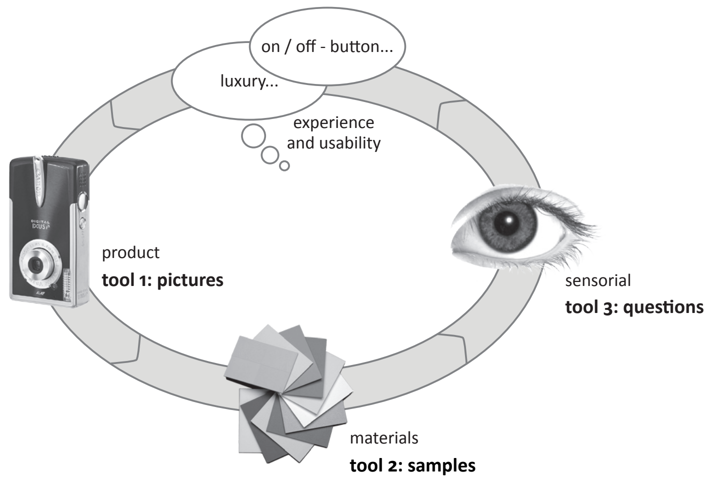


Figure 8.2
User-product interaction and how the three tools focus on the different elements of the interaction.

The use of product examples for designing pleasurable products is not unique. For example Bonapace (2002) introduces a technique called SEQUAM that provide steps to analyse the pleasantness of existing products and the properties these products are made of. In this technique, these properties are assessed and verified in prototypes and user-studies. Although some properties directly refer to the materials these example products are made of, the picture tool focuses only on the material properties, which have an advantage in the materials selection process. Another difference is that the picture tool offers a prepared set of images of products that represent different personalities and include different visual properties.

Idea 2: Samples
As seen in section 2.3, material samples are widely used in materials selection. They are used as a communication tool and to compare and test candidate materials. For example, material samples from suppliers show the various different colours or different transparencies available in their material portfolios. They are used in client meetings to generate a shared understanding of the design (Eckert & Stacey, 2000). The idea is to use samples in the defining phase of materials selection, thus to formulate a material profile. The existing sample sets from suppliers are too detailed for this purpose: they only vary on a few material aspects. A set of samples that represents a wide range of sensorial properties can support the defining phase. These samples help to discuss which materials best fit the required user-interaction aspects. Tactile aspects especially are more easily discussed with physical samples.

Idea 3: Questions
In design brief meetings, topics are discussed that are important in the project. The product designers often have a generic list of questions that are relevant for every project, such as costs, available manufacturing facilities and target group. These topics are formed by experience and sometimes written down in a checklist. The idea for this tool is based on asking questions, namely about the specific topic of how the user interacts with a product. The aim of these questions is to discuss the sensorial properties that form, emphasize or weaken the interaction. The questions help to structure the discussion and point towards relevant issues in the sensorial interaction.

Picture tool design

For the picture tool, a structure was necessary to organize the images of products in a meaningful manner. Such a structure is developed by Govers (2004). She developed a product personality scale in which product personality refers to the character of a product. This scale consists of 20 personality terms that are visualized with pictures. These pictures show situations and objects, not necessarily products. For the picture tool, a similar set of images was made, but then of existing consumer products. To create uniformity in product examples the product category ‘consumer electronics’ was chosen, to which most products can be assigned. Different Internet stores provide numerous pictures of products to select from and these were categorized into the 20

Table 8.1
Personality terms used in the picture tool.

Personality terms			
Cheerful	Cute	Obtrusive	Business like
Open	Silly	Dominant	Aloof
Relaxed	Lively	Untidy	Modest
Easy-going	Interesting	Childish	Honest

personality terms in two steps. In the first step, five main groups were defined in which we categorized the products (calm, pleasant, happy, expressive and provocative). In the second step, the products were categorized per personality term.

Pasman (2003) shows in an experiment that organizing product examples in types, in this case personality types, diminishes the product specific evaluations into a more general level, compared to using single examples of products. He argues that this general level is needed to generate new ideas and reduces fixation on the characteristics of a single product. Therefore, three products were assigned to each personality term.

To verify the preliminary selected set of pictures, five design students[1] were asked to group the selected products in the personality categories. They first categorized one of the groups themselves and then discussed the categorization with the other students. Their second assignment was to look at the material characteristics of the products in each group. They were asked to formulate clues about the materials that created the personality in the products, e.g. the transparency of the materials in the 'interesting' category (figure 8.3).

Based on the discussions with the students, two terms were omitted and two terms were combined for the following reasons. The term 'pretty' was more subjective than the other terms. There appeared no overlap of material characteristics in the products that were grouped in this category. The same held for the term 'idiosyncratic'. Both terms were omitted in the final set. The terms 'serious' and 'boring' appeared to have products with the same material characteristics that were associated with these terms. These two terms were therefore replaced with the term 'business-like'. Lastly, the terms 'provocative' and 'lively' were combined into one term, namely 'lively' (table 8.1).

The picture tool now consists of a set of 16 cards that all represent a different personality. At the front of the card, product pictures are placed, that visualize the personality. The back of the card helps to translate the product aspects into material characteristics by means of clues about the material aspects in the form of keywords

1 Students of the Master program in Industrial Design Engineering at the Delft University of Technology in The Netherlands.

(figure 8.3). While discussing the user-interaction aspects for a new product, clients can show which personality cards are representative for their desired product personality. During the following phase, product designers can discuss the clues related to the selected product examples. Questions the product designer can ask the client are for example: "These products are semi-transparent. Is this what you had in mind, too?" These aspects then form the basis for the material profile.

Sample tool design

The idea of this tool is to offer a wide range of sensorial properties in a set of material samples. The number of samples is limited to the practical issues of storage, portability and ease of use during a discussion. To create uniformity, colour was not used other than the natural materials colour, and similar shaped samples were used.

A matrix with sensorial properties was made to create the set. For every property the variations were put in the matrix. For example, the variations belonging to sensorial property 'transparency' are: transparent, semi-transparent and opaque, and those for sensorial property 'gloss': high gloss, gloss and matt. For each variation a physical or picture of a material sample was selected from different material databases (www.materialexplorer.com, private collection, collection of the faculty of Industrial Design Engineering). The samples selected in this step represented one variation of

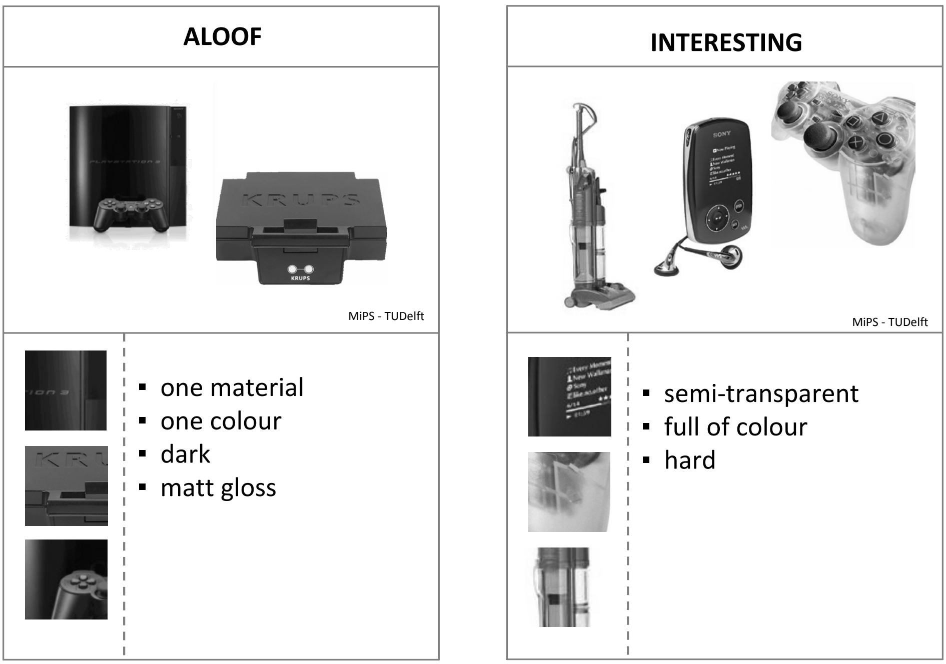


Figure 8.3
Examples of the picture tool.

a sensorial property. The number of selected samples was then reduced in a way that the samples in the reduced set together represented all the variations in sensorial properties.

In another set, samples were selected to represent a certain personality. To this end, a selected group of Govers' product personality aspects (2004) were used. The aspects were selected based on being positive experiences. For every personality term, two or more samples were selected.

Six students[2] evaluated the materials sets to find out whether the samples were grouped logically. The students were first asked to describe the sensorial properties of each sample. Thereafter, they arranged the samples in the same matrix that was used to create the sets, and discussed why they chose to arrange them as they did. Lastly, they selected a set of samples that best represented the variations in sensorial properties and that represented the personality term.

The sample tool now consists of eleven material samples, which were selected to represent a wide variation of sensorial properties (figure 8.4). The samples are card-shaped with dimensions of about 90x60x3mm. Together with the samples a card was developed with the following aspects on this card: 1) the personality terms and definitions, 2) a picture of the sample that was selected for that personality, 3) sensorial properties of the sample. The product designer and client can select a combination of samples that represent the required sensorial properties, while discussing the user-interaction aspects of the new product.

Questions tool design

The aim of this tool is to define the required user-interaction aspects of materials via the sensorial interaction of the user with the product. The tool offers discussion topics that refer to aspects of the interaction. The selection of these topics and the formulation of the questions in these topics were performed in the following way.

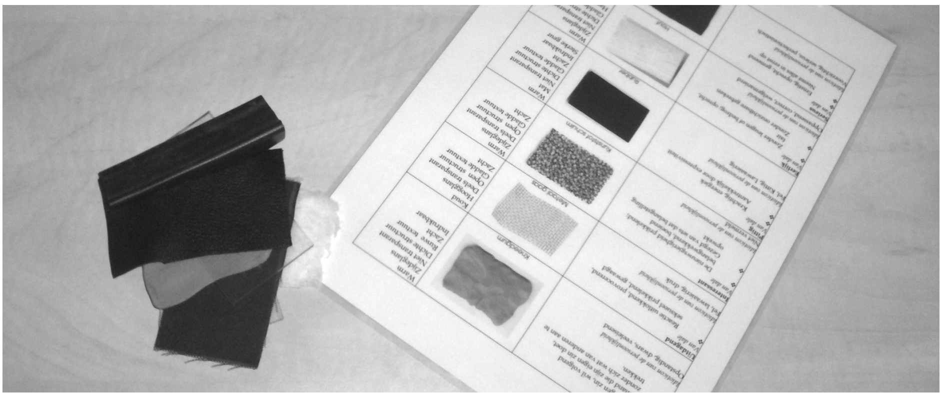
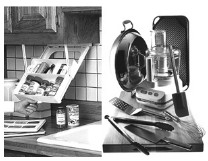


Figure 8.4
Examples of the sample tool.

Table 8.2
Questions tool. The pictures in the right column were added after the usability study described in section 8.4.

Phase	Questions	
1. First contact		
distinctiveness	How will the product attract attention? How does the product differentiate itself? **Which sensory aspects play a role in this?**	
2. Try out		
distinctiveness	How will the product convince when trying it out? **Which sensory aspects play a role in this?**	
3. Transport		
product experiences	Which feedback will the product give during transport? **Which sensory aspects play a role in this?**	
4. Unwrapping		
product experiences	Which lasting experiences will the product evoke? **Which sensory aspects play a role in this?**	
5. Usage		
functional use	Which interaction takes place in using the product? How does the product provide feedback? **Which sensory aspects play a role in this?**	
6. Rest		
product experiences	How will the product convince to be used again? How will the product fit in its environment and with related products? How will the product say good bye? **Which sensory aspects play a role in this?**	

First, topics of the interaction were defined and discussed with two experts[3]. The topics were product experiences, being the emotional, associative and perception responses to the product; the functional use, and the distinctiveness of a product compared to other products. A set of questions was composed for each topic. Second, a structure was created to organize the questions. Requirements for this structure were that it should be easy to remember and follow the natural course of having a conversation rather than being a questionnaire for the client.

A familiar way of organizing product requirements is via a process tree or life cycle analysis (Roozenburg & Eekels, 1995). In a process tree, all phases of a product life cycle are elucidated, from designing to disposal. The approach forces product designers to consider the consequences of their design for every phase. One of the phases is the 'use' phase, which is used as a basis for the questions tool. The questions were organized in six sub phases, i.e.: 1) first contact phase, 2) try out phase, 3) transport phase, 4) unwrapping phase, 5) usage phase and 6) rest phase (table 8.2). In sub phases 'first contact' and 'try out phase', the topic of distinction is discussed. Functional use, as a topic, has been assigned to the 'usage' sub phase. Topics relating to product experiences are discussed in the remaining phases.

After selecting the topics, questions and structure, everything was combined and formatted on an A4 sized sheet of paper. Furthermore, a checklist with sensorial properties was composed (table 8.3). This checklist offers the same aspects that are used in the tool for the translation step (section 8.3). The preliminary design of the tool was discussed with experts again and fine-tuned in several steps.

The tool was used in a workshop with four students[4], who were in the middle of their design assignment. At that point, they had formulated an idea to design a product for adding product personality to a vegetable. The next step was to materialize this product. After a short explanation of the tool, the students' ideas were discussed one by one. One student acted as a 'client' (the idea owner) and the other students used to tool to specify the user-interaction aspects and the related sensorial properties of the product. The researcher acted as a designer, too, taking part in and asking questions during these discussions.

The students evaluated the tool as being very helpful to organize thoughts and not to forget anything. The questions helped them to think about the sensorial properties of their designs and provided arguments for their choices. It provided a new angle of looking at things. However, the students needed training in the tool usage. The questions and phases were not intuitive and the researcher helped them

---

2 Students of the Master program in Industrial Design Engineering at the Delft University of Technology in The Netherlands.

3 Geke Ludden, PhD candidate in Sensory incongruity and surprise in product design (2008); Marieke Sonneveld, PhD in Tactile Experiences (2007).

4 Third year product design students of the Gerrit Rietveld Academy in Amsterdam, The Netherlands.

Table 8.3
Checklist with sensorial properties for the questions tool.

Sensorial properties in the checklist		
Reflection	**Pressure**	**Temperature**
reflective - not reflective	denting - not denting	warm - cold
glossy - matt	soft - hard	
transparent - translucent - opaque	fast - slow dampening	**Sound**
no brilliance - brilliance	massive - porous	muffled - ringing
rough - smooth		low - high pitch
regular - irregular texture	**Manipulation**	soft - loud
	stiff - flexible	
Colour	ductile - tough	**Smell and taste**
hue of colour	brittle - tough	no odour - fragant
one colour - many colours	light - heavy	fragrance
colourless - full of colour		flavour
durable - changable colour	**Friction**	
pattern	sticky - not sticky	
	dry - wet - oily	
Light radiation	rough - smooth	
low - high light emission	regular - irregular texture	

a lot in the first discussions. The students suggested providing more examples in the instructions accompanying the tool. Another drawback was that the questions did not elicit answers about the sensorial properties that are needed to start a search: the conversations remained confined to product experiences, functional use or distinctiveness. By changing the order of the questions and using another word for sensorial[5], we expect to have solved this problem.

The concept of the questions tool consists of a list of questions and a checklist of sensorial properties. The product designer and the client project their minds into the interaction that the user will have with a new product in a specific phase. The discussion about every phase should end with the question: “Which sensory aspects play a role in this?” The answers on this question provide the understanding about the sensorial properties of a product required in a phase. The checklist can be filled in during the discussion and can be used to summarize the material requirements for the material search.

5 The Dutch words ‘zintuiglijk’ and ‘sensorisch’ are both translations of the English word ‘sensorial’. We use the word ‘zintuiglijk’ in the final Dutch version of the tool.

Remarks on the tools

All three tools are practical to bring to client meetings and are expected to appeal both to the client and product designers. The tools enable to make choices as they stimulate to discuss the sensorial properties (the backs of the picture cards, the card with information about the samples and the last question in the question tool). However, to verify these assumptions, the tools were used in a usability study in section 8.4, for comparing the tools on these and the other issues discussed hereafter.

The tools focus on different senses. The picture tool focuses on visual properties, although some links to tactile properties are made. This concerns mainly the tactile properties that are also visual, such as texture. The sample tool focuses on tactile properties; it encourages people to feel the materials. Colour has been omitted, so that it does not distract from feeling the materials. The questions tool focuses on all senses, although in different phases of the interaction some senses can be more important than others. For example in the first contact phase, more distance senses are used and in the trying out phase more proximate senses (Fenech & Borg, 2006). Whether a combination of tools is better to discuss all senses or that only using one tool is sufficient, is one of the questions answered in the usability study.

The tools differ in the amount of visualisation that is required in the tool usage. The picture tool is the most concrete of the three. Clients and product designers can discuss about products with the help of concrete examples. The client can react directly to the characteristics of these products and compare them with the product he has in mind. The sample tool requires more visualisation and mental translations than the first tool. The look and feel of the material samples needs to be translated to the new product via the sample's sensorial properties. Explaining what is felt is difficult and the terminology of e.g. tactile aspects is limited. The questions tool requires the most visualisation of all three. Clients and product designers need to imagine all things they discuss.

Product designers are used to understanding subjective terms, to visualizing these and translating them into concrete product ideas. However, clients are not, and need help with visualising the things that they want. However, if the methods show examples that are very concrete, product designers can feel restricted in their creativity. They might feel that the tool directs them towards single solutions, which is unwanted. The tools should therefore increase creativity by providing new directions and ideas, but should also help to converge to sensorial properties that can be used for materials searches. The questions that still remain are which of the tools is most effective and usable in the design brief and how the tools affect the creativity of product designers.

Table 8.4
Experts consulted for composing the sheet with related properties.

PhDs on sensorial design topics		Material specialists	
Elvin Karana	Meanings of materials (TUDelft)	Rolf Koster	Designing in plastics (TUDelft)
Elif Öscan	Sound in product design (TUDelft)	Sybrand van der Zwaag	Materials Science (TUDelft)
Geke Ludden	Sensory incongruity and surprise (TUDelft)	Egi van der Veeken	Visual effects of Plastics (GE Plastics)
Marieke Sonneveld	Tactile Experiences (TUDelft)	Nico Noort	Visual effects of metals (Corus)
Lisa Wastiels	Materials selection in Architecture (Vrije Universiteit Brussel)	Peter Legierse	Look and feel of products (Philips)

8.3 Relation sheet for sensorial and physical properties

In the second step in the MiPS technique, the sensorial properties, selected for the required user-product interaction, are related to the equivalent physical properties and put in a material profile (figure 8.1). The sensorial properties are those characteristics that can be perceived by the human senses, such as glossiness, colour, texture, smell, flexibility. These aspects create the product's personality and influence how a person can use a product. To aid product designers in this step, a sheet is developed that they can use to translate sensorial properties into physical properties (see appendix 9).

The sheet does not pretend to be complete at this point. The main purpose of the development of the sheet is to see how it could offer a background for the questions that product designers need to ask when consulting material specialists. The sheet is thus not intended to be a substitute for the conversations that product designers have with specialists, but is meant to help product designers with preparing and focusing the discussions. For that reason, the sheet offers an overview of the kind of relations that exist between the sensorial properties and the physical properties. How the sensorial and physical properties are related, e.g. which reflections correspond to which light absorption coefficients, was not studied in this project. The assessment of these relations is labour-intensive, but valuable, once is established that product designers see the benefits of using such a sheet.

The sheet provides an indication of the properties that can be varied to create the sensorial effect. For example, when transparency is defined as a key property to create an interesting product, the sheet shows that transparency is determined by the light transmission per thickness property and the index of refraction property. Candidate materials can be compared on these properties. Furthermore, variations of these properties can be made, to fine-tune the transparency of the material.

The sheet does not yield a list of possible choices of materials, as materials that are suitable for a specific application not only fulfil the user-interaction requirements, but also the functional, environmental, cost and manufacturing requirements. Before choosing a material, all the properties that are related to these areas must be considered. Selecting materials based on sensorial properties alone can lead to unnecessary iterations. Furthermore, new materials of which the properties are known can be considered as well, using a profile based on properties.

The sensorial properties and the finishing of a product together contribute to the sensorial perception of the user (van Kesteren & Ludden, 2006). For example, colour and reflection can both be a characteristic of the material and the coating used. Furthermore, the tactile aspects of a product are influenced by the materials, as well as the mould texture. The sheet, therefore, not only provides the physical properties related to the sensorial properties of materials, it also provides alternatives for creating a sensorial effect. For example, when a specific hue of colour is required, but the material does not have that reflection property, it is possible to add a surface layer with the specific colour.

Approach for finding the properties and relations

The sheet was created in an iterative manner based on literature and discussion with experts in designing for the senses and material experts (table 8.4). The aspects considered to create the sheet were; 1) What are the sensorial properties? 2) What are the related physical properties for these sensorial properties? 3) What is a suitable arrangement of the properties?

In literature, many sources explain the working of the human senses. From these sources, the different actuators for sensing, such as light, temperature, movement and smell were derived. When these actuators can be created by a product or by materials they are put as a property in the sensorial properties column. For the physical properties column, the mechanical, optical, electrical and thermal properties that create a sensorial property of a material were found in material handbooks and discussions. The basic arrangement of the sensorial properties in the list is, like in many books, per sense. The categorization per sense was discussed with the design aspects to find a relevant arrangement for product designers. The sensorial properties and related physical properties that can be found on the sheet are discussed in the following.

Seeing and the visual aspects of materials

The human eye has two kinds of sensors, one for colour perception and one for light perception. The aspects that we can see are generated by the materials' optical properties. The optical properties are the materials' response to exposure of electromagnetic radiation and in particular visible light (Callister, 1994). The sheet categorizes the visual aspects of materials in colour and other reflection aspects (table 8.5). A special category is formed by luminescence, which is the capability of materials

Table 8.5
Visual aspects presented in the sheet.

Categories	Visual aspects
Colour	Hue of colour, number of colours, pattern, fullness of the colour, darkness of the colour and durability of the colour
Reflection	Reflection (mirroring), glossiness, transparency, brilliance, roughness and texture
Luminescence	Light emission

to absorb energy and then reemitting visible light (e.g. glow in the dark).

Colour

Kreitler and Kreitler (1992) mention that people experience rich and significant meaning when perceiving colour and this is much stronger than with other qualities such as odours, tastes or shapes. This might be one of the factors that brought about many studies on colour theory. Hence, the aim here is not to make a complete new organisation of aspects related to colours, but just to select the ones that seem relevant in product design.

The following aspects related to colour are present in the sheet: hue of colour, number of colours, fullness of the colour, darkness of the colour, durability or changeability of the colour and the pattern. Specific colours can be created by the natural colours of a material or by additional pigments. The hue of colour is the specific wavelength that is reflected by a material. The human eye can perceive this wavelength as, for example, red, blue, green or orange. The number of colours is related to how many distinguishing wavelengths are reflected. For example, in wood many colours can be distinguished. The pattern aspect is related to how the colours are organized in a material. For example, wood has a different pattern in crosscut than in longitudinal cut. The fullness of the colour has to do with the intensity of the wavelengths, so how much light is reflected. Darkness is related to the amount of white and black that is added to a colour.

The durability of a colour explains how a colour evolves over time. Physical properties such as UV resistance, absorption of water and adhesion of pigments influences the durability of colours. For example, older plastic types and paper change colour over time. A special form of changeable colours is the characteristic of some pigments to have different colours in different temperatures.

Reflection

The reflection category includes the aspects reflection (mirroring), glossiness, transparency, brilliance, roughness and texture. According to Callister (1994), three things occur when light meets a material. Some of the light may be transmitted through the material, some will be absorbed and some will be reflected at the surface. These three occurrences have different visual effects. Transition has to do with transparency, absorption with colour and gloss and reflection with colour and mirroring. The aspects are related with each other since the sum of transmitting, reflection and absorption must be equal to the total amount of light radiation. Note that some materials transmit, absorb or reflect only a spectrum of the visual and non visual light. Translucent materials are those through which light is transmitted diffusely; that is, light is scattered within the interior, to the degree that objects are not clearly distinguishable when viewed through a specimen of the material. Those materials that are impervious to the transmission of visible light are termed opaque (Callister, 1994). We define brilliance as a local form of reflection. Brilliance can be created by adding reflective pigments to a lesser reflective material. The material then has high reflection intensity on specific spots compared to the surroundings of these spots.

Chang & Lue (2003) found that the texture of a material distinguishes the perception of that material via the sense of sight more than the sense of touch, however, can not be completely replaced by sight. Roughness and texture are two tactile properties that are added to the visual category as well. Roughness is caused by the material configuration, e.g. concrete has a roughness because it is a mixture of different sized particles and Styrofoam™[6] has a roughness because it is formed by small bubbles. Texture, however, is not a material property but an aspect created by the designed pattern, defined by the differences in depth in the surface in a certain configuration. Textures are made by moulds and machining. Both roughness and texture were added to the sheet to be able to show the influences of these aspects on each other. For example, a certain texture may be required, while the roughness of the material prevents the required texture from being realized.

Luminescence

Some materials are able to absorb energy and to reemit this energy as visible light (Callister, 1994). This 'glow in the dark' effect can vary in how much light needs to be added to reemit light, the wavelengths of the added light and the reemitted light and the magnitude of the delay time between the absorption and reemission events. A process that can be used to produce visible light is called electroluminescence, which is applied in light-emitting diodes (LEDs) (Callister, 1994).

Touching and the tactile aspects of materials

Touching is a sense that is activated by contact between an object and the skin. There are different sensory cells in the skin that perceive touch. These are pressure cells, movement cells and temperature cells (Geldard, 1972). Together they form the complex sense of touch. We categorized the tactile aspects of materials, not according to the sense cells, but according to how a material reacts to manipulation (table 8.6). In the pressure category, aspects have been grouped together that can be sensed by pressing the material. The manipulation category contains aspects that can be sensed

6 Styrofoam™ is a trademark of the Dow Chemical Company.

Table 8.6
Tactile aspects presented in the sheet.

Categories	Tactile aspects
Pressure	Denting, softness and dampening
Manipulation	Stiffness, ductility, brittleness and weight
Friction	Stickiness, wetness, smoothness and texture
Temperature	Warmth

by applying a manipulation other than pressing, e.g. bending. Friction is a category relevant in the user-product interaction, because it has to do with the resistance towards movement. In addition to the manipulation categories, a category was added that deals with perception of temperature.

Pressure

The pressure category includes the tactile aspects of denting, softness, dampening and massiveness. They are explored when people exert pressure to the object, for example by squeezing, pulling, pushing or knocking (Sonneveld, 2007). Materials perceived as hard are not the opposite of materials perceived as soft, at least not in engineering terms (Ashby & Johnson, 2002). The physical property hardness relates to the manipulation that is needed to leave an imprint after pressing. Softness is related to the properties elasticity and bending and has to do with the lack of stiffness (Ashby & Johnson, 2002). Soft materials compress and after handling, return to its original shape and leaves no imprint. The time it takes for a material to return to its original shape after a pressure is applied is termed as dampening. It has to do with the response time of the elasticity.

Manipulation

The manipulation category contains the tactile aspects stiffness, ductility, brittleness and weight. The stiffness of a material is caused by its resistance to being bend. The elasticity modulus of a material is responsible for this. In the pressure category, softness was introduced as a property that represents a lack of stiffness. The properties are, however, perceived via different sensations (pressure and manipulation). The product designer thus has two entrances to search for this property. Therefore, we put them in the list twice.

The ductility aspect is the extent to which a material can be deformed. Lead, for example, can be easily deformed. The difference between this aspect and a material's softness is that after a manipulation is applied, a ductile material retains its new shape; as soft materials, it returns to its original shape. The properties uniform strain and yield strength are responsible for the ductility of a material. The brittleness of a material is caused by the properties elongation at break and fracture toughness. Brittleness can not only be perceived by touch, but also by hearing. For example, porcelain is perceived as brittle when put on a table. The weight of a product is related to the density of the materials used.

Massiveness is the aspect that refers to the structure of a material. For example, some materials are manufactured as foam or as solids. The material molecules are similar, but their structure differs. This affects the pressure and manipulation aspects. For example, the elasticity of foam is different than of a solid and thus the softness is different.

Friction
This category shows the properties that can be sensed by stroking the surface of an object. The friction category includes the aspects stickiness, wetness, smoothness and texture. The smoothness and texture aspects are actually the same aspect as the one categorized as visual aspect and their explanations will not be repeated. Both are aspects that can be seen and felt. Stickiness has to do with the adhesion of a material, i.e. the extent to which it bonds to the skin. Sticky tape is an obvious example. Wetness is caused by the water or oil expulsion under load. For example, the plastic know as 'high density polyethylene' has an oily feel.

Temperature
Very high and very low temperatures are perceived immediately after contacting an object while smaller differences of temperature need longer contact. This is related to the temperature flow, which is related to the temperature difference between the object and the body temperature (Sonneveld, 2007). The temperature aspects are related to the conductivity property and the specific heat of a material (Ashby & Johnson, 2002). These properties influence how fast heat is conducted from the skin and thus whether a material is sensed as being warm or cold.

Hearing and the auditory aspects of materials

The sound of an engine gives clues about how fast the user is driving. Furthermore, the perception of the quality of the car is influenced by the sound the doors make when they are closed. These sounds are influenced by the materials the product is made of, in combination with the mechanical and electrical sounds of the engine and the closing mechanism (Öscan & van Egmond, 2004). Materials only produce sound after impact and the recognition of materials based on the sounds it makes is better for some materials than others (Hermes, 1998). For example, glass, wood and metal are better recognized than plastics. The sheet is limited to the auditory properties that are caused by materials, acknowledging the risk at a representation that has been too simplified when it comes to designing complex products. These are the auditory aspects frequency/ pitch, dampening and intensity in the sheet (table 8.7).

Klatzky *et al.* (2000) studied contact sound in order to understand how persons can perceive materials in virtual reality. They found three auditory cues to materials, namely elasticity, the internal coefficient of friction and the state of stress of a material.

Table 8.7
Auditory aspects presented in the sheet.

Category	Auditory aspects
Sound	Frequency / pitch, dampening and intensity

Table 8.8
Smell and taste aspects presented in the sheet.

Categories	Smell and taste aspects
Smell	Fragrance and odour intensity
Taste	Flavour

Elasticity is directly related to the speed of sound and therefore influences all aspects of sound production, including frequency. The internal coefficient of friction, or damping, influences how the sound will decay over time. This parameter is shape invariant. The state of stress of a material influences the frequency or pitch of sound, as illustrated in many musical instruments. The frequency of sound is related to the density property and damping (or brightness) to the loss coefficient property (Ashby & Johnson, 2002).

Smelling and tasting and the smell and taste aspects of materials

Smelling is considered the most emotional sense. This means that choosing the right smell for a product can be very effective in creating a product personality. Materials have their own smell, for example cork smells earthy and plastics can have a chemical smell. To reduce the smell of plastics, it is possible to add special neutralizing additives (Noiset, 2005). With additives it is also possible to add a fragrance to a material. The adhesion of these fragrance additives cause the material to smell in a certain way. The intensity of the smell has to do with the concentration of fragrance compounds that are released in a time period. The smell aspects of materials are thus the fragrance and the odour intensity (table 8.8).

Taste is perceived when particles of the material dissolve in the saliva and are sensed by the taste sensors located on the tongue. For products that interact with the tongue, it might be interesting to think about the flavour of the material. However, this field is still new. Note that the perception of taste is an interaction between smelling, touching with the mouth and tasting. For example, cinnamon can not be tasted without smelling.

8.4 Usability study in a design brief meeting

The design of the tools has reached the stage where it is now possible to study how the usability of the tools can be optimized. The aspects of the usability of interest are the achievements of the tools, how usable they are and how they influence the creativity of the users. To understand the tools' achievements in design brief meetings, the tools were evaluated in a real life setting. The tools aimed to achieve a high certainty to start an effective materials search, to have a high consensus between client and product designer about the key sensorial properties that create the desired personality and to formulate a material profile in terms of sensorial properties.

Table 8.9
Categories of terms that can be used to describe a material.

Category	Description	Examples
Perception	Most abstract; includes perception, emotions, associations of materials, references to brands or products	Outdoor look, modern, personal, recognizable, fit the target group, natural
Use	All words related to the usage	Usability, withstand dirty environment, hygienic
Sensorial	Less abstract; All aspects of materials that can be perceived by the senses	Texture, warmth, colour, soft, smooth, stiff
Physical	Least abstract; Material and manufacturing properties	Scratch resistance, durable, price, producible in mass
Material labels	Concrete: material names	Plastics, wood, metals

Six professional product designers and six professional clients were invited to use the tools in design brief meetings for two fictive design assignments. Furthermore, twelve students who were not all necessarily in a product design school did the same. The student that did not study design acted as clients. The tools could therefore not only be compared, but also the influence of the participant's experiences on the usability and achievements of the tools could be assessed. The questions that were studied are:

> ***Question 1*** *What do the tools achieve in the design briefs and how do they differ?*
>
> ***Question 2*** *How usable are the tools for clients and product designers?*
>
> ***Question 3*** *How do the tools influence the creativity of the product designers?*

Procedure

The participants of the study used all three tools to be able to compare them. Furthermore, they used no specific tool to compare their own approaches with the created tools ('own method'). The participants discussed two different design assignments in product designer/ client couples. Per assignment, two tools (or the own method and one other tool) were used for ten to fifteen minutes. The total session took 2 hours. The first assignment was a cutlery set with an outdoor look for daily use. The second assignment was a product for a new concept based on the Polaroid camera, but then with moving pictures instead of stills. This assignment was termed 'Polaroid video'. The participating clients were provided with instructions about the assignments. Herein, a fictive company profile was given, as well as the problem definition and task for the designer.

Table 8.10
Summary of the achievements of the tools in a fictive design brief meeting.

Aspect	Score		
	high	medium	low
Increased certainty	Own method	Picture tool	Sample and Questions tools
Consensus about key properties	Own method, Picture and Questions tools	Sample tool	
Profile in sensorial properties	Questions tool	Picture and Sample tools (including a high score on perception aspects)	Own method

Profiles
The consensus between client and product designers was measured at three different points, namely before, in between and after the use of the two tools. We surveyed the participants' ideas about the required materials for the new product at these points. Two questions were asked per profile. First, the participants were asked to indicate their certainty about the product designer's ability to start an effective material search at that point. Second, the participants were asked to describe the material aspects of the new product. The descriptions were used to assess on which level the participants described their material requirements (table 8.9). Next, the participants were asked to complete an extra profile, in which they picked a maximum of five key sensorial properties that they thought were important basing a materials search on. The profile mentioned the sensorial properties of the checklist of the questions tool (appendix 7).

Questionnaire
After the two design brief discussions, the participants were asked to fill in a questionnaire. The aim of this questionnaire was to evaluate and compare the different tools on usability and creativity topics.

Results

Achievements
The certainty indicated on the profiles that were filled in by a participant before and after using a tool were compared. Three situations could occur, namely an increase of certainty, a decrease of certainty or neither (same certainty). The tools creased the certainty about the ability to start a material search (table 8.10). However, the sample tool and questions tool were least effective in increasing the certainty.

In general a limited agreement on sensorial properties in the profiles made by clients and product designers was found (table 8.11). In all sessions and with both assignments a minimum of 1 to a maximum 3 terms out of the 5 selected were similar.

Table 8.11
Number of terms that were filled in similar in the sensorial properties profiles after using two tools.

Tools used	**Number of similar selected terms**			
	Cutlery set		Polaroid video	
First, second	*Students*	*Professionals*	*Students*	*Professionals*
Own method, Picture tool	3	3	2	2
Own method, Sample tool	1	1	1	3
Own method, Questions tool	3	3	3	1
Questions tool, Sample tool	1	1	2	1
Questions tool, Picture tool	3	1	1	2
Picture tool, Sample tool	2	1	1	1

The terms that were agreed upon differed per session, indicating that in every session different material profiles were made.

The picture tool and the questions tool led to most consensuses. Almost every time these tools were used after the 'own method' the product designer and client agreed on 2 or more terms. In the other combinations of tools we do see an agreement on 2 or 3 terms occasionally, but also a lot of agreement on only one term. The picture tool and the questions tool led to most consensuses between client and product designer about the key sensorial properties.

The material terms used in the profiles that the participants made before and after using a tool were grouped into the different property categories (table 8.9). All the created tools stimulated thinking in terms of sensorial properties; however, the picture and sample tool also to the unwanted perception terms in 33%-50% of the profiles (appendix 10).

Usability

In general, the product designers were able to use the tools after reading the introduction. They adjusted the tools to their own approaches. For example, some product designers used the picture tool to make categories of wanted and unwanted personalities together with the client (figure 8.5). Others made a selection before showing the cards. The sample tool invited participants to touch the samples and to explore them (figure 8.6). Some couples grouped the samples as well during the discussion. The questions tool was understood, but the participants had more difficulties in using this tool directly. Only one couple of twelve was able to discuss all the phases of the interaction in the time given in the study. Some product designers advised to not apply the tool in the first design brief. They prefer to prepare themselves by adjusting questions to a specific situation before asking the questions to a client.

The participants mentioned different benefits per tool. They remarked that the picture tool provides a perception of the personality the new product should have. It gives an idea about the materials that create the desired personality. The example products leave plenty of freedom for the product designers, but help the client to define what he wants because he is used to think in product examples. The sample tool quickly brings up the tactile aspects of the materials, according to the participants. It is easier to judge whether or not the materials provide the right feeling with the sample tool than with the picture tool. The sample tool however requires visualisation; some participants found it difficult to imagine the materials in a product. The questions tool works as a checklist. The participants mention that the questions force the client to think about all aspects of the interaction in a more detailed manner than without the tool. A drawback of the questions tool was that it led to long discussions in many cases, but did not resulted in defining sensorial aspects.

All 24 participants (except for one) preferred to work with a combination of tools. They argue that every tool focuses on different aspects of the new product. They suggest that the picture tool is better for the design brief discussion and the samples and questions tools are better in a later stage. The most preferred combination is the picture tool together with the sample tool and thereafter combination of all three.

Creativity
The participants varied much in their opinions about how inspiring the tools were (appendix 10). The picture tool was judged as very inspiring by the majority of the participants. It leads to new ideas quickly. Mentioned drawbacks of the picture tool are that it is hard to think 'out-of-the-box' because the tool provides so many examples. The professional participants found the sample tool inspiring, although it is on an unconscious level, while the student participants did not find the sample tool inspiring. Students experienced the samples as difficult to imagine in the new product. Other students were afraid that the materials were settled after selecting the samples from the set, which was not the intention of the tool. The questions tool was not found inspiring by most participants, although they found the tool clarifying. It

Figure 8.5
Different tactics used with the picture tool.

helped the participants to approach the project form another angle. One participant mentioned that the questions tool was not directing to materials, but to aesthetics and visual characteristics of materials, which is actually the purpose of the tool. Hence, the objectives of the questions tool were not clear in its current form.

In general, the tools were judged as directing, especially the questions tool. Some found the picture tool not directing. The professional product designers and clients did not find the directing of tools annoying. They argue that in a design brief there is no time for chitchats and the questions help to get to the point. The students, however, found it annoying that the tools directed them. They argue that every tool restricts creativity. Half of the student product designers even found this very annoying.

The tools influence the creativity of the users; however, it is hard to say if the tools improve or restrict a person's creativity. The participants' opinions about this issue varied greatly. In general, the results indicated that professionals were stimulated in their creativity and students were restricted in their creativity. The picture and sample tools score better than the questions tool.

Recommendations for improvement of the tools

This section first summarizes the recommendations the participants gave for the improvements of the tools. Thereafter, three areas for improving the tools are discussed, which are a combination of the tools, a clear converging step and focusing on professional designers.

Picture tool

Although the picture tool was generally very well understood and judged as inspiring, the following adjustments can be made to improve the translation of personalities into sensorial properties of materials.

The back of the cards offered clues about the materials of the pictures shown, but did not always lead to describing a material profile in sensorial properties. One reason could be that the backs were not always used by the participants. More emphasise

Figure 8.6
The sample tool invites to touch and explore the required physical properties.

should be given to this side, for example by providing a checklist with all the clues. A simple checklist with sensorial properties can also help, as not every designer agreed on the clues given on the back of the cards. Some participants advised using only product examples and no personality terms; however, we advocate using the terms because they facilitate the discussion, even when clients and designers do not agree on the terms.

Sample tool

The samples help to select the kind of properties that are required for the new product, but the discussions often ended with the selection with one or two samples. The purpose of the tool was in addition to look up the sensorial properties that were represented in the sample to make a converging step in the discussions. The samples could be looked up in a card with all the samples on it. The connection between the samples and information could be emphasized, for example by putting the information on the back of the sample. The use of a checklist with sensorial properties to sum up the discussions is also advised.

The samples that are now present in the set were not considered as very inspiring by the participants. Also, some samples were missing in their opinion. Efforts could be put in compiling a new set of samples with the same background ideas, namely to represent a wide variety of sensorial properties that are more extreme. The material characteristics that the participants felt needed to be added were transparency differences, more plastics, soft materials, stone or ceramics, metals, fibres and gels.

Questions tool

Many participants judged the questions tool to be less usable in its current form. However, the questions tool was the tool most concerned with eliciting sensorial properties, compared to the other tools. For this reason, abandoning the tool is not recommended, but improving it with the help of the following suggestions. The questions were now given as one list, but can be more effective when the phases are separated on different cards. The order of the phases can then be changed easily, which was often needed in the discussions. Although it is still important to discuss all relevant phases, the discussions can follow a more natural sequence than with a predefined order of questions. The next suggestion is to add pictures of situations to the question cards. It is then easier to imagine the new product in the different phases. For example, the first contact phase can be illustrated by a picture of a shop.

Some participants suggested using the questions tool at a later stage in the design process; however, this is not recommended. As soon as the project objectives are defined, it is wise to consider the materials objectives as well to reduce the number of iterations. However, preparation by reformulating the questions before the actual meeting with the client is recommended.

Combination of the tools

The tools could be improved by making a combined form. Although the participants considered a combined form with the picture and the sample tool, starting with the questions tool would be most beneficial, as the questions tool was more focused on sensorial properties than the other tools. In addition, this tool led to a high number of similar key properties on which to base a materials search. The uncertainty caused by the questions tool can be reduced by using the picture tool or sample tool to aid the discussions per user-product interaction phase of the questions tool. The combined tools are especially effective when the picture and sample tool focus on different sensorial properties.

The results showed a wide variety of opinions about usability and creativity of the tools. Not only did it show differences between professionals and students, and between clients and product designers, it also revealed differences within the groups. This means that one tool does not suit all. A combination of tools may meet the needs of more users; however, product designers should then be able to select and use only some parts of the combined tool. The tool could then be effective for different product designers, working with different clients and in different projects.

Material profiles in terms of sensorial properties

Not every tool yielded a material profile described in terms of sensorial properties. Although the tools were designed for this, especially the picture and sample tool led to material profiles described in perception terms. Although clients and product designers use the same perception terms, they still might translate the terms differently into materials characteristics, which is undesirable. The picture and sample tools thus seem to lack a clear translation step.

The questions tool resulted in a material profile in sensorial terms. In this tool, the translation step was indicated by the last question for every discussed phase, namely "Which sensorial properties play a role in this?" Furthermore, a checklist of sensorial properties was provided. Although not every product designer used this checklist, it helped to direct the discussions towards sensorial properties. A similar translation step can make the picture and sample tool more leading to sensorial properties than they are now.

Professionals and students

Students and professionals differ in their experience with the execution of materials searches for design projects and the background of these projects. Students have almost no experience with projects for clients and with design brief meetings. Despite these differences, we expected that the tools would be usable for both professionals and students. However, the results show that both groups respond differently to the tools.

Students have more difficulty with the tools than the professionals. The students find the tools more restrictive their creativity and have more trouble using them than professionals. Some students were very explicit in their disinterest in using the tools for future projects. An explanation might be that students do not yet encounter the

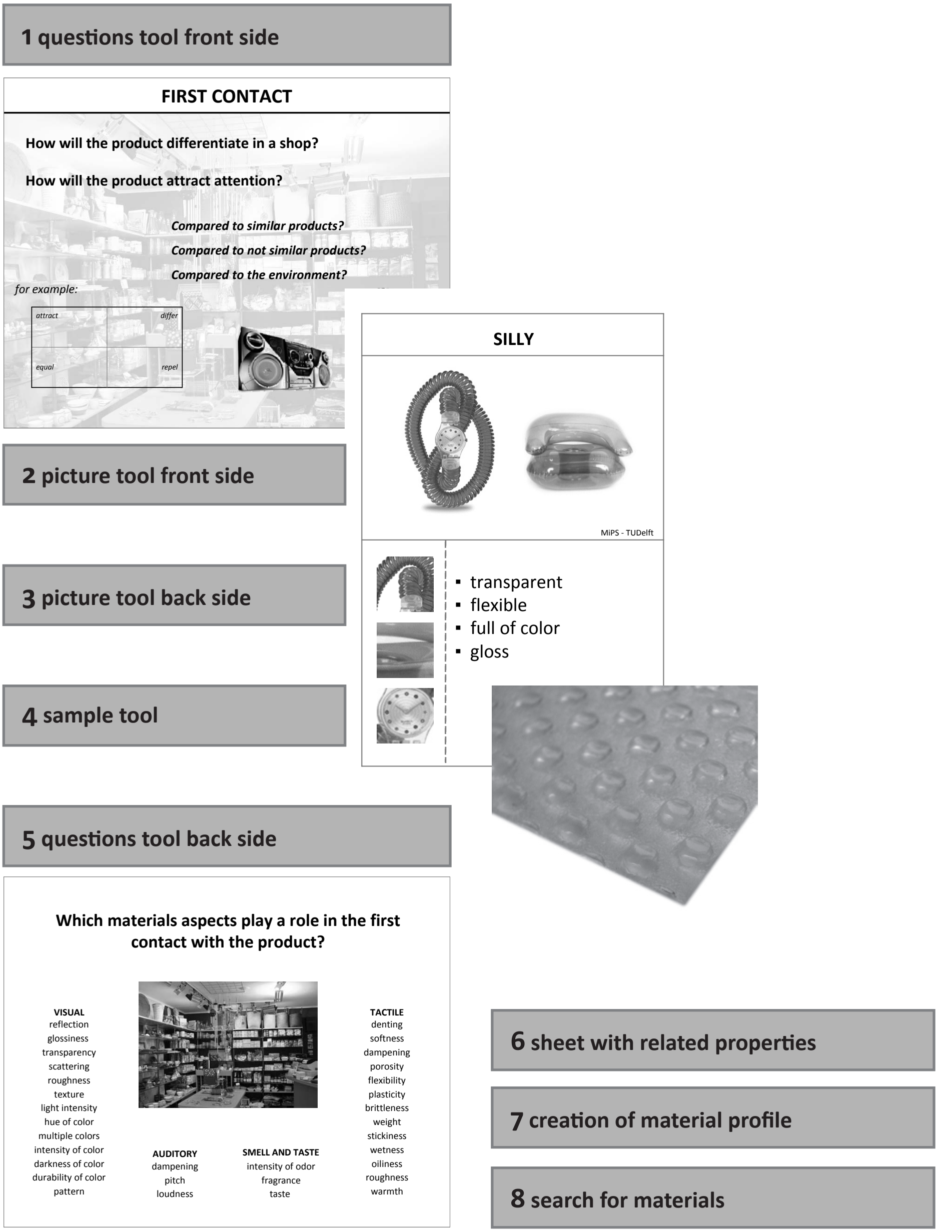


Figure 8.7
Order in which the Materials in Products Selection (MiPS) tools are ideally applied. Step 1 to 5 are performed in the defining phase of the MiPS technique, step 6 and 7 in the translating phase and step 8 in the usage phase.

problems in materials searches addressed by these tools. They did not understand the effort needed to diminish these problems, and therefore were less willing to use the tools. Furthermore, Ahmed *et al.* (2003) found that novice designers were less experienced with using design strategies, such as this tool requires. Students probably need more time to learn the tools before they can use them.

8.5 One combined tool for the MiPS technique

The usability study clearly showed that the current tools can be improved to increase their functioning. The recommendations for improvement were to combine the tools and to increase the communication about the sensorial properties. The expected advantage of a combination of tools is that the strengths of every tool can be extended to reach consensus about the key sensorial properties that create the required user-product interaction. This section examines the considerations made to integrate the tools. How the tools are integrated is visualized in figure 8.7. The questions, picture, sample tools and checklist with sensorial properties can be found in appendix 5, 6, 7 and 8.

The basis for the combined tool is the questions tool. In the concept form, the questions of every phase were presented on one piece of paper. In the combined form, the questions will be separated per phase and presented on cards. The advantage is that the product designers can change the order of the phases more easily with separate question cards. Furthermore, the back of these cards can be used too. This creates space for a checklist mentioning the sensorial properties of materials. Just as with the picture tool, one side of the card can then be used as a diverging step (the questions) and one side can be used as a converging step (the sensorial properties).

For every phase in the user-product interaction, the picture cards and material samples support the discussions about the desired visual and tactile interaction. The picture cards and samples were adjusted such that they can be used in a mixed form. Every card with product examples is now accompanied by a material sample. The set of material samples was thus extended from 11 to 16 samples. The samples represented one of the material characteristics of the products on the cards. To maintain a wide variety of sensorial properties in the sample set, some of the product examples were changed. For example, the product examples of the 'modest' card were changed to be able to add a textile material. Some of the materials as suggested during the usability study were added in the new version.

The samples were made the same size as the picture cards (80x60mm) and on the back of the picture cards a fragment of the materials sample was added. The product designer is then provided with a visual clue to the sample and when using the sample, the product designer can find the sample characteristics on the back of the picture card. The card with properties that was used in the concept form of the sample tool is then no longer necessary. On the questions cards, visual clues are given of the picture cards and samples to stimulate the product designers to use them as aid for answering the questions.

In the concept version of the tools, a clear converging step was missing. The checklist is an important element of the tool to facilitate the converging step. Using the checklist forces product designers to define the required user-interaction aspects as sensorial properties. Although the sensorial properties are given on the back of the question cards, which already function as a checklist, a separate checklist is provided on which the designers can make notes. The checklist is designed in such a way that there is a white space available to make a sketch or add text. The aspects mentioned on the back of the picture cards can be directly noted on the checklist when using the cards or the samples. Both use the same terms. Using the picture cards and samples as aid for the questions discussed per interaction phase, could stimulate the designers to make a converging step. The importance of this converging step will be stressed in the instructions of the tool.

8.6 Conclusions

For the first two steps in the Materials in Products Selection (MiPS) technique, the defining and translating step, tools were designed. The first kind of tools facilitates the communication of product designer and client for defining the required user-interaction aspects in terms of sensorial properties. The second tool provides a sheet to translate the sensorial properties into physical properties of materials so that they can be used to get material advice from technology-oriented information providers.

The communication tools (questions, picture and sample tools) were evaluated separately in design brief meetings with product designers and clients. The tools were effective in different ways. The picture and questions tools led to a high consensus between product designer and clients about the key user-interaction aspects in a material profile. Only the questions tool did this by directing product designers to sensorial property words, which was the purpose of the tools. The picture tool was very user-friendly and together with the sample tool they were stimulating creativity of clients and product designers. The questions tool was not evaluated as being user-friendly or stimulating creativity in its concept form.

Adjustments were made to be able to combine the tools. This combined form uses the advantages of every tool and improves the converging step in the tool. Although the initial tools helped product designers with defining user-interaction aspects, they still translate only a low percentage of these aspects into sensorial properties. Emphasising the importance of the checklist with these properties could stimulate to define the material profile in sensorial properties. The combined tool is therefore expected to be successful in increasing the effectiveness in the materials selection searches, which will be studied in the next chapter.

Chapter 9 Evaluating the tools in design practice

The previous chapter explains the design of the new materials selection tools for the Materials in Products Selection (MiPS) technique. These tools help to communicate about the required user-interaction aspects of a new product and its materials in a design brief meeting. Furthermore, the tools help to formulate this profile in sensorial properties and its physical equivalents. Using the tools is expected to facilitate the materials searches following the design brief. For example, the material profiles that are formulated with the tools help technology-oriented information providers in giving advice about the suitable materials. Furthermore, the results of these searches are expected to correspond to the clients' expectations about the materials. In this chapter, the tools are evaluated in ongoing design projects. The results of this study increase the understanding about the situations in which the tools are effective and in which they are less effective and how they can be improved. The results are used in chapter 10 to revise the MiPS technique and tools.

9.1 Objectives and expectations of the study

The function of the tools that support the Materials in Products Selection (MiPS) technique is to create clear criteria in a material profile about the required user-interaction aspects of a new product (table 9.1). The tools involve the clients, who are the persons that contract product designers to do a design project, in creating this profile. This material profile is formulated as sensorial properties, which form the bridge between the user-interaction aspects and the physical material properties. The tools are expected to increase the effectiveness in materials selection by diminishing the extra steps needed to clarify criteria and needed to find materials that create the required user-product interaction. Furthermore, they intend to support the increase of user-interacting qualities of the product.

Saakes (2007) found that when discussing a tool, product designers often focus on the limitations, but when they actually used the tools, they focused on their designs and

Table 9.1
Usage and functions of the MiPS tools.

Tool name	Consists of	Used in	Function
Questions tool	6 cards with questions *(appendix 6)*	Defining phase with client	Discuss the sensorial aspects in the user-product interaction phases
Picture tool	16 cards with product examples *(appendix 5)*	Defining phase with client	Define the sensorial aspects of the new product based on existing products
Sample tool	16 material samples *(appendix 8)*	Defining phase with client	Select the leading sensorial properties based on material samples
Checklist	Overview of sensorial properties *(appendix 7)*	Defining phase	Summarize the discussion into a material profile
Relations sheet	Sensorial properties and their physical equivalents *(appendix 9)*	Translating / searching phase	Relate the sensorial properties with the physical properties of materials to make a combined material profile

experiences rather than on the limitations. He mentions that it is important to explore tool use in practice using real-world projects. Only discussing the tools with design professionals might not reveal the actual effects of the tool. Product designers were therefore allowed to experience the effects of the tools by using them in practice before they were asked to evaluate them. The approach yielded insight into the effects in larger projects, compared to projects that are possible in a fictive laboratory situation.

Aim and research questions

The variety of demands that practice puts on the tools, means that they need to be flexible for various different design situations. The evaluation method is therefore to put the tools in design practice and not test them in a streamlined pre-described process. The aim of the present study is to assess the tools within the MiPS technique in design practice and evaluate their effect on the materials searches in the synthesis phase.

Product designers were asked to use the MiPS tools in the client meetings of their own projects and then to evaluate the tools. The tools were not only evaluated during the client meeting at which the product designers used the tools, but also during the preceding materials selection activities. Participating product designers were given a diary to recall their observations and reflections on the effect of the tools on the materials selection process soon after they experienced the effects. The tools are effective when three criteria are met. First, the product designers used the tools. Second, they understood the benefits of the tools and third, they noted a positive change in the design brief meetings and the materials searches compared to projects in which they did not use the tools. Such effects were, for example, fewer changes in the project, an increased understanding of the material profile or easier materials searches compared to other projects. The criteria were studied via the following research questions:

> ***Question 1*** *Which of the tools do product designers use in their process?*
>
> ***Question 2*** *What are the benefits of the tools according to the product designers?*
>
> ***Question 3*** *How is the tools effective in the synthesis phase?*

Furthermore, we tried to find ways to improve the effectiveness of the tools. We therefore asked the product designers to make suggestions for improvements based on their usage experience of the tools. The results help to revise the tools and to create a user-instruction for the tool. The fourth research question is:

> ***Question 4*** *What is needed to make the tools more effective?*

Expectations

The focus of the evaluation of the tools is on three first phases in the materials selection process, namely 1) the design brief meeting, 2) the preceding materials searches and 3) the meeting in which the product designer proposes the candidate materials to the client. This means that the tools are studied in the analysis phase and during at least one cycle of the Materials Selection Activities (MSA) model (figure 9.1).

In the usability study in section 8.4, in which the tools were evaluated only in the design brief meeting, we had found that the professional product designers were able to use the first versions of the tools and adjust them to their own preferences. The current tools are expected to be equally useable, although some improvements were made as described in section 8.5. An extra aspect that will be studied here is how the use of the MiPS tools affects the agreements made between product designer and client about the materials. In the MiPS technique, these agreements are summarized in a material profile and form the starting point for the materials searches. In the previous study, the product designers were not starting a material search based on the design brief, therefore, they did not document the material objectives and constraints. The use of the tools before an actual search should lead to a material profile in terms of sensorial properties.

The translation of sensorial properties into physical properties is expected to improve the materials searches. The reason for this is that technology-oriented information providers are able to give specialised recommendations about the physical properties related to the required user-interaction aspects of the materials. This advice accelerates the materials selection process (section 6.3). Furthermore, it should be easier to make a balanced comparison of materials based on both the technology and user-interaction aspects.

After the materials searches, the product designers meet the clients again to discuss the candidate materials found based on the product designers' understanding of the objectives and constraints discussed in the design brief. After using the tools, the candidate materials are expected to better match the expectations of the client and that he or she will be less eager to indicate changes. There are two reasons for this assumption. Firstly, the client was more involved in defining the user-interaction criteria for the materials and thus knows what to expect. Secondly, the product designer could do his search based on the leading sensorial properties and therefore was able to focus the search on the required properties.

9.2 Case study method

About 25 product designers were approached by mail and telephone to invite them to participate in the study. Most reacted enthusiastically about the tools and the emphasis these tools could have on the materials selection process. They acknowledged the fact that they needed new tools and were willing to try them. Although, in design agencies, design projects are regularly started, it appeared extremely difficult to find shorter projects within the time frame of the study that included the user-product interaction. Most of the product designers contacted declined to participate because of these restrictions.

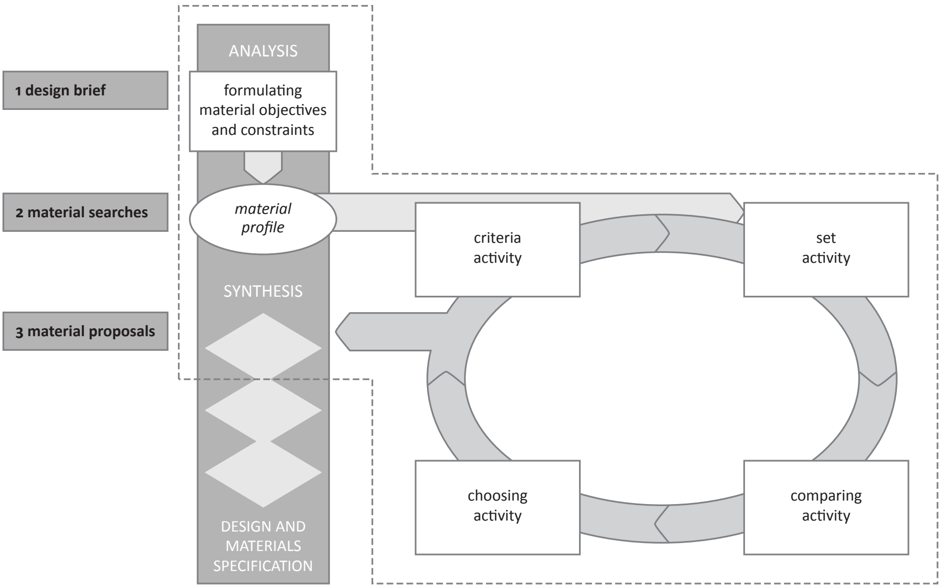


Figure 9.1
Part of the materials selection process that is evaluated in this study shown in the simplified version of the MSA model.

Table 9.2
Summary of the cases in which the tools are used. The product will be used as a label for the case.

Case	Product	Relation with the client	Moment in the project
1	Child saver	Known client	After technical design phase
2	Beverage packaging	New client	Very start
3	Interior for a reception room	Known client	After research period
4	Hearing aid	Used with colleague	After research period

Four product designers were interested to invest in the evaluation of the tools and were willing to use the tools with their clients. Furthermore, they were able to find a project in which user-interaction aspects were relevant that fell in the time frame of this study. The four projects form a heterogeneous group; they differ on product category, on the relationship between product designers and client and the project phase during which the tools were used (table 9.2). Because the aim was to explore the variety in demands that practice puts on the tool, this proved an effective combination of projects for the study. All product designers worked for an agency that offers the design project to clients from initiation to finished product.

Procedure

The MiPS tools as explained in section 8.5 are used in this study (table 9.1, appendix 5 to 9). The tools were given to the product designer in person to be able to explain the different tools, give a quick demonstration and explain the purpose of the study. The benefits of using the tools were not revealed in the instructions of the tools as this was one of the research questions. In addition to the tool, the product designers received a research diary. This diary contained instructions for using the tool (appendix 11), instructions about the study, and questions that the product designers were to answer during the specific phases in the study (figure 9.2). The instructions in the booklet were similar to the ones given in the previous study described in section 8.4. Those participants were able to use the tools on the spot, without training. The participants of this study read the booklet and studied the tools before they used it in their client meeting.

The participating product designers were interviewed twice: once after the design brief meeting and then again, after the meeting in which the product designer presented the candidate materials to the client. The first interview took approximately one and a half hours, the second, one hour. Otherwise, the researcher was not present.

Diary questions A: Pre-briefing of the study. The product designer answered questions about his normal design and materials selection approaches and his communication with the client. Furthermore, he explained the project in which he would use the tools. These questions were important to understand how the product designer usually worked and to compare his customary approach with the process followed in this study.

Phase 1: Design brief meeting The product designer used the tools in a meeting with the client and thereby actively changed his approaches. He or she could decide which parts of the tools to use and in what manner. This phase resulted in a material profile on the basis of which the product designer could start phase 2.

Diary questions B: After the meeting with the client, the product designer was asked to fill in questions about the meeting and the material profile that was made. Specific questions were asked about which (parts of the) tools were used and why *(question 1)*, as well as what the effect of using the tools on the discussions was. The product designer was asked to compare the design brief meeting, in which he used the tools, with a previous design brief meeting in which he did not use the tools.

Interview 1: The diary answers for A and B were discussed during the first interview. After explaining a general impression about the tools the product designer was asked about his answers in the diary pages one by one. The focus of these discussions was on the benefits of the differences *(question 2)* and effects *(question 3)* mentioned by the product designers.

Phase 2: Materials searches After the design brief meeting, the product designer could start the design process and the materials searches in this process. No special instructions were given with regard to these searches.

Diary questions C: Before the product designers presented the candidate materials chosen to the client, they were asked to fill in the questions for item C. These questions concerned the materials searches and the iterations required herein. Special attention is given to the information providers contacted during these searches. Again, questions were asked about the differences between materials searches in other projects and in the studied project.

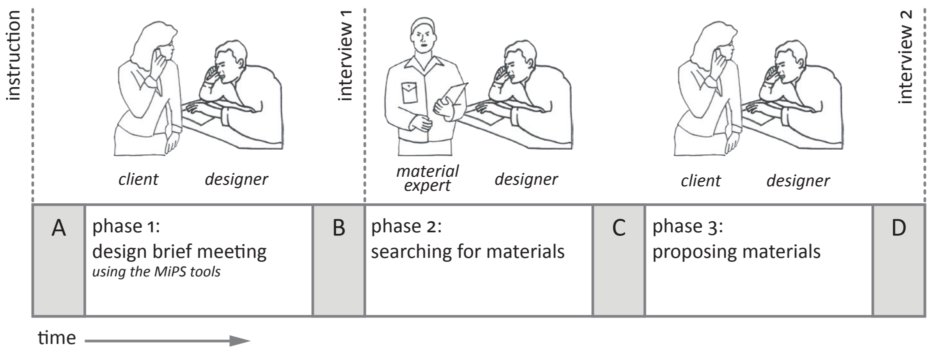


Figure 9.2
Procedure of the study.

Phase 3: Material proposal The last phase studied was the second meeting with the client in which the product designer presents the results of his searches and proposed candidate materials for the new product.

Diary questions D: The last set of questions could be filled in after the second client meeting. These questions were about the client's reaction on the proposals and whether or not adjustments were needed after this meeting. Finally, the product designer was asked to summarize the most important effects of using the tools on the different phases in the materials selection searches.

Interview 2: In this interview, the answers for C and D were discussed. The focus was on the benefits of the differences experienced *(question 2)* and the product designer's visions on the effect of the use of the MiPS tools on the course of the project *(question 3)*. Furthermore, possible improvements to the tools were discussed *(question 4)*.

Data processing

The interviews and diary answers were processed into a case description per project. These case descriptions consisted of the following topics in order to be able to answer the different research questions.

1 A project description and a description of the context in which the tools were used, where in the process, and the product designer's relationships with the client.

2 The way the tools were used, which parts were used and in which order *(question 1)*

3 The difference between the product designers' approach with and without the tools in the design brief meeting *(question 2)*

4 The course of the materials searches and the differences with other projects *(question 2)*

5 The product designer's vision on the effect of using the tools on the materials searches and on the reaction of the client on the proposed candidate materials *(question 2)*

Besides a textual description of the case an outline was made per case in which the following aspects were presented (figure 9.4, 5, 6 and 8). The legend of the outlines is presented in figure 9.3.

1 Project outline with the design steps taken in the studied project. Three kinds of steps were distinguished, namely steps where the product designer meets a client, steps in which the project designer works alone or in a team and steps in which the designer contacts materials experts. The steps where the product designer used the tools were indicated in the scheme.

2 The studied period related to the design steps taken.

3 The period the tools were used and the specific parts of the tools that were used. Indicated is whether the product designer just looked at the tool, used the tool as part of a conversation or when the tools were used to drive the conversation.

4 The main effects of the tools that the product designers noted during the different design steps.

The case descriptions were sent to the participating product designers to allow them to make corrections.

9.3 Case descriptions

The functioning of the tools was studied in a sequence of materials selection activities in design practice and the realities of field studies in an industrial context were encountered. For example, in one project the client of the product designer cancelled the project after the studied client meeting. The tool was used here, but the effect of the tool in the next phase could not be experienced, simply because it was cancelled. In another project, the focus shifted from user-product interaction towards technical design and further studying of the project was not relevant. As a result, the product designer of the child saver and hearing aid products did not follow the whole sequence of the study. However, most of the topics were discussed during the first interviews.

The different cases are described in the following. The opinions in the descriptions are those of the participating product designers. The interpretation of these opinions is presented in section 9.4: 'discussion of the results'.

Case 1 – Child saver[1]

The child saver is a new product that gives an alarm signal when a child falls into the water. The user-interaction aspects of materials are relevant in this project because the child should enjoy wearing the product. However, the technical aspects drive the development as the functionality of the product is new and there is a range of safety requirements involved.

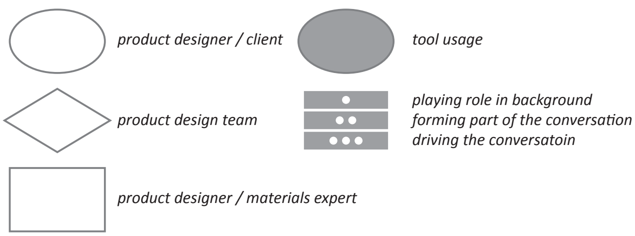


Figure 9.3
Legend for the outlines of the cases (in figure 9.4, 9.5, 9.6 and 9.8).

The MiPS tools were used in a meeting with a known client at a moment where most of the basic material decisions had already been made (figure 9.4). The technical development of the product was already in progress for a year. Unfortunately the project was cancelled shortly after this meeting. Hence, this case only describes the results of the first interview.

Use of the MiPS tools

The general impression of the product designer was that the tool was compact and easy to bring to clients. “It is effective in a sense that I do not have to make a set of samples from the extensive collection available at the design agency”. As a drawback of the sample tool, the product designer noted that the translation from a sensorial property to a product is rather abstract, both for himself and his client as illustrated by his comment that: “I prefer to use samples of buttons to discuss which softness or flexibility is required by the client in the buttons of a new product”.

The picture and sample tools were used at a client meeting. These two tools are attractive; they can be shuffled around, played with. The questions tool and the checklist were not used. The product designer: “The project had progressed quite far and the questions were suitable for the beginning of a project”. The sensorial properties, both in the checklist and the sheet with related properties, did not fit the product designer’s usual approaches of referring to materials.

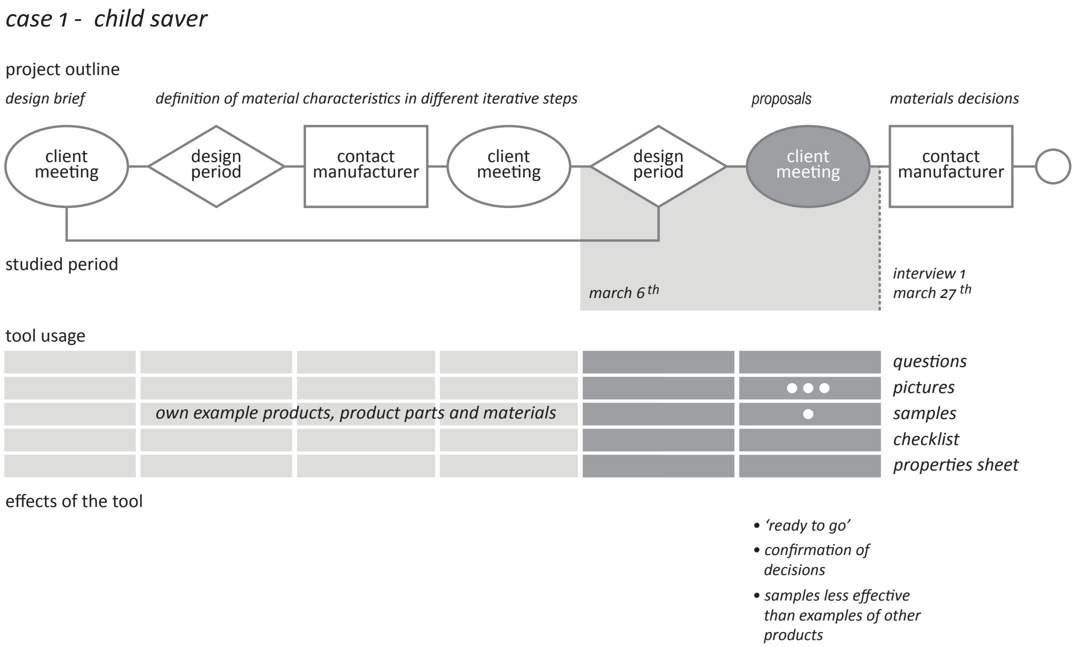


Figure 9.4
Outline of case 1 - child saver.

The product designer liked the picture tool more than the other tools. Similar pictures are usually used in projects to make collages, but the picture tool provides a reference framework for the ambiance of the product. The product designer could probe whether or not the client had the same ideas for the new product, using this tool. Especially clarifying were the discussions about the products that, in their opinion, were wrongly placed in the personality categories.

Differences in the client meeting

In general, one of the questions in the design brief is about the clients' ideas for the aesthetics for the new product. For example, what does the client indicate as beautiful? The product designers then explore why the clients consider the examples provided beautiful, or not. The product designer takes along a great many examples of products and parts to client meetings. The sample set can be use in the same manner, but has some drawbacks. He prefers to control the selection, by showing parts that are as similar as possible to the ideas for the new product.

After using the tools, the same materials were chosen that had been selected without the tools. There were no differences in this respect, although the procedure by which the choice of materials was arrived at was different, in the sense that it provides a step-wise technique and elements to play with. Similar descriptions were used to describe the materials.

Materials searches

During the materials searches the product designer often contacts the client to choose candidate materials. The product designer proposes a material, shows it to the client, who confirms the choice, and the product designer continues his work. The product designer follows a very pragmatic approach, for example uses textures based on the materials used in the computer monitor in the office. Comparing the new product characteristics with existing product parts helps to quantify the materials. Existing materials are sometimes exactly copied.

In general, the client asks for advice about aesthetics and quality of the materials. The product designers determine these aspects for the client during their materials selection process. However, the client makes the decisions, so the product designer should be able to motivate his choices and convince the client that if he advises a certain materials that it will work. Physical examples are seen as the most important elements in presenting the proposals. The materials are not discussed as a single element, but integrated in the concept design proposal. Material proposals are convincing when they are combined into a similar form of the product that is being designed. Selected physical examples of e.g. textures, softness and colour are taken

1 Henk Crone MSc. Cuckoo Company, Delft. Tools provided on March 6th. Interview was taken on March 27th 2007.

2 Marjolijn Min MSc., MINID, Den Haag. Tools provided on March 8th. Interviews were taken on April 6th and May 3rd 2007.

to a manufacturer, who measures the properties in order to obtain information about the possibilities. The product designer only speaks about the sensorial properties of materials in context with example parts.

The product designer would not extend the set of materials samples, because he prefers to use examples of materials that are shaped in a certain form to be able to show the characteristics of the material in relation to geometry. The card shaped materials samples of the tool are too limited for this.

Case 2 – Beverage packaging[2]

The project is about a new concept for a beverage packaging. The user-interaction aspects are relevant in this project during the sales and use of the product. The consumer needs to be attracted by its colour, tactility and emotions. The product should convince the consumer to buy the product again. The end-user should have the feeling that the packaging will not break during transportation.

The tools were used with a new client during the very first meeting in the project (figure 9.5). The purpose of this meeting was for both parties to become acquainted with each other and to settle the budget. No design ideas were generated or discussed at this moment. Afterwards, the product designers found this too soon for using the MiPS tools, which is explained hereafter.

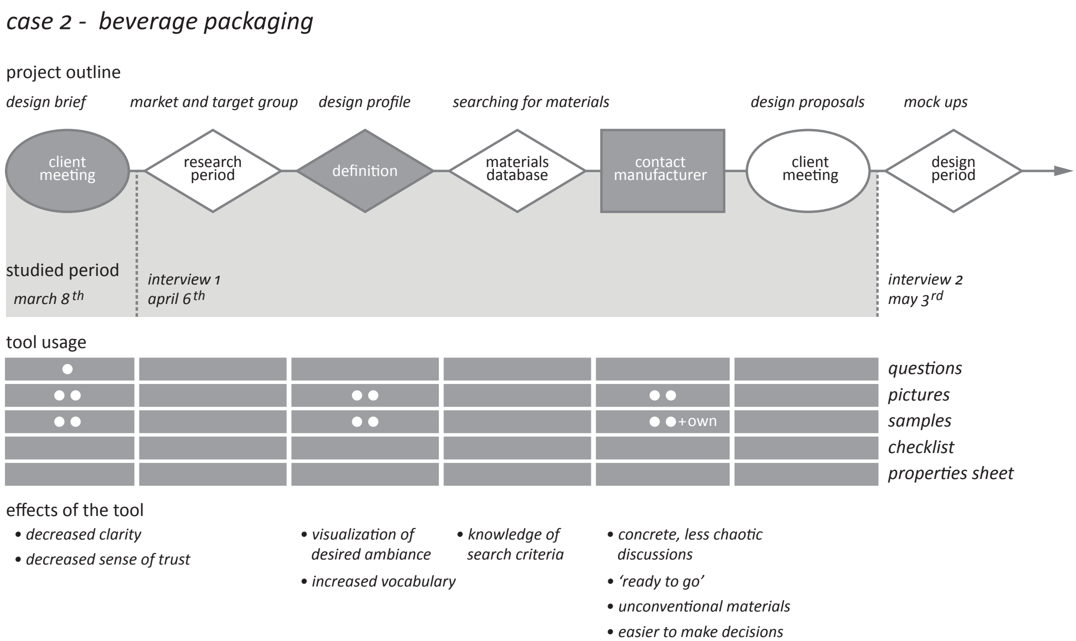


Figure 9.5
Outline of case 2 – beverage packaging.

Use of the MiPS tools

The questions tool was used to prepare the client meeting. During the meeting, the picture and sample tools were used. The client hardly interacted with the picture cards and samples. For the client, it was difficult to focus on the materials properties in the example products, which made it difficult to discuss which specific aspects the clients preferred in the new product. The product designer found that the checklist and sheet with related properties contained too much text and therefore did not use it. She suggested that with a more complex product than the current product, the lists might be of use.

The picture and sample tools were used a second time in the definition step shown in figure 9.6. This definition step took place after a research period in which the target user group and the market were investigated. The two designers in this project used the tools to define the design profile and the materials in this profile. This profile consisted of collages that showed the desired ambiance of the product. Here, the tools helped to describe this ambiance and to discuss the meaning of the collages.

The product designer used the samples and picture tools a third time when they consulted the potential manufacturer for the product. The designer had worked before with this manufacturer. During the consultation, the example products on the picture cards were discussed together with the material samples of the manufacturer.

The product designer liked the samples most because it is often difficult to get samples or to collect them. Furthermore, the set contains some examples that the product designer would not have thought of themselves. However, she mentioned that, for the client, it is difficult to explain whether they prefer a sample for its visual properties or its tactile properties. Hence, the product designer suggested making two sets that differ on the sensorial modality of which they represent the properties.

Differences in the design brief

At a first meeting with a client, the product designer discusses the budget for the project. User-interaction aspects of the product are usually not yet discussed at this moment. The product designer only asks, at this point, how innovative the clients want to be, and the appearance the clients associates with this. Only then, they start a research period in which they investigate the target group and market. The tool forced the product designer to discuss the user-interaction aspects before this investigation. This was viewed as a distinct disadvantage: "The client provides one opinion on a possible user-product interaction. However, a product is used by many users and the task of the designer is to translate their needs into a product. Giving the client this task can result in products that do not match the needs of the end-users, which is not a desirable situation".

In other projects, the product designer tries to make concrete agreements about budget, in which user-interaction aspects are only discussed in broad outlines. Using the MiPS tools made the design brief meeting less clear than usual, because more details were discussed than necessary at this point, according to the product designer. They bring examples of materials later in the projects, but then to manipulate the client and not to give him a say in the materials selection process. The product designer wants no discussion about subjective topics with the client, but wants the freedom to create their own user-product interaction based on their target group and market research. The product designer had the idea that the tool diminished their status as a project leader, because the tools enable the client to participate in the design process.

The product designer mentioned the difficulty for a client to imagine the end product of the design process. This is the product designer's task. The picture and samples are therefore too overwhelming for the client and the product designer does not want to discuss the lack of skills of the client.

Materials searches

Before the first materials searches, the product designer performed a target group and market investigation. After this, they defined a preliminary product profile with the help of collages and the tools. The product profile normally describes the characteristics of the new product, the ambiance and feeling, but not necessarily the materials. Using the tools here offered them an understanding of the sensorial material properties in the profile. Based on the profile, a material search was started with Cambridge Engineering Selector (www.grantadesign.com) and a manufacturer. The client was not consulted during the materials searches.

Effect of the tools on the materials searches and material proposals

The tools consist of elements that are usually used by the product designer in a design project, but the tools organize and gather some of these elements in an orderly way. The tools clarified how materials could contribute to the desired ambiance and helped to describe how they do that. The product designer will probably use a new material for the product, but they do not know whether this particular choice was affected by the tool usage. They did mention that they felt more secure about the choice.

The picture and sample tools were used during the consultations with the manufacturer, who added his samples to the tools. The product designer described this as follows: "The conversation was accelerated, more tangible and less chaotic compared to other consultations. The manufacturer was used working with product designers, so he was used seeing the product examples and samples as representations of certain required properties. He also has the required knowledge about material to be able to make the connections between the properties represented by the pictures and samples".

After using the tools, it was clearer for the design team what kind of solutions they were looking for. The product designer suspects that the search for materials accelerated and became more tangible. Moreover, it was easer to decide that the material was suitable for the product. The product designer explained: "Without using the tools, it takes longer to find the words to describe what you are looking for. Using the tools resulted in a vocabulary of required material aspects".

The client reacted positively to the proposed materials. The product designer attributes this to the convincing power of the presenting product designer. The tools influenced the preparations for the second meeting. This effect may be augmented by using the tool in a brainstorm session before the client meeting.

The product designer indicated as the main difference between a project in which the tool is used and a project in which this is not the case as being: "Without the tools there are more checks needed to verify whether the materials are suitable for the desired ambiance of the product. Normally these checks are only performed with words, and they were now made tangible with example products and samples". They concluded by saying that the MiPS tools can probably be used internally with different designers in a team and with manufactures, but in client meetings, the tools are less effective.

Case 3 – Interior for a reception room[3]

The project is a new interior for a reception room of Maison Descartes, the French institute in Rotterdam, the Netherlands. The design aim is to improve the communication of the building with the people walking by and coming inside and to improve the appearance and functionality of the reception. The new interior should make the people outside curious about the institute. The interviewed product designer was responsible for the spatial design and concept. One graphical design duo is involved for the exterior of the building. Later, it was decided to involve an extra party, namely a furniture maker.

The MiPS tools were used in a client meeting in which the concept ideas were presented (figure 9.6). The tools were used to fine-tune the materials selection. The designer proposed a fan-shaped interior with large surfaces. The dual language culture of the institute (French and Dutch) is reflected by the desks and brochure displays.

The product designer proposed using the material Corian™[4] in the interior and had brought some samples of this material to the meeting. After the meeting, the product designer and client decided to choose this material. The reasons were the well-balanced combination of emotion and function represented in the material, the desire to touch it and it's modern, but at the same time classical look.

Use of the MiPS tools

At the meeting, the product designer used the questions, picture and sample tools. She started with the question cards and selected three to discuss, namely the 'first contact phase' card, the 'usage phase' card and the 'rest phase' card (table 8.3). The product

3 Sophie Krier BSc, designer and design teacher, Rotterdam. Tools provided on March 14th. Interviews were taken on April 18th and May 17th 2007.

4 Corian is a trademarked product of DuPont (www.corian.com).

designer asked the question and the client answered. Some parts of the question were adjusted to the situation. The client answered that the design should be allowed to contrast with the surroundings in a soft confrontation in an echo of the space. It must attract people. Serenity, softness and generosity were important words related to the required user-product interaction.

After the discussions of the different interaction phases, the picture and sample tools were used (figure 9.7). The pictures were used first, in random order. The client was asked to order the cards from yes to no; from the desired characteristics to those that were not. The personality terms on the cards were used first and then the example products per term. The pictures and personality terms do not always match; which can confuse the client but also lead to animated discussion. The cards were reordered and then turned over to discuss the sensorial properties of the example products. The client then took the samples and laid them on the cards. The combination was reordered during further discussion. The Corian samples were also used in this step, to be able to discuss the desired appearance of the Corian.

The checklist with properties was used last in the discussions. The important properties were discussed with the client. The product designer liked to generate ideas with the tools, but the checklist felt as if it were homework. It was unclear how the checklist worked in the discussion.

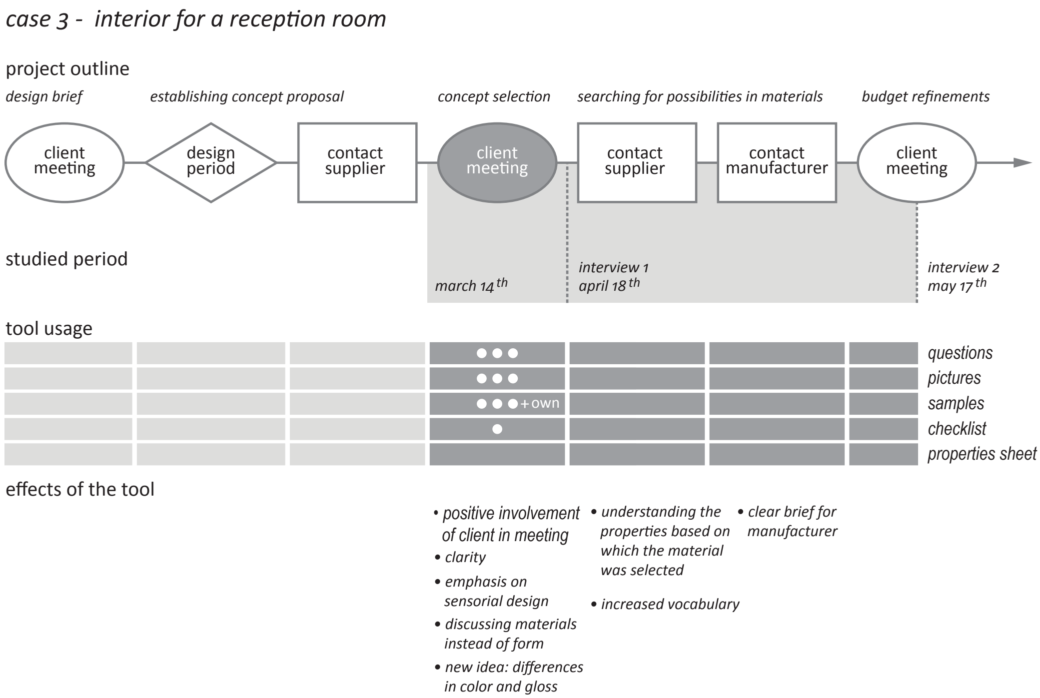


Figure 9.6
Outline of case 3 – interior for a reception room.

The terms that were most frequently used in the discussions were glossiness versus matt and different grey and blue colours. As a result of the meeting, the product designers started to vary these properties in the different parts of the interior. This was not officially formulated in a material profile, but did affect the subsequent materials searches.

Differences in the meeting

The product designer mentioned that the most remarkable aspect of the use of the tools was that material aspects were discussed in relation to the user's interaction with the interior. She discussed the material properties with the MiPS tools, and via that discussion arrived at a discussion on the intentions of the product. The attention was thereby withdrawn from form, which was refreshing. The product designer liked the fact that the tactile aspects of the user-product interaction come forward when using the tools.

The use of the tools led to a different relationship with the client during the meeting. The product designer explains: "At other meetings I propose my concepts and the client poses critical questions. Use of the tools during this meeting encouraged cooperation. The client also had the opportunity to provide input, which I like. The meeting was more relaxed".

The results of the meeting were more concrete compared to other meetings, yielding more clarity for the product designer about the project and for third parties involved in manufacturing certain parts of the concept. The client gained awareness of the possibilities in the project. Materials are normally not explicitly mentioned during meetings with the clients.

Figure 9.7

Use of the tool in case 3. Client orders a selection of the cards to his preference (left picture), uses the back sides of the cards to verify the order (middle picture) and places the samples on top of the cards (right picture).

Materials searches

The discussed concept design was sent to the Corian supplier and he reacted enthusiastically. The supplier explained the aesthetic and processing possibilities of the material. Based on this information, the product designer was able to fine tune the design. For example, the material is less durable in the high gloss variant, which makes this variant less appropriate for a public desk. The material can be supplied in sheets and processed in the same way as wood. It is, for example, possible to mill words in the plates and fill them with transparent Corian afterwards.

The product designer contacted the manufacturer of Corian and a furniture maker to ask for an estimate to build the interior as designed. This estimate forms the basis for the detailed design phase and is discussed with the client. In this phase, the aim is to analyse the estimate and find ways to lower the costs, for example by changing the sizes of the desks or using Corian in combination with wood.

Effect of the tools on the materials searches and on the material proposals

The product designer explained that after using the tools, more emphasis was given to the material properties. The product designer had more words in mind while designing. Normally the materials do not drive the design process, the intentions and interactions do. The tools provide ideas to create these intentions and interactions with materials.

Parts of the interior were to be fabricated by a furniture maker. After using the tools, the product designer could clearly explain the important ideas behind the assignment to the furniture maker. She thinks that he was consequently better able to decide how the parts that he was to fabricate would connect to the other parts.

The product designer suggested improving the MiPS tool by making an own version of the picture and sample tools. In the sample tool, she would put together a set of materials samples used in previous projects to show her expertise and style, and yielding a new kind of mood board, with more concrete aspects than the ones currently used by her. The mood boards could become blueprints for evaluating the designs.

The tools did not affect the client meeting after the material search. This meeting concentrated on the budget estimates and the overruns. The product designer indicated that the main effects of the tools were the shift in the relationship with the client, from that of a presenter/ listener to cooperation. Use of the tool did not result in a documented material profile, but the words that were discussed stayed in the designers mind and were used in the materials searches. It was important to bring the Corian samples into the meeting, but the samples of the tool were relevant to nuance the selection for Corian and its aesthetical form.

Case 4 – Hearing aid[5]

The project is a new range of hearing aid products. The product designer distinguishes the following user-interaction aspects for the product: the emotion of the first contact, the senses, ergonomics and feedback during use. Applying new materials would not be a problem in this product as the technology is relatively more expensive than the material costs.

After presenting the first ideas, the client required a more technically focused solution than initially indicated. The MiPS tools were therefore not used at a client meeting in this project, as the use of the tools would not be appropriate here. The product designer explained that it is, in general, very difficult to co-create and discuss the required user-product interaction with a client. Much depends on who sits on the other side of the table, such as an engineer, marketer or director, so they perform this step themselves and present it to the client to discuss. Hence, the MiPS tools were instead discussed with a designer from the project team who knew the client from previous projects (figure 9.8). At the time of this discussion, the product designers had performed a user and competitor research. The case is based on one interview.

Use of the MiPS tools

The product designers would use the MiPS tools to discuss and communicate their created pre-design vision. They sometimes use a systematic design profile tool for this which was developed in the design agency. The MiPS tools would then be used as an addition to their tools.

The product designer explained: “The MiPS tools could be used in a client meeting, but we would then limit the discussions about certain predefined aspects and not have everything open for the client, which is the intention of the MiPS tool”. The back of the cards comprising the picture tool would not be used by the product designers. They preferred to translate the aspects of the given examples into sensorial properties themselves and not with the client.

The samples of the tool are difficult to visualize in a new product. The product designers prefer to work with products. A watch, for example, illustrates better than a sample how the experience of the material changes when it is given a certain form, with respect to tactile and visual aspects as well as the quality experience. They expected to discuss a selection of the sample tool in combination with their own found samples and products. The product designer said: “I would extend the tool before using it with a client, for example, by adding cards to nuance the user-product interaction discussions with the client”.

Only a few questions of the questions tool were discussed, especially those questions about expected use, ergonomics and perception of quality. The checklist was mainly useful for internal discussions, but would never be used as a checklist with clients

5 Marcelle van Beusekom MSc., Van Berlo Studio’s, Eindhoven. Tools provided on March 13th. Interview taken on April 26th 2007.

(although a selection of questions from the internal discussion makes it to the client meetings). The designers mostly use images instead of sensorial properties to make their design profile. However, some words such as flexible or warm are used in the profile. The sheet with related properties would not be used, as the detail level is too complicated for using with clients.

The product designer is uncertain about the moment at which to use the MiPS tools. She explained: "The design brief meeting is too early to use the tools, because the target user group was not yet been investigated. Therefore, their interaction needs can not be discussed at that point. However, after the target group research, we propose the first ideas and using the tools here to define the required user-interaction with the product would be too late".

Differences in preparing a client meeting

Material criteria are discussed from the beginning of a project, especially to determine the required perception of quality. After the research period, in which materials samples and example products are collected, everything is combined into a design profile and discussed with the client. The product designer stressed that to convince a client, it is very important to make the interaction possibilities tangible.

The same discussions were conducted using the agency's own tools as with the MiPS tools. These tools, however, are rarely used with the client. Only parts of the

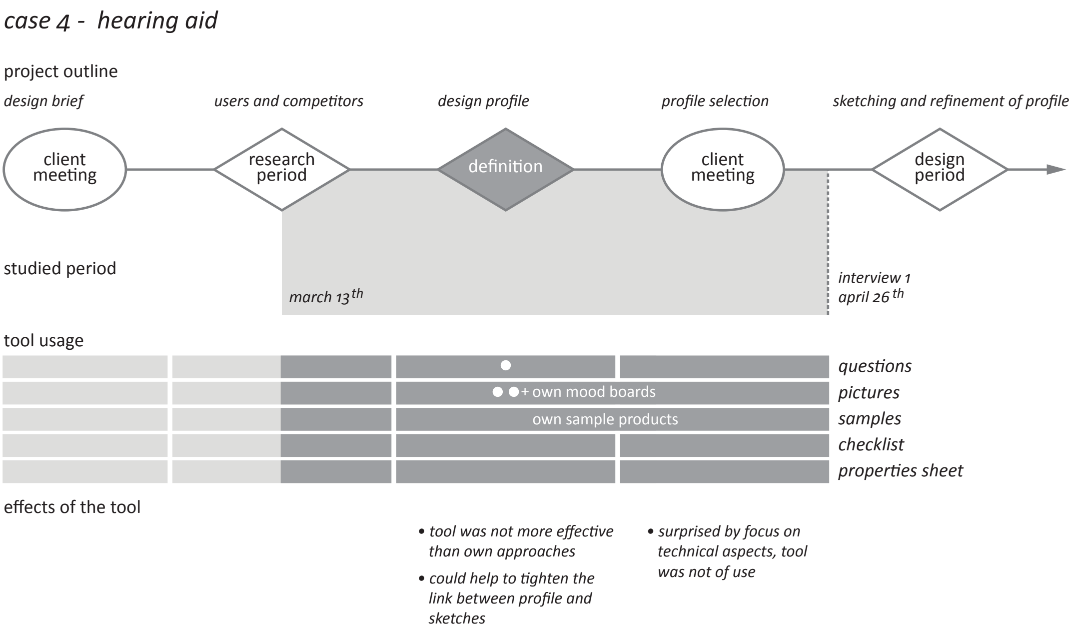


Figure 9.8
Outline of case 4 – hearing aid.

discussions are communicated to the client. Some clients have no idea about the new directions a product can take. To use the MiPS tools effectively, it must be established whether or not the client is able to develop a vision.

After a research period, the product designers prepare a design profile in which all the discussions of the design team members are summarized. During the next client meeting, this profile is transferred to the client in order to involve him in the ideas. It is important that the product designers are able to guide the clients toward their ideas. Normally, the product designers bring example products to the client meetings. These products come from their own product portfolio, competitors and from other product fields. They are used to illustrate design ideas. The product designer mentioned: "The MiPS tools could help to transfer ideas and convince the client by having him have the same ideas as the product designer. The tools can furthermore help to justify the sketches made in a project. The clients would then understand the choices made in the sketches better than without such tools".

9.4 Discussion of the results

The case descriptions and the diagrams were used to evaluate the effectiveness of the tools in the different situations in which the tools were used. The tools are effective when they met the three criteria mentioned in section 9.1 (product designers use the tools, they see the benefits and notice positive changes in their process). Four research questions were formulated to study these criteria that will be discussed hereafter.

A remarkable finding in the cases is that the relationship with the client strongly influenced the effectiveness of the tools in the synthesis phase (question 3). These results are therefore discussed first, followed by the usable and unusable aspects of the MiPS tools (question 1). The benefits of the tools acknowledged by the product designers are summarized thereafter (question 2). The final sub section summarizes the suggestions for improvements of the tools (question 4).

Conditions before the tools can be effective

Two aspects appeared to be very important for the product designers' usage of the tools. These aspects were the relationship of trust the product designer builds with his client and the clients' knowledge of the user. These aspects influence the effectiveness of the technique and may not be dependent on the design of the tools.

Trust and tasks in the client – product designer relationship
One of the most important activities during the first meeting on new design projects appears to be establishing the relationship of trust. Especially, if the client is unknown, product designers put a lot of effort in getting to know the client and trying to get a feeling for the client's attitude towards innovation. Furthermore, budget discussions are dominating the first meetings. By contrast, the tools are designed to be used in

the first meetings to clarify the objectives and constraints about the material aspects in the user-product interaction. Hence, the tools are used in a situation where trust building and budget discussions are driving factors, instead of the user-interaction aspects. This led to problems in the packaging case. As a result, the client of this project was overwhelmed and the discussions were lacking in clarity and structure – an undesirable effect. In the other projects, the tools were used in a later phase, but the product designers mentioned this as one of the things they usually do in a design brief meeting.

The product designer assigned to a project is responsible for the design activity. This means that a tool that tries to involve the client in the design activity is not always welcome. The product designers explained that they do not want the client to choose examples to which they must subsequently stick. A client's preference on one aspect could very well limit the integral decisions that the product designer needs to make when combining all aspects of the product, including e.g. manufacturing and cost issues. Product designers try to give the client a limited amount of information about the project and direct them to want certain choices that are made after a research or design phase. The product designers see that as their jobs and try to avoid time-consuming discussions with the client.

Client's knowledge of the user

The results showed that the tools are only effective when the client is able to make decisions about the user-product interaction of the new product. This was the case in the reception room interior project. In the other projects, the client was more technically oriented or mainly concerned with controlling the budget. In these cases, the product designer included a research phase in the project in which the target user group and market was investigated. This is a regular task of the product designer and results in the required user-product interaction with the new product. The clients themselves do not know enough about the user to be able to discuss and define the required user-interaction aspects of the materials. The product designers of the packaging case emphasized that using the tools could lead to design solutions preferred by the client, but not necessarily by the target group. They are afraid of the ego-design principle where a client projects his or her own frame of reference to the new product. This could be an unwanted effect which could occur through inappropriate use of the tools. Hence, the tools can only be effectively used together with a client whose knowledge of the user is decisive to the project.

Usable and unusable aspects of the tools

The product designers liked the fact that the tools were compact and ready to use. They liked the playfulness of the picture and sample tools and the fact that these tools opened the discussions with clients and each other. The product designers were not always agreed on the combination of product examples, personality terms and sensorial properties in the picture tools, although, this was not a drawback, because the disagreements opened the discussions. Two product designers suggested separating the terms.

In all projects, the tools were mixed with their own samples and example products of the product designers. The tools are thus easily embedded in their own approaches. The tools were less usable in the case where the product designer already has structured techniques to generate a design profile. The product designers mentioned that in that case, the tools had little added value.

The activity of defining the product profile and creating ideas is intermingled in the early design phases in which the tools are used. The tools are thus not solely used in the cases for ascertaining the required properties, but also to make ideas more tangible.

The checklist and sheet with related properties were hardly used. The product designers felt that there was too much text and that it was too structured. They preferred the more intuitive parts of the tool, i.e. the picture and sample tools. The checklist and sheet were structured, such as to aid the product designers in formulating a clear profile in terms of sensorial properties. Explaining this purpose to product designers could increase the use of these tools.

The product designers stressed the difficulties that clients might have with visualizing aspects of the example products and samples in new products. It is difficult for clients to see only the characteristics of a product or material without also judging the context or preferences towards the product as a whole. For example, the textile sample refers to a pair of jeans and the aluminium coffeemaker is associated with the preferences for the coffee system. In addition, product designers explained how difficult it is for a client to explain whether the visual or the tactile aspects of a material sample dictate the preference for a sample. They suggest making two sets, one for visual aspects and one with tactile aspects. The samples are, furthermore, too limited for most explanations of the material properties. They lack information about shape, size and thickness, although these aspects influence the perception of the sensorial properties.

Benefits of the tools

The product designers were expected to experience benefits of the tools in the design brief meeting and in the materials searches. They indicated that they gained an increased understanding and vocabulary about the material properties they were looking for and had easier searches after using the tools.

Increased understanding and vocabulary in the material profile

In the design brief meetings product designers increased their understanding about the material profile. This profile is not always documented and discussed with the client, but after using the tools in the design brief meetings, the relevant words are still in the designers head. These words are later used in discussions with colleagues and in the materials searches.

The product designers see a benefit of using the tools to summarize and document the findings of the research period about the target users of the end products and market. The tools are then not used with the client but in a design team. The tools were only used in this way in the hearing aid project, but the product designers of the packaging project explained that they expected the tools to be more effective for this. In the reception room project, the tools were used with the client after this research period.

The increased understanding was not only beneficial in the materials searches, but in the formulation of the briefs for third parties that were hired to execute certain parts of the project. This was, for example, the case in the reception room project.

Easier searches

The discussions about the desired materials resulted in a better understanding of the material profile and this effect was recognized in the materials searches as illustrated in the MSA model. It not only helped to find materials in data bases or when discussing with material experts (information gathering for the set activity), it also helped to make decisions (choosing activity). The design team of the packaging project indicated experiencing less hesitation after using the tools. Furthermore, in presenting the material options to the client, the reason for these choices is clearer after using the tools (comparing activity). This means that the benefits are experienced during all the different materials selection activities.

In the packaging project, the tools were used together with the potential manufacturer. The effects of the tools during this consultation were that the discussions were better structured than without the tools and the manufacturer came up with unusual material ideas. The sample tool contains a wide range of materials including some that are unusual in certain product categories, e.g. cork and leather in packaging. The product designers and manufacturer, however, could use the properties of these materials to find material options beyond the conventional materials.

The product designer of the reception room project stressed that she liked the focus on sensorial design or design with materials. She usually worked with form and intentions, but changing the focus to materials gave her a new technique. She explained that through discussing the materials, many other aspects are also decided, which she felt was an extra advantage of the tools.

Suggested improvements of the tools

Some product designers suggested separating the terms and the pictures of example products and materials samples and others found it interesting to discuss their disagreement with the given combinations. The same result was found in the previous study. The argument then was that discussion was easier when clues were provided. Especially product designers who are not skilled in translating user-interaction aspects of materials into sensorial properties can profit from keeping the clues on the cards, as this can help to train these skills. As the sensorial properties terms are used on the back of the cards, this would not be a problem. A mid-way solution could be to place the personality terms on the back of the cards as well.

When using the tool to sell clients on their ideas, product designers find it relevant to have more pictures of product examples. This enables them to make a set of cards that shows more nuances in the selected directions. The product designers prefer less concrete examples of products, to limit the associations with the products itself. One product designer suggested making a tool of her own, with materials that she is familiar with or that represent her design philosophy.

The sample tool currently represents both the visual and tactile aspects. Clients who select a sample find it difficult to explain what sensorial properties they liked about the sample. One product designer suggested separating the visual and tactile aspects of materials in the sample set, to make two sets. Other product designers explain that the small samples are too limited to sense how the material properties influence the user-product interaction. They prefer 3D examples of materials used in products and product parts. This means that the material samples do not only show the set of sensorial properties on which a material can vary, but also the relations with shape details and surfaces. The sample tool could be improved by separating the visual and tactile aspects and providing more information in a sample via a product example.

9.5 Implications of the results for the MiPS technique

The aim of the study was to assess the effectiveness of the tools in the MiPS technique in design practice. The results section explains the usage, benefits and effects of the tools on the materials selection process and the suggested improvements for the tools. Here, the results in relation to the aims of the MiPS technique are discussed, thus how effective the tools are in supporting the steps in the MiPS technique and more specifically, in improving the communication about the user-product interaction with the client, leading to a sensorial profile including the physical properties.

Before discussing the technique, it is necessary to note the following. The product designers used the tools in this study for the first time and with a client, without any training that included the expected benefits and effects of the tool. Information about why the tools were created and the advantages of using the tools was omitted, as not to bias the participating product designers in their evaluations. First use of the tool could, however, differ from more experienced use and the effectiveness of the tool could differ likewise.

In the previous study, the same approach was used and the designers were able to use the tools on the spot (section 8.4). Therefore, not too many problems with this strategy were expected. However, the product designers appeared to be not very confident about using the tools and were therefore not eager to use the tools with their client. The relationship with the client was too precious to try unknown things. The results of this study could therefore be moderate compared to a study in which product designers have more experience with the tools.

The effectiveness of the tools in the MiPS technique

Not all the MiPS tools were used by the product designers. The tools are thus not effective in leading the product designers through the full MiPS technique. Specifically, product designers did not use the question tool to its full end, thereby ignoring the opportunities for discussing the possibilities for the user-interaction qualities of the product in a structured way. Furthermore, they did not use the checklist and sheet with related properties to summarize their material profile in sensorial properties and translate them into physical material properties so this step of the technique was not followed. Hence, the tools do not lead to the expected procedure of making material profile in terms of sensorial properties.

The first reason for not using all tools might be that product designers tend to select one or two material families based on their experience and search for material options within this frame of reference. Like the findings in chapter 5, they follow this approach and the instruction and the tools did not trigger them to change this. The picture and sample tools could even stimulate the product designers to stick to their approach. The picture and sample tool make use of existing products and materials. Discussing these examples could easily result in choosing the materials in the examples instead of their properties. Making a material profile based on material properties then seems to be superfluous. Ullman (2002) mentions about this: ‘Prior knowledge of similar applications can be a blessing and a curse. It leads to reliable choices, but in the mean time obscures the new and better choices’. This approach is adequate for many projects; however, new materials with better properties can not be selected with this approach. Furthermore, product designers risk missing the opportunity to increase the user-interaction qualities of product, when they fail to consider how materials influence the user-product interaction.

The second reason for not using all the tools could be the positioning of the use of the tools in client meetings. The results indicate that it is better to use the tools within the design agency if the client is lacking the expertise to define the user-interaction with the new product. When product designers use the tools within the team, it might be more natural to talk about sensorial properties of materials. The results of these discussions should, however, be discussed with clients, in the first place to involve them and secondly, have them decide on the candidate materials in the choosing activity. Both reasons are feasible. Based on the results of this study, it is not possible to explain why product designers did not use all the tools. However, in the activity of preparing a client meeting, in which the product designers’ proposed user-product interaction, the technique could be more effective than using it during the first client meeting. Furthermore, giving product designers a thorough training before studying the effect of the tools in practice is advised.

Involving the client in making a material profile

The MiPS technique involves the client in the formulation of a material profile to increase the clarity of the user-interaction aspects required in the new product. It is important that a common understanding of the requirements of a project be arrived at as soon as possible; however, the cases show that there are different priorities in the very first meetings. These priorities are the trust building and budget discussions. The tools were obtruding these discussions in the case where they were used in the very first meeting. It seems therefore more logical to use the tools at a later stage. However, in the studied projects, the next meeting was after the analysis phase, when most requirements had been set. The product designers proposed product ideas in this meeting. It seems too late to discuss the user-interaction requirements here. The tools are then more effective in the preparation of the meeting. The product designers can than use the tools in the team and discuss the results with the client.

The product designers tended to use the material samples of the tool to present their ideas about the materials aspect rather than exploring and defining the aspects. The tools were not designed for this, but the question is whether it is possible to discuss only the material aspects based on a sample. The product designers preferred example parts and prototypes for this purpose. It thus seems to be easier to use example products to show material properties than flat shaped samples.

Defining a material profile in terms of sensorial properties

The MiPS technique aims at defining a material profile in terms of sensorial properties to enable technology-oriented information providers advising about the physical equivalents of these properties. The studied design projects in section 5.3 showed that product designers consider user-interaction aspects when they formulate material criteria. This study revealed that the participating product designers defined the user-product interaction, and thought about materials that create this interaction, but not in a structured or explicit way and not via the (sensorial) material properties. The product designers are not used to considering the user-product interaction in terms of material properties and do not readily try to do so when guided in that direction with the tools.

Although the product designers did not use all parts of the tools, they recognize benefits in using the tools especially in the increased vocabulary about the user-interaction aspects of materials. They indicated as a benefit of the tools that it makes the material criteria more tangible and easier to use in finding and deciding about materials. However, they did not use the checklist with sensorial properties. Not defining the material criteria in terms of properties can thus be a result of the limited expertise of product designers about how materials contribute to the user-product interaction. For example, Sonneveld (2007) found that product designers seem not be able to talk about tactile aspects in their designs. Product designers are often trained to see materials as a platform for the shape and function of the product and not necessarily as a platform for the sensorial interaction with the product. Recognizing this might help to define requirements about the materials in terms of the sensorial properties.

Remarkable is that Keller (2005) found that product designers explicitly do not use images of existing other products. However, the results of the study presented here shows that they use physical example products to discuss form giving and material aspects. There seems to be a difference between the information that product designers are looking for in 2D and 3D examples. In 2D, the images of products are less suitable to visualize the user-product interaction than other images. In 3D, the product designers look for hands on information that they can directly translate to their projects.

9.6 Conclusions

The results of this study demonstrate that the MiPS tools help to clarify criteria about the material aspects that can create a required user-product interaction with the new product. The tools do not facilitate doing this in a systematic profile, but increase the awareness of the driving properties. This lead to easier discussions with other people involved in the project, such as product designers from the team, manufacturers of product parts and material experts. Furthermore, the product designers felt more confident about their decisions when having used the tools. The effects of the tools were thus acknowledged in the different activities of the MSA model.

The tools appeared not to be effective in having the client decide which material aspects to consider when creating a required user-product interaction. Product designers often determine the user-interaction aspects without the client, after a user or market research period. They communicate their findings via the first design ideas to the clients later. The tools can be used to create these ideas and to make them tangible by adding the material properties. The tools can than help to convince the clients of the product designers' ideas. Required changes for the current tools are that the tools can be adjusted to the findings in the project, for example by adding more picture cards that visualize the findings. Furthermore, the sample tool should not only consist of materials samples, but also of 3D samples of existing products.

The present approach takes into account a single iteration of defining, searching and choosing in the materials process. Therefore, the longer term effects of the usage of the tools were not revealed in this study. Product designers are expected to be experienced enough to overlook and evaluate the consequences of the tools even on the design phases that are executed after the studied period. However, it is advised in proceeding research to study the tools and technique for a longer period.

The tools were developed for the MiPS technique that is needed to keep up with new material developments and higher user-product interaction needs. The tools proved to be effective in increasing the awareness of the desired material aspects for the user-product interaction, even during first time use. The effects of the tools could, however, be improved with a training course or workshop.

Chapter 10 The Materials in Products Selection technique

The previous chapters describe the design and evaluation of the Materials in Products Selection (MiPS) tools. These tools are effective in increasing the vocabulary about user interaction aspects of materials; however, some aspects of the tools and technique need further attention. The study in chapter 9 showed that knowledge about the required user-product interaction is necessary for successful use of the MiPS technique. Furthermore, the product designers made several suggestions for improving the tools, especially with regard to the use of the tools with the client. This chapter discusses how these issues can be improved.

Some revisions of the technique and the tools are made to clarify the steps in the technique and embed the technique in design methods that are used to create and visualize a required user-product interaction. In addition, the transfer of the MiPS technique to the product designers will be discussed. This transfer will be facilitated by a workshop for product designers and design teachers. Describing this workshop gives us the chance to combine the knowledge gained during the different studies into a practical outcome of this thesis.

10.1 Revised MiPS technique

The key idea of the Materials in Products Selection (MiPS) technique, used in the analysis phase, is that it leads to a clear material profile about the user-interaction aspects for the new product. This profile is described in sensorial and physical properties to enable technology-oriented material specialists to give advice about the best available materials. The technique involves the client to increase the mutual understanding of the criteria.

The MiPS technique is effective the moment the product designers start to shape their user-product interaction ideas. The results of the evaluation study in chapter 9 clearly showed the importance of this step and therefore it is included in the revised version of the MiPS technique.

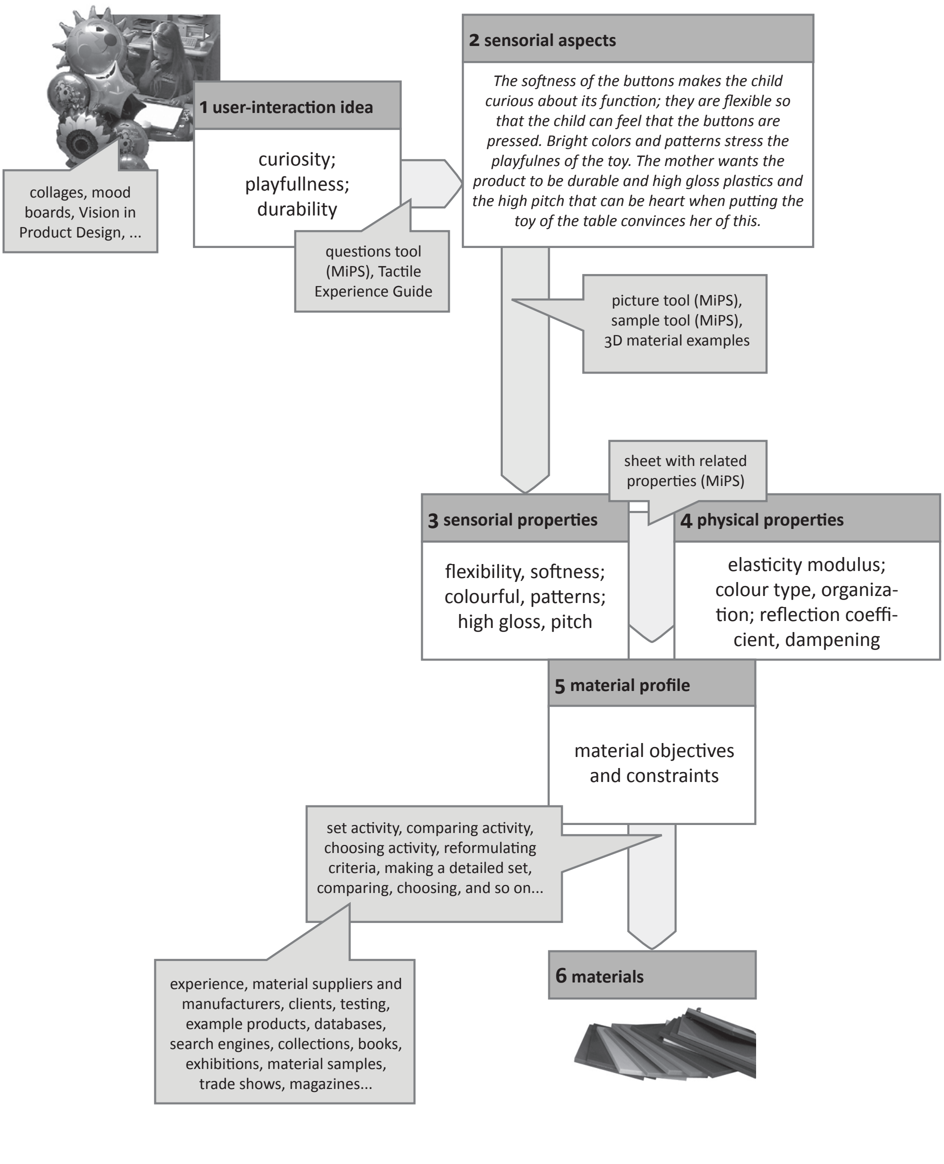


Figure 10.1
Illustration of the steps in the MiPS technique.
1. Determine the required user-interaction with the product.
2. Discuss the sensorial aspects in the interaction with the client.
3. Determine the leading sensorial properties for the materials searches.
4. Look up the physical properties related to the sensorial properties.
5. Formulate a material profile with key sensorial and physical properties.
6. Use the profile in the materials searches.

In the following description of the technique, the different steps are explained including the tools that can be helpful in a step. The suggested tools are not only the tools developed in this thesis, but also other tools and techniques that could fit well in the MiPS technique. In section 10.3, these other techniques are outlined and discussed. The design project used to describe the MiPS technique is a design of a new music toy for children (figure 10.1). The steps in the technique are:

1 Determine the required user-product interaction. The first step of the MiPS technique is the development of an idea about the user-product interaction that the product designer wants to create with a new product. This idea can be a result of target group studies, market research or the client's ideas. Different means, which are already used by product designers, can be used to visualize this user-product interaction, such as collages or mood boards. The result of this step is a description or visualization of the required user-product interaction.

2 Determine the sensorial aspects in the interaction and discuss them with the client. Based on the required user-product interaction, the product designer needs to describe the sensorial aspects in this interaction. Focusing on the senses helps to make the user-interaction requirements concrete. The questions tool can aid the product designer think of and discuss the sensorial interaction, which the end-user might have with the product. It is necessary to discuss the results of this step with the client to make sure that there is a mutual understanding of the aimed for user-product interaction. The result of this step is an overview of the sensory aspects needed in the product.

3 Determine the leading sensorial properties for the materials searches. In this step, the aspects in the interaction that can be influenced by the materials of the new product are decided upon. The product designer evaluates the visual resources and descriptions of the interaction and summarizes which sensorial properties are relevant in the interaction. The sensorial properties are the aspects of the product that can be created by materials. Sensorial properties can be measured, such as colour, transparency, roughness, warmth or flexibility (section 8.3). The picture and sample tools, but also three dimensional examples of products and materials can aid the product designers to find the sensorial properties required for the interaction. The result of this step is a list of required sensorial properties.

4 Look up the physical properties related to the sensory properties. This step forms the preparation for the formulation of a material profile that can be understood by technology-oriented specialists. The physical equivalents of the sensorial properties are therefore established in this step. Also, this offers the opportunity to examine the material criteria related to e.g. a product's functioning and manufacturing, such as strength and hardness. To verify whether sensorial, functional and manufacturing criteria are conflicting, it is less complicated to evaluate the properties on the same level. To support product designers with this translation, a sheet with related properties was developed. The result of this phase is a list of physical properties that

are related to the required user-product interaction.

5 Formulate a material profile with key sensorial and physical properties. The material profile is a summary of the leading material properties for the new product. Both the sensorial and physical properties are part of this profile. At first, the profile contains only the relevant properties, without stating how e.g. transparent or glossy a product should be. Before these questions can be answered, a material search based on these aspects can be necessary. The profile changes during the project when more details are clarified, as visualized in the MSA model with the criteria activity (figure 9.1). The profile initially does not mention materials, in order to be able to use the full potentials of existing and new materials. The result of this phase is a profile of leading properties, on the basis of which a material search can be performed.

6 Use the profile in the materials searches. In the synthesis phase, the material profile forms the basis for the activities of making a set of candidate materials, comparing them and choosing them. The information required during these activities can be derived from all kinds of sources, such as manufacturers, suppliers and scientists. The material profile helps to get recommendations from these specialists about the materials that fit the profile. Furthermore, the profile can help to explain to the client why certain design decisions were taken or what changes are needed based on insight gained during the project.

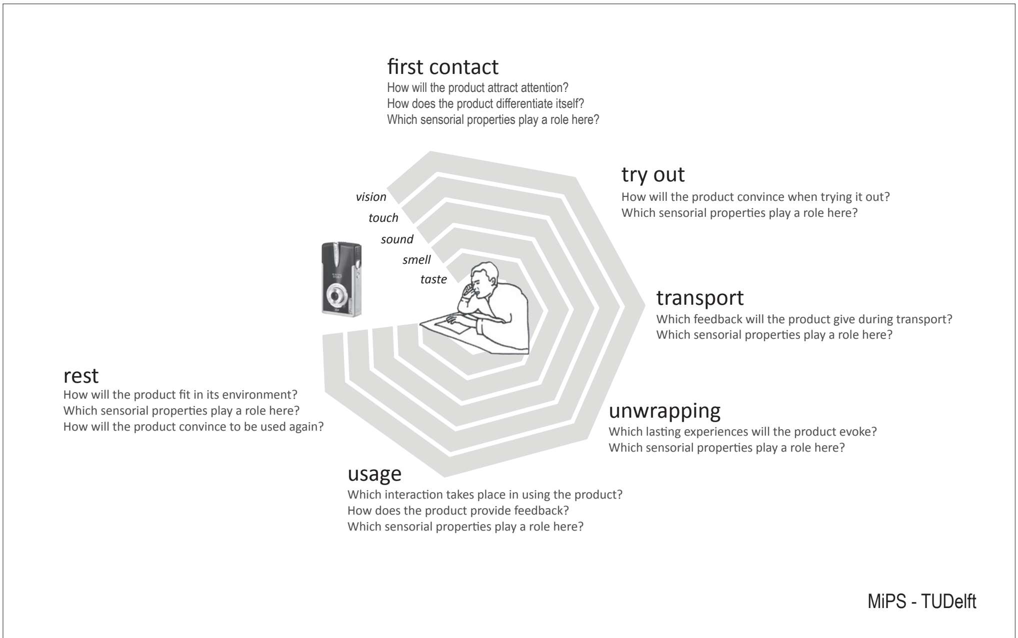


Figure 10.2
Question tool inspiration sheet.

10.2 Revised tools

This section describes the revised design considerations of the MiPS tools in the context of this thesis. The tools could be used in different steps in the MiPS technique as indicated in figure 10.1. The background considerations for the tools were explained in chapter 8.

Questions tool – inspiration sheet

The questions tool helps to discuss (alone or in teams) the sensorial properties in the user-product interaction in different usage phases. It offers example questions on relevant issues in a specific interaction phase. While discussing the interaction issues, the product designer is triggered to explore the sensorial properties in the interaction. The picture and sample tools can help with this.

The question tool was not used in the discussions with the client in the evaluation study, although the product designers looked at the questions before the meeting. The question tool then serves as a preparation tool for a client meeting for which it is developed further. The questions tool is based on the interaction sequence found in the usage phase in life cycle analysis and the sensorial interactions in this phase.

The appearance of the tool, a set of question cards, was selected for using the tool during discussions with a client. As a preparation tool, it will be used by product designers alone or in a team, so the appearance can be changed. The appearance should stimulate users of the tool to go through the interaction phases and think about the sensorial properties in these phases. An A3-sized inspiration sheet was developed for this (figure 10.2). The phases and the questions are present on this sheet, as well as a link with the five senses of a person. The question: “Which sensorial properties play a role here”, is placed as a final question in every phase.

Print outs of the inspiration sheet can be used by product designers alone or in e.g. brainwriting[1] sessions, while thinking about or discussing the sensorial properties of the different interaction phases. The power of the tool is that it gives a structure to the topics to think of and is a sort of checklist of topics. Posing all questions on one sheet enables the product designer to overview the different phases and the aspects considered in an earlier phase.

In every interaction phase, other sensorial perceptions can be relevant (figure 10.3). For example, in the first contact phase, the product should attract attention to enable the user to get curious to come closer and to try the product. The visual, additive and smell characteristics of the product are more relevant in this phase than the tactile characteristics. During the try out phase, the tactile aspects become more relevant as the user will try the product, touching it in doing so. The sense of touch is an important aspect in the perception of quality of the product (Sonneveld, 2004) and hence an

1 A brainstorming technique in which participants sketch and react in writing, based on previous given notes.

important factor in persuading the user to try the product again or to purchase it.

Most products are transported before they are used. This is an interesting phase, as the transport phase enables the product to get in contact with other people than the end user, e.g. people on the street. The product designer can decide how the product is transported and what feedback the product should give during transport. Is the product for example hidden in the back of a trunk or displayed on the dashboard because the user is proud to show that he has just bought the product? Furthermore, when the product is transported in a packaging, what experience should the user have when unwrapping and installing the product? The sensorial properties of the product can create a positive experience in these phases, which increases the user-interaction quality with the product.

The usage phase is probable the most extensive phase in the discussions. The usability of a product is highly influenced by the sensorial properties of the materials the product is made of. For example, different coloured buttons can help to find the right one and high gloss displays are problematic to read outside. Discussing the sensorial properties of the interaction can increase the usability of products.

The last phase is the rest phase. The product is stored for a certain period of time at a certain place. It is interesting to note how the product fits in its surroundings and with the related products. For example, how does a coffee maker fit in a kitchen? Is the aim to create a contrast with the surroundings, or let the product blend in? And what sensorial properties do you need to create that? The rest phase is also about using the product again and what sensorial properties can convince the user in doing this.

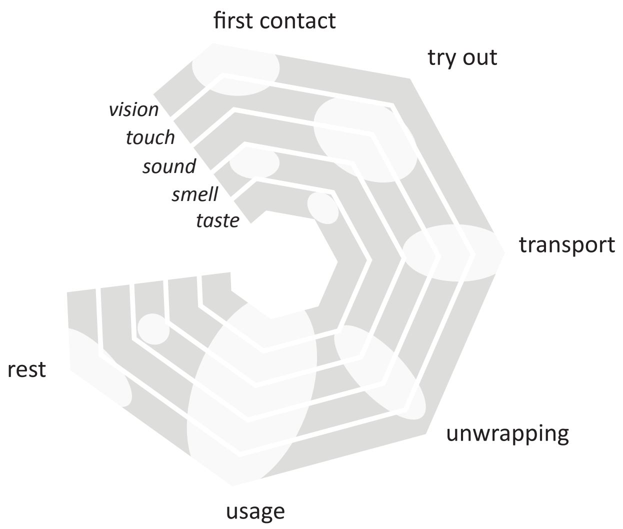


Figure 10.3
Different senses are dominating in the interaction phases with a product.

Table 10.1
Some product examples and the relevant user-product interaction phases.

Product	Interaction phase					
	1st contact	try out	transport	unwrap	usage	rest
Interior	•	•	•		•	•
Packaging	•	•	•	•	•	
Mobile phone	•	•	•	•	•	•
Kitchen appliance	•	•	•	•	•	•
Car	•	•	•		•	•
Office computer					•	•
Clothing	•	•	•		•	
Washing machine	•	•			•	•
Jewelry	•	•	•	•	•	•
Art work	•					•

Not all interaction phases are relevant for every product. For example, the transport phase is only relevant for products moved from a shop to home or from a storage place to a usage place. Some products are frequently ordered through Internet or given as presents. The interaction phases are in these cases different. To increase the user-interaction qualities of the products, it is important to use the philosophy of discussing the interaction with the product. It is up to the product designers to select the relevant phases. As an example, some products and the relevant phases are given in table 10.1.

Picture tool

The picture tool consists of cards with visual examples of products and sensorial properties of materials. A prepared set of cards shows possible relations between example products and personalities such as businesslike, cute, easy-going or modest and the sensorial properties. The cards can be used to discuss and sort the pictures within the user-product interaction ideas. The cards are two-sided, and are used in two steps. In the first step, the example products can be sorted intuitively. In the second step, the other side of the card can be used, which contains a set of sensorial properties that are present in the product. Sensorial properties that appear in the groups can then be discussed in detail.

The picture tool was effective in its current form, although the product designers who used the tool in the evaluation study suggested some changes. These changes concerned the words used on the cards (the personality terms and sensorial properties) and the example products used. Some product designers suggested separating the personality terms and example products and others liked the discrepancy between the cards and their own ideas.

In the revised version, the words were all left on the cards (figure 10.4), but, one side was used to show the visual examples and one the textual clues. In this way, the product designers are triggered to discuss the interaction in terms of sensorial properties and help them with establishing an appropriate set of words in their mind that they can use throughout their project. Another reason to put the pictures on one side and words on the other side is to support a stepwise approach. First, the pictures can be sorted and discussed to generate ideas. After that, the ideas can be made concrete by discussion the sensorial properties.

The example products are not shown as a whole on the new version of the cards. Example products were often associated with different things by different people and it is therefore difficult to focus on solely the sensorial properties of the products. Fragments of these products that show the visual characteristics of products might be a better alternative. However, using pictures of things that are not products on the cards such as flowers, animal skins or artistic pieces might not work. These images are used in mood boards or collages and are ideal for showing an ambiance for a new product, but are less relevant for finding the elements for a material profile. The sensorial properties of the materials used in the example product are appropriate for this.

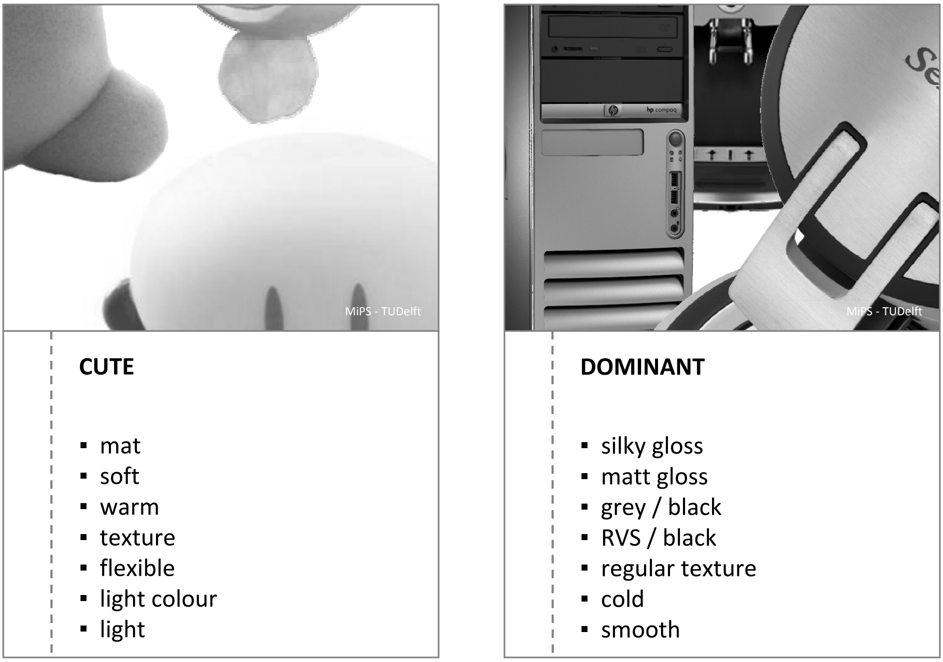


Figure 10.4
Two examples of the new version of the picture tool.

In addition to above described proposals, the product designers that used the tools, suggested making a set themselves. This set would enable them to show a client the nuances of the sensorial experience suggested by them after, for example, studying the target group of the new product. For this reason, the revised version of the picture tool is a set of 16 cards and an empty outline (figure 10.5). The prepared set of 16 cards has the important advantage of being ready to go and inspirational, as examples outside the scope of the new product are also shown. The empty outline can be used to make a subset of 3 to 4 cards relevant for the project. These cards should contain some relevant images on one side and the sensorial properties on the other side.

Extending the set of cards has several benefits. First, the cards can be effective in showing the design directions in a specific project. The options are then limited in a discussion, which is relevant when guiding the client towards the design ideas that are based on user studies or market research. Second, the examples used can reflect the current trends and possibilities better. The prepared set consists of products released in the last few years and will thus need to be replaced as time goes on. A third advantage is that the product designer can build an archive of cards that can show the product designer's personal style.

Sample tool

The sample tool supports the discussion about the sensorial materials aspects and to make them tangible. The materials samples represent a wide range of sensorial properties and are divided between visual and tactile properties and act as examples of the different properties. These samples can be used to explore the properties in discussions before a client meeting. Some studies suggest that it is easier to explore the samples blindfolded, to be able to define the different properties (e.g. Sonneveld, 2007; Burns *et al.*, 1995). After exploring the sensorial properties, these can help to find example products and product parts for the actual meetings. All types of materials should be present in the set, e.g. wood, cork, plastics, metals and fabrics, in order to

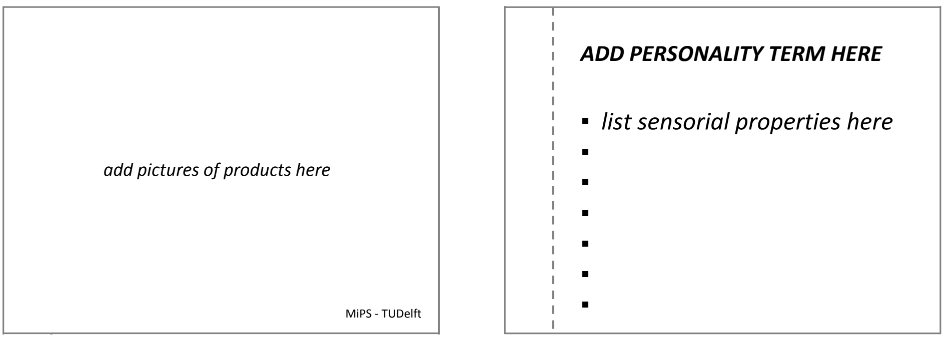


Figure 10.5
Empty outline for the picture tool.

be able to gain inspiration for properties beyond the conventionally used materials in a product category. It is therefore perfect for brainstorms to derive the sensorial properties from the user-product interaction ideas.

The evaluation study showed that product designers would prefer to use the samples to convince the clients of their ideas and not to explore the different sensorial properties of materials. The samples in the tools are lacking details in aspects such as size, transition between materials, manufacturing aspects and shape. After using the tools to explore the user-product interaction, it therefore, is better to find material examples in existing products and parts with the same properties as the selected samples. These 3D examples of the properties can then be used in presentations of the aimed for user-product interaction to the client.

Sheet with related properties

The sheet with related properties shows the sensorial properties and their physical equivalents. It can be used as a back up document when product designers or information providers are unfamiliar with either the sensorial or physical material properties. The sheet is mostly useful for inexperienced product designers or when material requirements are complex. Besides the relations between sensorial and physical properties, the sheet provides alternatives. For example, the sensorial aspect 'colour' can be created by the properties of a material or by a surface layer.

The checklist with sensorial properties and the sheet with related properties were not used by the product designers in the different studies and are therefore not thoroughly evaluated. This means that they can not be adjusted based on the findings of the studies in this thesis. Hence, they are very similar to the ones presented in section 8.3. Further studies are necessary on this topic.

10.3 The MiPS technique in relation to design methods

The MiPS technique assumes that product designers are able to perceive and comprehend the aesthetic qualities of a product and understand how these can be created in a new product. This is defined as aesthetic intelligence by MacDonald (2001). He explains that people use this aesthetic intelligence subconsciously when interacting with the world. Sonneveld (2007) therefore suggests that product designers need to be aware of this natural aesthetic intelligence before being able to design for the senses. In one of her studies, she found that people lack the words to express the nuances of their experiences; they stick to general terms like "It feels good". Furthermore, she found that people find it difficult to distinguish the experiences into the different senses.

As seen in the study in chapter 9, product designers do not readily describe their material profile in terms of sensorial properties, even when they are offered the MiPS tools to support them in this. The assumption that product designers are able to break down the aesthetic qualities of a product into experiences could thus be too optimistic. However, there are design methods that product designers use or could use to aid them in this. This section therefore explains more about how product designers start to shape the required user-product interaction and how the MiPS tools can be used in combination with the existing methods they can use in this process.

Three design methods of which are expected to mesh well with the MiPS technique are discussed in this section. The first method is frequently used by product designers for creating the visual aspects of the interaction, namely collages and mood boards (e.g. described by Muller, 2001). The second method is the Tactile Experience Guide (Sonneveld, 2007) that focuses on the tactile experiences of a user-product interaction. The last method discussed is Vision in Product design (Hekkert & van Dijk, 2001). This method defines the user-product interaction of a product via the context of use.

Collages and mood boards

Product designers use all kind of visual methods to support their design process. An important activity in the early design phases is to create collages or mood boards (Muller, 2001). These visual representations of ideas and ambiances of the new product show the combination of visual (and sometimes tactile) aspects of images to visualize the characteristics of the new product. McDonagh *et al.* (2002) explain that designers use this tool to communicate and express intangible and abstract emotions or to clarify and interpreted their own understanding of the design brief and implications for the project.

Keller (2005) studied the use of visual means for inspiration in the design process. He found that product designers use collages, for example as a form of visual agreement with the client. The product designers have visual and physical collections to make the collages. The collections are extended during projects with new images and examples products specially selected to represent the interaction possibilities with the new product. Keller (2005) also found that product designers find it difficult to talk about how they used these visual materials in their design projects. In the study presented in chapter 9, the product designers indicated they felt the MiPS tools were beneficial for these situations. The tools helped to find the materials aspects from their collages and mood boards. The MiPS technique can thus offer product designers a concretization step by using the collages and mood boards as starting point to explore the sensorial properties in the interaction with the product.

Tactile Experience Guide

Sonneveld (2007) developed the ‘Tactile Experience Guide’ as a tool to support product designers in describing and assessing the aesthetic experience of interacting with objects. The Guide offers a conceptual framework of aspects that can be used to describe the experience and a format that guides people through the experience. Being a tool that focuses on the tactile experiences of the interaction, could make it a good addition for the MiPS technique.

Table 10.2
Content of the maps provided in the Tactile Experience Guide (Sonneveld, 2007, chapter 5).

Domain of tactual experience	General question	Examples
Movements	Why do you touch and how do you move?	To use, I ...; to play, I ...; to explore, I ...
Affective behaviour	What do you experience?	Feedback; familiarity; perfect match; personality
Sensations	What do you sense (own body)?	Pressure; vibration; pain; temperature
Gut feelings	What do you feel?	Energy; Vulnerability; self image; physical pleasure
Tactual properties	What do you perceive (product)?	Texture; hardness; geometry; temperature

The Tactile Experience Guide uses mind-mapping (Buzan & Buzan, 1993) as an associative technique and consists of 6 maps. Five maps represent the five domains of tactual experience (movements, affective behaviour, sensations, gut feelings and tactual properties). The sixth map is an overall map to summarize and draw conclusions on the tactual experience. The domain maps show a question and aspects of the domain as a template (table 10.2). The questions and examples are carefully selected to make sure that users are conscious of the topics and are thus able to answer the questions. For example, people are aware of the tactual properties of a product when their attention is directed toward the material object, regardless of its functional or affective value (Sonneveld, 2007). The users are encouraged to start with the domain maps and move through them while putting associations, key words and thoughts on them. Especially the tactual properties map is interesting in the MiPS technique, as it can form a direct starting point for describing a material profile.

The Tactile Experiences Guide proved, after studying it with 93 students, to contribute to the understanding and ability to describe the tactual experience with a new product (Sonneveld, 2007). However, she explains that students were highly frustrated in the design phase, when they could not find the means to express the experience they had in mind in the product. As a solution, Sonneveld suggested that offering the guide in a setting with exemplary objects and materials for hands on experience; to instantiate tactile experiences, can help in this. These samples can be very inspiring, but it can also be difficult to pinpoint their properties. The sample tool could be a helpful addition here. The sample tool represents a wide scope of sensorial properties in a simplified manner, namely as card shaped samples. It is therefore easier to identify the properties that create the experience, for example softness or texture. Hence, exploring the tactile experience with this tool can provide the required information in the design phase, as it shows the tactile material properties that create the experience.

Vision in Product design

Hekkert & van Dijk (2001) argue that the design of a context should be the start of all design projects. According to Hekkert & van Dijk, a context comprises all aspects or factors which a designer, implicitly or explicitly, considers for his design. Such a context-driven view on designing has lead to the Vision in Product design (ViP) technique. This technique offers a framework that helps to define a set of parameters for the user-product interaction based on a vision of the context for the new product. This framework consists of six stages in two phases, known as the deconstruction phase and the designing phase. In the deconstruction phase, a product designer asks himself why products are the way they are, on a product level (stage 1), interaction level (stage 2) and context level (stage 3). Subsequently, the design phase starts with building a new context (stage 4) and imagining the new interaction qualities in this context (stage 5). The last stage is back on the product level and looks at the particular form that produces the quality of the interaction vision (stage 6). All stages are explained with examples, for example in the course material 'Vision in Product Design, the warm bath', however, the last stage is left to the design experience of the ViP-user.

Within the ViP technique, product designers define the interaction of the end-user with a product. This vision of the interaction describes the concerns of the user and the product features, which address this concern, at the same time. Based on this vision, the product designer needs to define the product parameters that create the product. The MiPS technique can be used for this as illustrated in the car of the future project below.

Car of the future project

A graduate student in the master programme of Industrial Design Engineering was explained the questions tool, checklist and sheet with related properties during a short meeting at the beginning of her project (Klop, 2007). Her assignment was to design the interface of the interior of a car of the future. She used the Vision in Product design

Sparkling Reflecting		
Visual	**Tactile**	**Auditory**
Reflection	**Pressure**	Ringing High pitch Soft sound
Reflective Glossy Translucent Brillliance Smooth Irregular texture	Not denting Hard Slow dampening Massive compact	**Smell and Taste**
	Force	Soapy smell; cool and sweet Natural Soapy taste
Colour	Stiff Tough ductility Brittleness: tough Weight: light	**Light radiation**
Blue, red, metal Less colour intensity Light greyness Durable clour Monochrome Structure	**Friction**	High luminescence
	Not sticky Wet Smooth	**Temperature**
		Warm

Figure 10.6
Collage made by Caroline Klop (2007) that expresses the design vision (left) and the list of sensorial properties that were derived from it (right).

technique to develop new user-product interactions with different components of the car. Her aim was to let these components work closely together to form one coherent interface in which the user's mindsets are shown.

The student created a context, interaction vision and product vision for the future car. Collages were used to visualize the required shapes and details in the interaction (figure 10.6, left). At this point, the student used the questions tool and checklist to discover the sensorial characteristics required to create the vision in the collages (figure 10.6, right). However, she is not very explicit about the sensorial properties in her answers. She answered, one of the questions, for example, with: 'It is a gentle car with a gentle interior, but it should be clear that the interior's behaviour is a bit naughty and has a little bit of his own will: the user's main hobby is communicating and navigating efficiently' (Klop, 2007). However, she was able to select the required sensorial properties from these descriptions: 'Selected materials will be reflective or glossy, smooth and have an irregular texture. They are hard, stiff, tough and light in weight. Colours are blue, red and metal-like' (Klop, 2007). These material characteristics served as a basis for the materialization phase in her project.

The feedback she gave after using the tools was: "It works well with the Vision in Product design technique. This technique results in a vision about the required user-product interaction with a product and with the tools offered by MiPS it is easy to translate this vision into a set of tangible material characteristics for the new product". This example shows that the questions tool could serve as a structure to translate the vision created with the VIP technique into product and material characteristics needed to design the product.

10.4 Workshop for explaining the MiPS technique

One important outcome of the evaluation of the tools was the evident need for instructions on the use of the MiPS technique and tools, to educate product designers, design teachers and students on the benefits of using them (section 9.5). In such a workshop, not only the steps in the technique and the working of the tools should be described and trained, but also the motivation for changing the current materials selection approach. Furthermore, the participants should get some familiarity about the relationship between the user-product interaction and the sensorial properties of the material that create this interaction. Explaining the working of the MiPS technique in this wide perspective is expected to increase the effectiveness of the use of the technique.

The objectives for the workshop are:

> ***Objective 1*** *Acquaint the participants with the benefits of changing the current materials selection approach.*

> ***Objective 2*** *Educate the participants about the relations of user-interaction aspects, sensorial properties and physical properties of materials.*
>
> ***Objective 3*** *Accustom the participants with the MiPS technique and the tools that can be used herein and the skills needed to follow it.*

The first and second objective could be reached with a presentation about the topic. For the third objective, a combination of a presentation and small assignments are considered necessary. In the following, the content of the different parts in the workshop and the assignments is presented. The order of the sections is the same as suggested for the workshop.

The need for changing the current approach

As explained in the introduction of this thesis, materials selection approaches need to change in order to keep up with the changing end-user needs and continuous development of new materials. The objective of the presentation is to change the mindset of the participants about selecting materials. The presentation acquaints the participants with the current materials selection process and the needs to change this process in order to stay effective in designing high quality products. Three topics are discussed, namely 1) the changing focus on user-interaction aspects of products; 2) the significant role of materials in creating the user-product interaction and 3) the critical factors in the current materials selection techniques. The information for these topics can be found in the introduction of this thesis and in chapter 7.

The changing focus on user-interaction aspects of products could be illustrated by some interesting examples of companies that let other factors than logistics and functionality drive their decisions in the product development process, such as illustrated in the workshop text box.

User-product interaction in sensorial properties

This presentation's objective is to increase the product designers' knowledge about the sensorial properties of the user-product interaction. It explains the sensorial properties of a material and shows examples of how the properties can influence the interaction. With the principles in mind, the product designer can start to look differently at products and teach himself to break down existing products in sensorial properties and rebuild them in their own projects. The theoretical background for this presentation is thoroughly described in section 2.1 and 8.3.

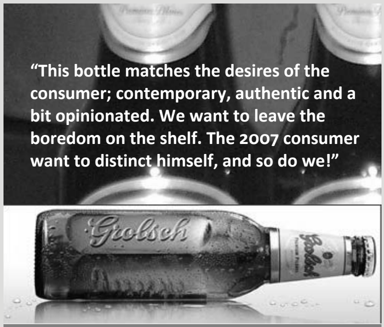
The Materials in Products Selection technique and tools

The objectives of this presentation are to explain the Materials in Products Selection (MiPS) technique and the tools that could be used in this technique. The Materials Selection Activities model explains the materials selection process (section 5.4) and within this model, the positioning of the MiPS technique. The explanations in section 10.1 and 10.2 form the basis for this presentation.

Examples in the workshop

a.

“A Dutch beer company Grolsch launched a new beer bottle in February 2007. This bottle is different from the standard bottles in shape and colour and therefore distinguishes itself in personality. Important drawbacks of the new bottle are the logistics of re-using the bottles. All beer brands used to have the same standard bottle, which made it possible to reuse it even for another brand. Although these consequences, Grolsch decided to launch the new bottle for personality reasons.”



Distinction through design

b.

“New materials are in continuous development as well as the manufacturing process to process them. These new materials can increase the user-interaction and functional qualities of products.”

New material possibilities

c.

“Sensory design is an interesting technique to emphasize the user-interaction qualities for product. The mobile phone company Nokia advertises with the sensorial experiences that their phones have and put effort in selecting unconventional materials in their product such as ceramics or flexible materials used in the phone presented on the last page of this thesis.”

Design for the senses

Assignments for the workshop

First assignment – exploring the sensorial properties in an interaction phase

Two participants select a product, a target user group and market for discussing the product in the light of these users. Ideally, the product is present, in order to be able to use that product as a starting point.

The first step in the assignment is discussing the questions and topics from the inspiration sheet (figure 10.2). The aim of this phase is to find the interaction aspects that are aimed for in the product. The participants are encouraged to define circa three aspects of the interaction that are interesting to explore with new materials. For example, in the try out phase, the curiosity of the user can be an interesting interaction aspect, but also what actions the user performs during try out and what he touches.

In the second step, the picture and sample tools are used to explore the different sensorial properties that can create the user-product interaction. The participants are encouraged to categorize the picture cards and samples according to their own defined categories and re-categorize them for the different interaction aspects they came up with. In this step, ideas are raised and explored about the sensory aspects in the interaction.

After the assignment a short evaluating discussion is held to allow the participant express and share their experiences with the tools. This evaluation must be performed between the two assignments, to make it possible for suggestions to be made before the results of the discussions are transferred into a material profile.

Second assignment – making a material profile of sensorial properties

The participants start the second assignment with the notes made about the sensorial properties of the interaction. The aim of this assignment is to formulate a material profile based on these aspects. The profile is intended to be useful in making decisions about the leading sensorial properties that are concrete and useful in using it in the materials searches. This might be a difficult step because the participants might not be experienced in describing the interaction as a set of single properties. A checklist is provided on which the sensorial properties are written.

Examples of techniques that can be used to start the flow of defining the leading sensorial properties are; 1) to discuss one single handling in the interaction and say out loud what the senses perceive during the handling, or 2) to select a single property and discuss how this property influences the interaction. The participants are encouraged to select a maximum of five properties that are interesting to explore in the materials searches.

When the material profiles are finished, the participants change partner. With the new partner, they discuss the interaction which they tried to create and the leading properties in this. This discussion can be similar to one in which the participant explains to a non-designer, e.g. his or her client, what his design directions will be. The presenters are allowed to use the tools in this discussion when they desires to do so.

After the second assignment, the experiences of the different participants are discussed again. This evaluation is relevant to hear the about the situations and tactics in which the technique is effective and when not.

The two phases in the MiPS technique that could need hands on experience are, firstly, the phase in which the tools are used to discuss the sensorial properties of the interaction and, secondly, the phase in which the leading sensorial properties are defined. The assignments, such as shown in the text box, are performed in pairs enabling the participants to share their experiences with other participants in the workshop. The design cases used in the assignments are products like cosmetics, watches, mobile phones, kitchen appliances or garden tools. Any product is possible as long as the user-interaction aspects are relevant herein. Different people in the workshop can do a different product and discuss the findings later to enlarge the leanings of the tools.

10.5 Conclusions

The effectiveness of the MiPS technique could improve when using it in combination with existing design methods that create and visualize a required user-product interaction with a new product. The MiPS technique can be a fruitful addition to translate this defined user-product interaction via the sensorial aspects into the material properties that can create the required interaction.

The tools that can be used in the MiPS technique (the questions, pictures, sample tools and sheet with related properties) in their revised form are not solely designed for discussion with the client, but also to prepare the client-meetings. Therefore, the tools do not only consist of ready-made components, but also of some elements that can be extended by the product designers. This is particularly necessary in the case of the sample tool, because it is impossible to make a set of informative 3D example parts that are relevant for every product.

The workshop, presented at the end of the chapter, aims at educating product designers about the MiPS technique and tools. A workshop enables the product designers to learn more about the technique and tools and practice them before using them in their own projects. Such a workshop increases the product designers' skills and knowledge on the topic and ideally is a fixed element of every development and implementation of new techniques.

Chapter 11 Findings and implications

This thesis was sparked by the curiosity about how product designers select materials for a product, in order to ensure that the end-users will enjoy interacting with it. The thesis offers insight into the complexity that product designers face when integrating user-interaction aspects into the materials selection process. Furthermore, a promising and practical solution for these problems was developed and verified in design practice. The outcomes offer a step-wise technique, with tools, to identify and clarify the user-interaction requirements for the materials of a new product. This chapter discusses the findings and implications of the project and provides recommendations for further research in the field of user-centred materials selection.

11.1 Results of this thesis

The user-product interaction is an increasingly important factor in the product development process. The materials, from which a product is made, form a strong element in the user-interaction qualities of a product. The proposition in this thesis is user-interaction aspects of materials must be included in the selection process in order to be able to survive in today's highly competitive market. Raising the effectiveness of the process was considered an important theme. The main research question in this thesis was, therefore, how can product designers effectively include user-interaction aspects in their materials selection process. Effectiveness was defined in this thesis, as being able to find the best available materials for the technology and user-interaction quality of the new product via the shortest possible path. The objectives of the research were to explore the issues that hinder an effective materials selection process and to improve the techniques to include user-interaction aspects in this process.

The research approach that was followed resembles a user-centred design process in which clarifying the context and specifying the requirements for the improvements precede the design and evaluation phases. The results of this thesis are the outcomes of the different phases in this approach:

> ***The clarification of the context*** *resulted in a validated model of the materials selection process*
>
> ***The specification of the requirements*** *led to an understanding of the critical factors in a user-centred materials selection process*
>
> ***The design phase*** *resulted in a materials selection technique and tools for this technique*
>
> ***The evaluation phase*** *identified which aspects of the technique and tools led to an effective inclusion of user-interaction aspects in the materials selection process and which aspects needed to be improved.*

The practical results of this thesis are the model, a technique and tools. The Materials Selection Activities (MSA) model describes the sequence of steps taken in the process and the role of information herein. In order to improve the current materials selection process, the Materials in Products Selection (MiPS) technique was developed, which includes the user-interaction aspects of materials via the sensorial interaction. To support the MiPS technique, four tools were created; the questions, picture and sample tools and a relations sheet. The first three aid the communication about user-interaction aspects and the sheet relates the sensorial properties of materials with the physical properties.

The implications of the MSA model, MiPS technique and tools for the design practice, and both the educational and design research fields, are summarized in table 11.1. The empirical studies in this thesis provided insight into the practical value of the MiPS techniques and tools and into the value of the MSA model in design research. The results of this thesis and directions for the further assessment of the implications that were not investigated in this thesis are discussed in the following sections.

11.2 Current materials selection process

Materials influence the interaction that users have with a product via their sensorial properties. These properties influence how a product can be used and perceived and influence the kind of associations and emotions a user can have with a product. Product designers can use the sensorial properties to create a required user-product interaction and consider other aspects of materials, such as manufacturing and shape

Table 11.1
Relevance of the different results of the thesis on different fields.

	Design education	Design practice	Design research
MSA model			
	Provides a realistic view on the material selection process of product designers Expected to bridge well between education about design methodology and material science	Expected to offer a framework for planning and acquisition of design projects	Demonstrated to offer a framework for process analysis of the materials selection process
MiPS technique			
	Held to provide practical steps to learn how to translate user-interaction ideas into product designs	Proved to enhance the user-centred materials selection process by leading to clear material criteria Expected to improve the materials discussions with technology oriented specialists	Provides a practical view on how to study design techniques and tools in practice
MiPS tools			
	Assumed to give students an attractive way to learn to explore and discuss other products and materials while designing	Proved to enrich the vocabulary about material aspects and the considerations in the process	Expected to form instruments to study the communication aspects in materials selection

aspects, while doing this. The effectiveness of the current material selection process is dependent on the information that is available about the combinations of aspects and on the way product designers can access and compare information. In the analysis section of this thesis the materials selection process was explored and the critical factors that hinder the effectiveness in this process were revealed.

Exploration of the materials selection process

The materials selection process was empirically studied to be able to understand and model the activities product designers perform in selecting materials. This model proposed to offer a realistic view of the materials selection process and to form an effective framework enabling the critical factors in an effective process to be identified and structured. Existing models are inadequate, as they often tended not to include user-interaction aspects or lacked the details to describe what product designers do. The practical findings of the materials selection process were used as input to form the MSA model.

The important characteristics of the MSA model are that it shows materials selection as an iterative problem solving approach central to which is the formulation of material criteria. In addition to existing models, it affords more insight into the role of information and expert consultations in the selection process. Materials selection cycles occur throughout the design project, with decisions in early phases being taken about different materials, and in the later stages about different material variations and specifications.

Validation

The validation of the MSA model proved that the model accurately represents the materials selection process of product designers, even when user-interaction aspects are involved. The model shows the relevant activities in the process and visualizes the iterations that are an inherent part of the design process in design practice. Furthermore, the fundamental role of the information activities was confirmed as these were significantly found in design practice. The discrepancy between the order of activities in the model and in the studied design projects needs to be studied further, as it could not be discovered whether this was caused by the retrospective recovery of the materials selection steps or an incorrect representation of the model (see section 11.4).

Practical implications

The MSA model is used in this thesis as a structure to study the critical factors in the materials selection process, which demonstrates the relevancy of the model for design research. This research method was successful in finding the areas which needed improvements. The MSA model helped to outline design projects and worked as a memory aid when product designers were asked to recall specific elements in the projects. However, the model only helps to describe projects on an activity level, hence when studying separate actions or the relations between people, the model is too general. For example, in this project, the research method did not help to predict the nuances in the relationship between the client and product designer. This means that the MSA model should be carefully used and an in-depth follow-up study, such as used in this thesis to evaluate the tools, is necessary to expand the understanding of the issues that were found, which in our case were the critical factors.

The MSA model is not only relevant for design research, but also provides insight that are useful for design education and practice. Product designers that work for a client often work on an hour planning that is established at the start of a project. Design models help to plan and visualize the activities to be performed in a project. Likewise, the MSA model could help in planning the materials selection steps.

In design education, such as at the faculty of Industrial Design Engineering[1], materials selection is taught in relation to the production and manufacturing processes. Moreover, students learn about the material properties in material science courses.

1 Delft University of Technology, the Netherlands.

Furthermore, in design courses, materials selection is often taught as part of the later phases of the design process. However, as shown in the MSA model, this segmentation does not reflect the process of materials selection, as it occurs in design practice. The MSA model illustrates that materials selection is an integral part of the design process and that material decisions are made even at the very beginning of a project. Therefore, educating future designers with separate courses might not be sufficient. To increase students' materials selection skills a separate course could be taught in materials selection in parallel with a materials science and design course. The MSA model could be used as a bridge between the design courses and material science courses. The model shows how materials selection is embedded in the design process and explains the need to communicate with specialists and thus to understand the properties of materials.

Critical factors in the materials selection process

The critical factors that influence the effectiveness of the materials selection process were identified based on the analysis of design practice. Important critical factors were revealed relating to the formulation of material criteria. Furthermore, a critical factor was that specialists could not advise about the user-interaction aspects of materials. These factors lead to unnecessary long searches for the best material options for a product. Furthermore, they prevent utilization of the full potentials of (new) materials to increase the user-interaction qualities with the product.

The clarity of the criteria was found to be dependent on the communication about the user-interaction aspects between product designer and client. Product designers indicated that clients were not always able to express their user-interaction requirements or follow the thinking process of the product designer. The materials searches, therefore, do not always lead to material options both the product designer and client are pleased with. The changes and adjustments of criteria as a result, affected the effectiveness in the materials selection process.

Product designers indicated a preference for recommendations from specialists to be able to accelerate their materials selection process. However, some information providers, such as manufacturers, are specialized in advising on the technological aspects of materials and less about the user-interaction aspects of materials. Product designers explained that they need to find information from several sources and combine the information themselves, leading to long searches or failure to find candidate materials that fulfil both the technical and user-interaction criteria.

Besides the factors found in the design projects, another critical factor was identified, relating to the potentials of new materials. New materials may offer a chance to increase the qualities of products, both on technology and user-interaction aspects. However, the current materials selection practice does not stimulate the inclusion of new materials in these considerations.

The above critical factors decrease the effectiveness of the materials selection process when user-interaction aspects are included. The effectiveness of the process can thus be improved when these problems are solved. A practical answer for this was proposed in the form of a new materials selection technique. This technique aims at improving the formulation of clear criteria on the user-interaction aspects of materials. Furthermore, the technique tries to diminish the difficulties which specialists have in advising on the user-interaction aspects, thereby facilitating the considerations of new materials. In the following, the design and evaluation of the technique and accompanying tools are discussed.

11.3 Materials in Products Selection technique and tools

Product designers use several tools and techniques to support their design process. In the synthesis part of this thesis, a new technique to support the inclusion of user-interaction aspects in the materials selection process was developed. In broad outlines, this technique supports product designers in the analysis phase, in including the user-interaction aspects in a material profile. This profile can thereafter be used in the materials searches. The technique involves the client in making the profile and uses a vocabulary to enable technology-oriented specialists advising about the user-interaction aspects of materials. The technique is accompanied by tools that were evaluated in design practice.

Design considerations

The Materials in Products Selection (MiPS) technique consists of defining, translating and using steps. In the defining step the user-interaction aspects are defined as sensorial properties. Sensorial properties were chosen as an effective vocabulary to mediate between the user-interaction aspects and the physical properties. Sensorial properties of materials influence the sensorial interaction with a product and have physical properties as equivalents. In the translation step, the product designer relates the sensorial properties with their physical equivalents and evaluates the material requirements on the relevant design aspects. In the usage step, the material profile is used to find candidate materials. Defining a material profile in these properties was expected to clarify the user-interaction requirements and enable technology-oriented information providers to recommend the best material options.

For the defining step, three communication tools were developed. These tools use pictures of example products (picture tool), a selected set of material samples (sample tool) and a list of questions (questions tool) to discuss the required user-product interaction with a new product. These tools were expected to ease the product designers' discussions with clients as they offer structure to the conversation and use relevant examples to define the sensorial interaction with the new product. In a usability study, in which the tools were used in a fictive design brief conversation, the tools proved to be usable and adjustable to the approaches adopted by the participating product designers. Furthermore, the tool lead to an increased consensus about the leading properties for the materials searches, although the discussions did not end in a profile in sensorial properties. Combining the tools was expected to solve this problem. Whether this was the case is explained in the next section.

A sheet that relates the sensorial properties of materials with the physical equivalents was developed as a tool for the translating step. This sheet contains the properties organized in different categories relevant for product designers and provides alternatives when the sensorial interaction cannot be created with a material, but requires, for example, other geometry or a surface layer.

Achievements of the technique and tools

The achievements of the technique and tools were evaluated in design practice. The tools were used by four product designers in their own projects for a period in which they defined the material criteria, searched for materials and proposed their material options to the client. The study revealed that product designers increase their vocabulary about the user-interaction aspects of materials when they use the tools. Hence, they were able to clarify their criteria. This accelerated their searches by having easier discussions with the people involved and having more confident choices.

The tools enable the product designers to involve the clients in the decision process of the user-interaction aspects of materials. However, the tools proved to be not effective in all client - product designer discussions. In those projects, where product designers are assigned to analyse the target group and market, they felt that the client was not able to discuss the user-interaction requirements. Moreover, they did not want the client to make these decisions. However, product designers felt the need to have tools to communicate and present the user-interaction directions to the client. In the final adjustments made in the tools, this aspect is included: besides a pre-made set, the tools offer an empty lay-out. The product designers can fill in this lay-out themselves for communicating the nuances in the desired user-product interaction.

In the current design practice, product designers start the materials searches with some presumptions for materials solutions. The MiPS technique tries to stimulate product designers to start the materials searches with a clear material profile that contains the required sensorial and physical properties. It was discovered that the tools were not so successful in having the product designers create such a profile. To solve this aspect a workshop that aims at training product designers in the technique and the benefits of using it, was developed. After following such a workshop, product designers are expected better able to formulate a material profile and in their materials searches.

Practical implications

The MiPS tools were found to enhance the materials selection process by leading to clear criteria about the user-interaction aspects of materials. They are relevant in projects where the product designer is able to make a materials selection, the user is important for the products quality and there is knowledge about the required user-interaction qualities of the product or time to investigate this. The MiPS technique and tools are then helpful to translate the user-product interaction ideas into a material profile. The revised technique and tools can be implemented in design practice in their current form.

The MiPS technique and tools were developed for product designers in design agencies, but could offer design students an attractive way to acquaint themselves with the knowledge and skills needed for selecting materials. The technique offers students a step-wise approach that helps them to structure their materials selection process. The tools could trigger a way of looking at products that helps students in their future design projects. Furthermore, students might raise their awareness of the materials selection process and the relevance of studying materials science when interacting with the technique and tools.

Not the MiPS technique itself, but the way it was evaluated, provides a practical view for the design research field. Developing design techniques and tools for practitioners requires that they are robust for the extensive number of situations product designers find themselves in when designing products. Evaluating the techniques and tools in design practice is therefore inevitable. However, evaluation studies also require a certain validity and repeatability, which might be complicated in design practice. In this thesis, the evaluation was performed by having product designers use the tools and explain their experiences in a research diary. Two interviews were used to discuss these experiences compared to other projects. This approach provided usable data about the effects of the tools and the product designers' opinions about these effects. This data lead to revisions and the development of a workshop.

11.4 Recommendations for further research

This thesis explains the explorative research work that was aimed at finding the directions for user-centred materials selection. The field was studied with a wide angle to be able to recommend the promising paths for an improved materials selection process. Table 11.1 shows the expectations and assumptions that offer a starting point for further research.

The Materials Selection Activities model can be studied further, especially the discrepancy between the order of activities in the model and in design projects. For validating this specific issue, a protocol analysis approach is recommended in which the materials selection process is studied at the time it takes place.

The practical value of the MSA model for design practice and education was not studied in this thesis. Effort is needed to investigate the value of the model for planning and teaching purposes. It is recommended that the model is first used in an elective course, to be able to fine-tune the instructions and find illustrative backgrounds to accompany the model, such as lists of information sources, exemplary objects and materials selection cases. The materials selection course could then form an obligatory part of the bachelor degree program.

The techniques and tools were used in design practice to be able to study their effects on the materials selection process; however, not all aspects could be evaluated. The product designers did not use the offered sheet that relates the sensorial properties with physical properties. The amount of text on the sheet was not appealing according to the product designers. As a consequence, it was not possible to evaluate the specific aspect of using sensorial and physical properties in the information requests for technology-oriented specialists. Evaluating this aspect is recommended for further studies, in order to be able to assess the expected benefits of using sensorial properties as a vocabulary for the user-interaction aspects of materials. Once it is established that product designers see the benefits of using such a sheet to make their materials searches more effective, research efforts are recommended on the specific relations of a sensorial property with the related physical properties. Important aims for such research is to relate e.g. the range from the tactile properties 'soft' to 'hard' to the elasticity modulus and hardness properties involved.

The technique and tools were used by some students during this research project, and their evaluations made apparent that they could benefit from them. However, the techniques and tools were not evaluated for their educational value in a research setting. Therefore, to understand the practical implications of the technique and tools for design education, studies are needed. These studies could focus on the effect of using the tools on the structure of the materials selection process and the quality of the designs made by the students.

11.5 Final conclusions

The practical value of this thesis is not restricted to the design field. Material scientists might also benefit, as most material development is driven by technology and not motivated by product design. This results in information that fails to reach product designers (Ashby & Johnson, 2002). Material scientists can use the models, technique and tools for understanding the design process and their role in the materials selection of product designers. This understanding can help material scientists to present information about their materials in a useful way for product designers. Furthermore, material scientists could use this understanding to get input from product designers and spark off the development of new materials. For example, in chapter 2, it was recommended that effort be put in finding the combinations of material information that can be put in a database. One of the combinations to be studied is the relationship between sensorial properties and physical properties, as used in this thesis. Furthermore, when product designers include a step in their process in which they make a material profile for the required user-product interaction, they can communicate this profile to materials developers, who could respond with new materials.

Improving a particular approach, in many cases, starts with the person's awareness of his or her current approaches. In this thesis, the aim was to improve the inclusion of user-interaction aspects in the materials selection process. Various product designers participated in the studies performed for the project and many of them mentioned that they were motivated to participate because they wanted to increase their own awareness of their materials selection process. Between the invitation and the actual research, they often thought about their approach or discussed this with a colleague. Hence, the fact that the studies in this thesis involved the different product designers might have been the first step to improve their materials selection process.

In conclusion, I have argued in this thesis that product designers can effectively include user-interaction aspects in their materials selection process if they clarify the criteria about these aspects and if information providers are able to give specialized advice about the user-interaction aspects of materials. The MiPS technique and tools developed facilitate the activities needed to translate user-product interaction ideas into a clear material profile in sensorial properties and their physical equivalents. Based on these properties, specialists are expected to be able to make recommendations about the best material options for creating the required user-interaction qualities of the new product. The tools proved to increase the product designer's vocabulary and awareness of the user-interaction requirements of the materials earlier in the design process than currently. In doing so, the tools help in solving the unclearness of criteria about the user-interaction aspects of materials and could thereby increase the effectiveness in the materials selection process.

However, one question still remains:

What sensorial properties does your favourite product have?

Summary

Selecting materials in product design

Product designers find themselves in a field where consumers demand more of their products and where new materials become available everyday. In the materials selection process of user-centred design projects, the emphasis shifts from technology towards user-interaction aspects of products. Materials form the interface of the product and influence the sense of quality, the pleasantness of the interaction, the personality of the product and the way it can be used; in other words the user-interaction with the product. The human senses, as the interface of the user, play an essential role in this interaction. Via the senses, the user perceives the characteristics of a product and transfers them into experiences and use-actions. Carefully selecting materials should thus be an integral part of the creation of a required user-product interaction.

Product designers need to enhance their materials selection activities to include the user-interaction aspects in their materials selection processes. However, information about the effect of materials on user-interaction aspects of products is not available or not adequately adjusted to the approaches of product designers. The objectives of the thesis were to explore the issues that hinder an effective materials selection process and to create techniques and tools that support product designers in effectively including user-interaction aspects in this process. The development approach in this thesis resembles a user-centred design approach with the phases ‘clarification of context’, ‘finding the requirements of product designers’, ‘design’ and ‘evaluation’.

In the analysis section of this thesis, a new materials selection model was created for the purpose of understanding the materials selection context. The ‘Materials Selection Activities’ (MSA) model describes the activities of product designers. It emphasizes the iterative character of the materials selection process and the role of information herein. The model proved being useful for finding critical factors in materials selection activities.

The critical factors in an effective materials selection process are related to the ability of product designers and their clients to discuss the user-interaction criteria for the product. Hence, product designers start their materials searches based on unclear

criteria, which lead to unnecessary long steps of clarifying the criteria and finding the candidate materials. Furthermore, a critical factor is that some information providers about materials, such as manufacturers, are specialized in advising about the technology aspects of materials and not about the user-interaction aspects of materials. Making a balanced decision about the best materials for the required user-interaction qualities of a product is, therefore, difficult.

The synthesis section describes the design and evaluation of the ‘Materials in Products Selection’ (MiPS) technique, which aims at diminishing before mentioned problems. This technique defines the user-interaction requirements of a product in a material profile. The MiPS technique differs from the current approaches of product designers because it explicitly formulates the material criteria in the form of the required sensorial properties of the materials. A search based on sensorial properties enables to include new materials (newly developed or new for the product category) and enables to combine the technology and user-interaction aspects of the materials.

Four tools were developed to support the MiPS techniques of which three aid the communication about the required user-interaction aspects and one relates the sensorial properties with physical properties. The communication tools defines the user-interaction via several means, namely 1) pictures of product examples and the materials these products are made of, 2) tangible materials samples and 3) the sensorial aspects of materials during several phases of the user-product interaction. The tools not only aid the discussions about user-interaction aspects of materials, but also support the translation of these into sensorial properties of materials. The relation tool enables technology-oriented material specialists to include the user-interaction requirements in their recommendations.

The evaluation of the tools, based on product designers using the tools in their own projects, demonstrated that the MiPS tools help to clarify criteria about the material aspects that can create a required user-interaction with the new product. The tools proved to increase the product designer’s vocabulary and awareness of the user-interaction requirements of the materials earlier in the design process than currently. For transferring the knowledge about the technique and tools to design practice, a workshop was developed. The workshop, model, technique and tools form the practical results of this thesis, which could be directly used in the design field.

Samenvatting

Materiaalselectie in het productontwerpen

Productontwerpers werken in een omgeving waarin consumenten steeds meer van hun producten verwachten en waarin steeds meer nieuwe materialen beschikbaar komen. In het user-centred ontwerpen verschuift de aandacht van technologie naar de interactie die een gebruiker heeft met een product. Materialen vormen de interface van een product en creëren daarbij het gevoel van kwaliteit, het plezier in de interactie, de persoonlijkheid van het product en de manier waarop het gebruikt kan worden, kortom, de gebruiksinteractie met het product. De zintuigen, die dienen als het interface van de gebruiker, spelen een essentiële rol in die interactie. Via de zintuigen neemt de gebruiker de eigenschappen van het product waar en vertaalt deze naar gebruiksacties en beleving. Het zorgvuldig selecteren van materialen is dus een belangrijk deel van de creatie van de gebruiksinteractie met een product.

Productontwerpers moeten hun materiaalselectie activiteiten versterken om de gebruiksinteractie aspecten mee te nemen. Er is echter weinig informatie beschikbaar over het effect van materialen op de gebruiksinteractie en de informatie die beschikbaar is, is niet altijd aangepast aan de werkwijzen van productontwerpers. Het doel van dit proefschrift is, enerzijds, het onderzoeken welke factoren een effectief materiaalselectie proces in de weg staan en, anderzijds, het ontwikkelen van technieken en tools die de productontwerper ondersteunen bij het integreren van gebruiksinteractie aspecten in dit proces. De onderzoeksaanpak in dit proefschrift volgt de stappen in het user-centred ontwerpen. Deze stappen zijn het verduidelijken van de context, het vaststellen van de eisen van de productontwerpers, het ontwerpen en evalueren.

In het analyse deel wordt een nieuw materiaalselectie model gecreëerd om de materiaalselectie context beter te begrijpen. Dit model, het ‘materiaalselectie activiteiten’ (MSA) model, beschrijft de activiteiten van productontwerpers in hun materiaalselectie proces. Het benadrukt het iteratieve karakter van de activiteiten en de rol van informatie hierin. Het model vormde een bruikbare basis voor het vinden van de kritische factoren in de materiaalselectie.

De kritische factoren hebben betrekking op de bedrevenheid van productontwerpers en hun klanten om de gebruiksinteractie eisen voor een nieuw product te bespreken. Hierdoor starten productontwerpers een materialenzoektocht op basis van onduidelijke criteria en dat leidt tot onnodig lange inspanningen om de criteria te verduidelijken en om materialen te vinden. Een andere kritische factor was dat sommige informatieverschaffers, zoals materiaalfabrikanten, goed zijn in het leveren van informatie over de technische aspecten van materialen, maar niet over de gebruiksinteractie aspecten. Productontwerpers kunnen daardoor slecht advies krijgen over de materialen die aan de gewenste gebruiksinteractie kwaliteiten voldoen.

Het synthese deel beschrijft het ontwerpen en evalueren van de 'Materialen in Producten Selecteren' (MiPS) techniek. Deze techniek heeft als doel een oplossing te bieden voor bovenstaande problemen. Met deze techniek definieert de productontwerper de gebruiksinteractie eisen van een product in een materiaalprofiel. De MiPS techniek verschilt van de bestaande aanpak van productontwerpers, omdat het expliciet de materiaaleisen formuleert in de vorm van sensorische eigenschappen. Een materiaalzoektocht gebaseerd op sensorische eigenschappen maakt het mogelijk om nieuwe materialen (nieuw ontwikkeld of nieuw voor de toepassing) mee te nemen in het selectie proces en helpt bij het combineren van de technische en gebruiksinteractie criteria.

Er zijn vier tools ontwikkeld om de MiPS techniek te ondersteunen. Drie van deze tools helpen in de communicatie over gebruiksinteractie aspecten en de vierde tool combineert de sensorische eigenschappen met hun fysische equivalenten. De communicatie tools gebruiken 1) plaatjes van voorbeeldproducten, 2) materiaalsamples en 3) de sensorische eigenschappen van materialen in verschillende fasen in de gebruiksinteractie met producten om de discussies te ondersteunen. Ze helpen daarbij niet alleen bij het vaststellen van de gewenste interactie, maar helpen deze ook te vertalen naar de gewenste sensorische eigenschappen in een materiaal. De eigenschappen tool helpt technische georiënteerde informatieverschaffers bij het meenemen van de gebruiksinteractie eisen in hun materiaaladvies.

De studie, waarin de tools geëvalueerd zijn door productontwerpers in hun eigen projecten, liet zien dat de tools effectief zijn in het verduidelijken van de eisen over de materiaalaspecten die een gewenste gebruiksinteractie kunnen creëren. De communicatie tools hebben bewezen dat ze het vocabulaire van productontwerpers vergroten en hun eerder in het ontwerpproces bewust maken van de interactie-eisen. Om deze kennis over de techniek en tools over te brengen aan de ontwerppraktijk is er een workshop ontwikkeld. Met deze workshop, het model, de techniek en de tools eindigt dit proefschrift in een praktisch resultaat dat direct bruikbaar is voor ontwerpers.

References

Abbaschian R, Marshall LM. (2006) *Material information for the design community.* Advanced materials and processes. 164(6):30-31

Adank R, Warell A. (2006) *Assessing the sensory experience of product design: towards a method for 'Five senses testing'*. Proceedings from the 5th Conference on Design and Emotion 2006. Karlsson, MA; Desmet, P; and van Erp, J. (eds). Chalmers University of Technology, 27-29 September, Göteborg, Sweden

Addington A, Schodel D. (2005) *Smart materials and technologies for the architecture and design professions.* , Architectural press, Oxford

Ahmed S, Wallace KM, Blessing, LTM. (2003) *Understanding the differences between how novice and experienced designers approach design tasks.* Research in Engineering Design. 14(1):1-11

Amen R, Vomacka P. (2001) *Case-based reasoning as a tool for materials selection.* Materials and Design 22(5):353-358

Arabe KC. (2004) *Materials' central role in product personality.* Thomas Net Industrial News Room (March)

Ashby MF. (1999) *Materials selection in mechanical design.* Butterworth-Heinemann, Oxford, second edition

Ashby MF, Brechet YJM, Cebon D, Salvo L. (2004) *Selection strategies for materials and processes.* Materials and Design. 25(1):51-67

Ashby MF, Cebon D. (2007) *Teaching Engineering Materials: the CES EduPack* Engineering Department, Cambridge University, England, May 2007

Ashby MF, Johnson K. (2002) *Materials and Design: the art and science of material selection in product design.* Butterworth-Heinemann, Oxford

Ashby MF, Johnson K. (2003) *The art of materials selection.* Materials Today. December 2003:24-35

Athavankar UA. (1997) *Mental imagery as a design tool.* Cybernetics and Systems. 28(1):25-41

Baya V, Leifer LJ. (1996) *Understanding information management in conceptual design.* In: Cross, N., Christiaans, H., Dorst, K. (eds) Analysing design activity. John Wiley and Sons, p151-168

Beiter K, Krizan S, Ishii K, Hornberger L. (1993) *HyperQ/Plastics: An intelligent design aid for plastic materials selection.* Advances in Engineering Software. 16(1):53-60

Bloch PH, Brunel FF, Arnold TJ. (2003) *Individual differences in the centrality of visual product aesthetics: concept and measurement.* Journal of consumer research. 29:551-565

Bonapace L. (2002) *Linking Product Properties to Pleasure: The Sensorial Quality Assessment Method- SEQUEM.* In: Green WS, Jordan P (eds). Pleasure with Products beyond Usability. Taylor & Francis, London and New York

Brechet Y, Bassetti D, Landru D, Salvo L. (2001) *Challenges in materials and process selection.* Progress in Materials Science. 46:407–428

Burchitz I, Boesenkool B, Zwaag S van der, Tassoul M. (2004) *Highlights of designing with Hylite - a new material concept.* Materials & Design. 26(4):271-279

Burns LD, Brown DM, Cameron B, Chandler J, Dallas M, Kaiser SB. (1995) *Sensory interaction and descriptions of fabric hand.* Perceptual and motor skills. 81:120-122

Buzan T, Buzan B. (1993). *The mind map book: How to use radiant thinking to maximize your brain's untapped potential.* Penguin Books USA Inc, New York

Callister WD. (1994) *Materials science and engineering, an introduction.* John Wiley & Sons, third edition

Chang YM, Leu MC. (2003) *The difference between the sense of touch and the sense of sight on the image of plastic texture.* Proceedings of the 6th Asian design international conference. Journal of the Asian design international conference. Tsukuba: Institute of Art and Design, University of Tsukuba

Cornish EH. (1987) *Materials and the Designer.* Cambridge University Press, New York

Crilly N, Moultrie J, Clarkson PJ. (2004) *Seeing things: consumer response to the visual domain in product design.* Design Studies. 25:547-577

Cross N. (2000) *Engineering Design Methods: strategies for product design*, John Wiley and Sons, Chichester, third edition

Cupchik GC. (1999) *Emotion and industrial design: reconciling meanings and feelings.* First International Conference on Design and Emotion, Delft, the Netherlands, p75- 82

Deng YM, Edwards KL. (2005) *The role of materials identification and selection in engineering design.* Materials and Design. 28(1):131-139

Desmet PMA. (2002). *Designing Emotions.* Delft University of Technology. Dissertation (PhD)

Dobrzanski LA. (2001) *Materials' design as an important element of engineering design of machines and their parts.* Proceedings of the XII ADM International Conference. September 5th-7th 2001. Rimini, Italy.

Dobrzanski LA. (2006) *Significance of materials science for the future development of societies.* Journal of materials processing technology. 175(1-3):133-148

Doordan DP. (2003) *On Materials.* Design Issues. 19:3-8

Eager TW. (1995) *Bringing New Material to Market.* Technology Review. Februari/March 1995:43-49

Eckert C, Stacey M. (2000) *Sources of inspiration: a language of design.* Design Studies. 21(5):523-538

Farag MM. (1989) *Selection of Materials and Manufacturing Processes for Engineering Design.* Prentice Hall, UK

Fenech OC, Borg JC. (2006) *A sensation based model of product elicited emotions.* Proceedings from the 5th Conference on Design and Emotion 2006. In: Karlsson, MA; Desmet, P; and van Erp, J. (eds). Chalmers University of Technology, 27-29 September, Göteborg, Sweden

Ferrante M, Santos SF, de Castro JFR. (2000) *Materials selection as an interdisciplinary technical activity: basic methodology and case studies.* Materials Research. 3(2):1-9

Fidel R, Green M. (2004) *The many faces of accessibility: engineers' perception of information sources.* Information Processing and Management. 40:563-581

Formosa D. (2005) *Mapping emotions.* Business Week On-line, 27 July 2005, available at: http://www.businessweek.com/innovate/content/jul2005/di20050727_882437.htm

Fulton Suri J, Marsh M. (2000) S*cenario building as an ergonomics method in consumer product design*. Applied Ergonomics. 31:151-157

Gant N. (2005) *Plastics design- the unlikely pioneer of product relationships.* International Conference on the Art of Plastics Design, Berlin, Germany (18-19 October)

Geldard FA. (1972) *The human senses.* John Wiley & Sons, second edition

Giboreau A, Navarro S, Faye P, Dumortier J. (2001) *Sensory evaluation of automotive fabrics - the contribution of categorization tasks and non verbal information to set-up a descriptive method of tactile properties.* Food Quality and Preference. 12(5):311-322

Goldstein EB. (2002) *Sensation and perception*. Wadsworth, Pacific Grove, sixth edition

Gonález FJM, Palacios TMB. (2002) *The effect of new product development techniques on new product success in Spanish firms.* Industrial Marketing Management. 31:261-271

Govers PCM. (2004) *Product Personality.* Delft University of Technology. Dissertation (PhD)

Gutteridge PA, Waterman NA. (1986) *Computer aided materials selection.* In: Bever, MB (ed) Encyclopedia of mateirals sciencee and engineering. Oxford: Pergman Press

Hall AD. (1962) *A methodology for systems engineering.* Princeton, New Jersey

Harris JS. (1961) *New product profile chart.* Chemical & Engineering News. 39(16):110-118

Hekkert P, van Dijk M. (2001) *Designing from context: Foundations and Applications of the ViP technique.* In: Lloyd P, Christiaans H (eds.) Designing in Context: Proceedings of Design Thinking Research Symposium 5. Delft: DUP Science.

Hekkert P. (2006) *Design Aesthetics: Principles of Pleasure in Design.* Psychology Science. 48(2):157-172

Hermes DJ. (1998) *Auditory material perception.* IPO Annual Progress report 33

Hertzum M, Pejtersen AM. (2000) *The information-seeking practices of engineers: searching for documents as well as for people.* Information Processing and Management. 36:761-778

Hodgson SNB, Harper JF. (2004) *Effective use of materials in the design process- more than a selection problem.* International engineering and product design education conference, Delft (2-3 September)

Holper, MPR, van der Meij, van Kesteren IEH. (2006) *Product personality considerations in materials selection.* Proceedings of International Future Design Conference on Changing Places of Digi-log Future, Seoul: The Institute of Millennium Environmental Design and Research, p494-507

Hubka V, Eder WE. (1992) *Engineering Design – General Procedural Model of Engineering Design.* Edition Heurista, Zürich

ISO 13407:1999 (1999) *Human-centred design processes for interactive systems.* International Organization for Standardization, July 1999, Geneva, Zwitserland

Jangager J. (2005) *User considerations in early stages of product development – theories and methods.* Department of Machine Design, Royal Institute of Technology, Stockholm. Dissertation (PhD)

Johnson KW, Langdon PM, Ashby MF. (2002) *Grouping materials and processes for the designer: an application of cluster analysis.* Materials and Design. 23(1):1-10

Jordan PW, Green WS (2002) *Pleasure with products: beyond usability.* Taylor & Francis, London, UK

Jordan PW. (2000) *Designing Pleasurable Products: An Induction to New Human Factors.* Taylor & Francis, London, UK

Karana E, Hekkert P, Kandachar PV. (2008) *Materials considerations in product design: a survey on crucial material aspects used by product designers.* Materials and Design. In Press, Corrected Proof, Available on-line 27 June 2007

Karana E, van Kesteren IEH. (2006) *Material effects' The role of materials in people's product evaluations.* Proceedings from the 5th Conference on Design and Emotion 2006. In: Karlsson MA, Desmet P, and van Erp J. (eds). Chalmers University of Technology, 27-29 September, Göteborg, Sweden

Keller IA. (2005) *For inspiration only. Designer interaction with informal collections of visual material.* Delft University of Technology. Dissertation (PhD)

Kelly T, Littman J. (2002) *The art of innovation. Lessons in creativity from IDEO, America's leading design firm.* HarperCollinsBusiness, GB

Kesteren IEH van. (2008) *Product designers' information needs in materials selection.* Materials and Design. 29(1):133–145

Kesteren IEH van, Kandachar PV. (2004). *Commercialization of new materials in consumer goods.* In: Redmond J, Durling D, Bono A de (eds). Futureground, Proceedings of the Design Research Society International Conference 2004, Melbourne: Monash University

Kesteren IEH van, Ludden GDS. (2005) *Product experiences, feeling, smelling and seeing of plastics (Productbeleving; voelen, ruiken en zien van kunststoffen).* Kunststof Magazine. 16(9):18-20

Kesteren IEH van, Ludden GDS. (2006) *Experiences translated into plastics, the sparkles of current time (Beleving vertaald in kunststoffen: de glitters van deze tijd).* Kunststof Magazine. 17(2):16-18

Kesteren IEH van, Stappers PJ, Kandachar PV. (2006) *Activities in selecting materials by product designers.* In: Su D, Zhu S (eds). Proceedings of the International Conference on Advanced Design and manufacture. Nottingham: ADMEC, p145-150

Klatzky RL, Lederman SJ. (1995) *Identifying objects from a haptic glance.* Perceptions and Psychophysics. 57(8):1111-1123

Klatzky RL, Pai DK, Krotkov EP. (2000) *Perception of material from contact sounds presence.* Teleoperators and Virtual Environment. 9(4) August 2000

Kleinsman MS (2006) *Understanding Collaborative Design.* Delft University of Technology. Dissertation (PhD)

Klop C. (2007) *A future interface of the c,mm,n car interior.* Faculty of Industrial Design Engineering, Delft University of Technology. Master thesis

Kolli R, Pasman G, Hennessey J. (1993) *Some considerations for designing a user environment for creative ideation.* Proceedings of the Interface '93, North Carolina State University, Raleigh, NC

Kreitler H, Kreitler S. (1972) *Psychology of the arts.* Duke University Press, Durhum NC

Lawson B. (1994) *Design in Mind.* Butterworth-Heinemann Ltd, UK

Lefteri C. (2001-2004) *Materials for inspirational design: Plastics, Wood, Ceramics, Metals, Glass.* Roto Vision, Switserland

Lefteri C. (2005) *The branding of plastics- how important is the branding of a material and how far do plastics go in helping to define brands.* International Conference on the Art of Plastics Design, Berlin, Germany (18-19 October)

Ljungberg LY, Edwards KL. (2003) *Design, materials selection and marketing of successful products.* Materials and Design. (24):519-529

Ljungberg LY. (2002) *Materials selection and design for structural polymers.* Materials and Design. 24(5):383-90

Love T. (2003) *Customers' Use of Products as Design Tools.* Proceedings of the 6th Asian design international conference. Journal of the Asian design international conference. Tsukuba: Institute of Art and Design, University of Tsukuba

Ludden GDS, Schifferstein HNJ, Hekkert P. (2004) *Visual - tactual incongruities. Surprises in products.* Paper presented at the First International Workshop on Materials and Sensations, Pau, France

Ludden GDS, Kesteren IEH van. (2006) *Designing product experiences - listening to ice creams (Het ontwerpen van productbeleving – luisteren naar ijsjes).* Kunststof Magazine. 17(1):16-18

Ludden GDS. (2008) *Sensory incongruity and surprise in product design.* Delft University of Technology. Dissertation (PhD)

MacDonald AS. (1999) *Developing aesthetic intelligence as a cultural tool for engineering designers.* In: Lindema U, Birkhofer H, Meerkamm M, Vajna S (eds). Proceedings of the International Conference on Engineering Design (ICED), Munich, p297-300

MacDonald AS. (2001) *Aesthetic intelligence: optimizing user- centred design.* Journal of Engineering Design. 12(1): 37-45

Manzini E. (1989) *The material of invention.* Design Council, London

Martini-Vvedensky JE. (1985) *Selection of Materials by Computer - What is Missing?* Materials and Design. 6(3):134-137

McDonagh D, Bruseberg A, Haslam C. (2002) *Visual product evaluation: exploring users' emotional relationships with products.* Applied Ergonomics. 33(3):231-40

McMahon CA, Pitt DJ. (1995) *Hybrid computer database systems for materials engineering.* Materials and Design. 16(1):3-13

Mejasson P, Petridis M, Knight B, Soper A, Norman P. (2001) *Intelligent design assistant (IDA): a case base reasoning system for material and design.* Materials and Design. 22(3):163-170

Muller W. (2001) *Order and meaning in design.* Lemma, Utrecht

Nielsen P. (2001) *Design for Usability – focus on the physical handling of products.* Department of Control and Engineering Design, Technical University of Denmark. Dissertation (PhD)

Noiset O, Henneuse C. (2005) *The impact of olfactive factors on plastic design or the sweet smell of success.* International Conference on the Art of Plastics Design, Berlin, Germany (18-19 October)

Özcan E, van Egmond R. (2004) *Pictograms for Sound Design: A language for the communication of product sounds.* Fourth international conference on Design and Emotion. Ankara, Turkey

Pahl G, Beitz W. (1996) *Engineering Design - A Systematic Approach.* Springer, London, second edition

Pasman G, Stappers PJ. (2001) *ProductWorld, an Interactive Environment for Classifying and Retrieving Product Samples.* Proceedings of the 5th Asian Design Conference, Seoul, Korea

Pasman G. (2003) *Designing with Precedents.* Delft University of Technology. Dissertation (PhD)

Picard D, Dacremont C, Valentin D, Giboreau A. (2003) *Perceptual dimensions of tactile textures.* Acta Psychologica. 114(2):165-84

Poelman WA. (2005) *Technology Diffusion in product design.* Delft University of Technology. Dissertation (PhD)

Poltrock S, Grudin J, Dumais S, Fidel R, Bruce H, Pejtersen AM. (2003) *Information seeking and sharing in design teams.* In: Pendergast M, Schmidt K, Simone C, Tremaine M (eds) Proceedings of the 2003 international ACM SIGGROUP conference on supporting group work. Sanibel Island, Florida. ACM, New York, p239–247

Pugh S. (1981). *Concept selection: a Method that works.* In: Hubka V (ed). Review of Design Methodology. Proceedings International Conference on Engineering Design, March 1981, Rome. Heurista, Zurich, p497-506

Pugh S. (1991) *Total Design – Integrated Methods for Successful Product Engineering.* Addison-Wesley Publishing Company, Wokingham

Rognoli V, Levi M. (2004) *How, what and where is possible to learn design materials?* International engineering and product design education conference, Delft (2-3 September)

Roozenburg NFM, Eekels J. (1995) *Product Design, Fundamentals and Methods.* Wiley, Chichester, UK

Rouse WB, Rouse SH. (1984) *Human information seeking and design of information systems.* Information Processing and Management: an International Journal, special issue: Empirical foundations of information and software sciences. 20(1-2):129-138

Saakes D. (2007) *Relight my model: new media in ideation workshops.* International Association of Societies of Design Research (IASDR) 12-15 November, 2007 at The Hong Kong Polytechnic University

Sanders EBN. (2000) *Generative Tools for Co-Designing.* In: Scrivener, Ball and Woodcock (Eds) Collaborative Design. Springer-Verlag, London

Sanders EBN. (2001) *A new design space.* Proceedings of ICSID 2001 Seoul: Exploring Emerging Design Paradigm, Oullim. Seoul, Korea, October 7-11, p317-324

Sapuan SM. (2001) *A knowledge-based system for materials selection in mechanical engineering design.* Materials and Design. 22:687-695

Shahin TMM, Andrews PTJ, Sivaloganathan S. (1999) *A Design Reuse System.* Journal of Engineering Manufacture. 213(6):621-627

Shanian A, Savadogo O. (2006) *A materials selection model based on the concept of multiple attribute decision making.* Materials and Design. 27:329-337

Shercliff HR, Lovatt AM. (2001) *Selection of manufacturing processes in design and the role of process modelling.* Progress in materials science. 46:429-459

Sleeswijk Visser F, van der Lugt R, Stappers PJ. (2005) *Participatory design needs participatory communication.* Proceedings of the 9th European Conference on Creativity and Innovation, Lodz, Poland

Smith CS, Wright PK, Séquin C. (2003) *The manufacturing Advisory service: web-based process and materials selection.* International Journal of computer integrated manufacturing. 16(6):373-381

Sonneveld MH. (2004) *Dreamy hands: exploring tactile aesthetics in design.* In: McDonagh D, Hekkert P, van Erp J, Gyi D (eds) Design and emotion, the experience of everyday things. Taylor & Francis

Sonneveld MH. (2007) *Aesthetics of tactual experiences.* Delft University of Technology. Dissertation (PhD)

Stappers, P. J., Pasman, G., & Groenen, P.J.F. (2000). *Exploring databases for taste or inspiration with interactive multi-dimensional scaling.* Ergonomics for the New Millenium. Proceedings of the XIVth tirennial confress of the International Ergonomics Association and 44th annual meeting of the Human Factors and Ergonomics Society, San Diego, CA

Stempfle J, Badke-Schaub P. (2002) *Thinking in design teams – an analysis of team communication.* Design Studies. 23:473-96

Ui E, Cho G, Na Y, Casali JG. (2002) *A fabric sound evaluation structure for totally auditory-sensible textiles.* Textile Research Journal. Jul 2002

Ullman DG. (2002) *Toward the ideal mechanical engineering design support system.* Research in Engineering Design. 13:55-64

Valkenburg R. (2000) *The Reflective Practice in product design teams.* Delft University of Technology. Dissertation (PhD)

Wallace K, Burgess S. (1995) *Methods and tools for decision making in engineering design.* Design studies. 16:429-446

Wastiels L, Wouters I, Lindekens J. (2007) *Material Knowledge for Design: The architect's vocabulary.* IASDR 2007 International Association of Societies of Design Research, Emerging Trends in Design Research, Hong Kong, November 12-15, 2007

Webcredible (Autor unknown) (2006) URL: http://www.webcredible.co.uk/user-friendly-resources/web-usability/user-centred-design.shtml. Published May 2006 Accessed August 2nd, 2007

Wood L. (1997) *Semi-structured interviewing for user-centred design.* Interactions. March-April 1997:48-61

Wright IC. (1998) *Design Methods in Engineering and Product Design.* The McGraw-Hill Publishing Company, Cambridge

Young RIM. (2003) *Informing decision-makers in product design and manufacture.* International Journal of Computer Integrated Manufacturing. 16(6):428-438

Zuo H, Hope T, Castle P, Jones M. (2001) *An investigation into the sensory properties of materials.* Proceedings of the international conference on affective human factors design. Singapore, 27-29 june. Asean Academic Press, London, p500-507

Zuo H, Hope T, Jones M, Castle P. (2004a) *Sensory interaction with materials.* In: McDonagh D, Hekkert P, van Erp J, Gyi D. (eds). Design and emotion, the experience of everyday things. Taylor & Francis

Zuo H, Jones M, Hope T. (2004b) *A matrix of material representation.* In: Redmond J, Durling D, Bono A de (eds). Futureground, Proceedings of the Design Research Society International Conference 2004, Melbourne: Monash University

Zuo H, Jones M, Hope T. (2005) *Material texture perception in product design.* International Conference on the Art of Plastics Design, Berlin, Germany (18-19 October)

Appendices

Contents

Appendix 1

Information sources used by product designers

This appendix provides an overview of the information sources that product designers mentioned during the interviews that are described in section 2.3 on page 33.

Source type	**Results from the interviews**
1. General material applications	
Experience Knowledge of the client, colleagues and experts, experience from former project	The product designers' experiences are a valuable and important starting point for making a set of candidate materials. The product designers mostly gain experience through former projects and from seminars and trade shows. If the product designers do not have experience with the design problem they are facing, they talk to colleague-product designers (senior product designers) or material specialists in the company. In addition, experience of the client (for example a production company) is valuable. Product designers of design agencies have close contact to the engineering department of their client.
Testing Knowledge institutions (e.g. Universities), finite elements calculations, experimenting for choosing materials, testing for verifying choice	Materials suppliers test their materials to provide information about performances such as chemical resistance, durability, and yield strength. Product designers, together with manufacturers, test selected materials in the product or in product parts to verify whether the materials act as expected when processed and shaped in the specific geometry. Testing is done with physical prototypes or with simulations, for example with finite elements calculations. Through experimenting, product designers discover the possibilities of materials, resulting in new ways of using materials in products.
Example products Inspiration from shopping, competition products, proven technology, trade shows (e.g. Milan international furniture show), magazines on design topics (e.g. i-D Magazine: www.idonline.com)	"Example products are very important in material selection; the product designer translates the applications to the design problem he is facing". The example products are of a similar type of the product that needs to be designed, or have exciting features that interested the product designers. In design related trade shows and magazines products are assessed for their materials use.

2. Independent sources	
Databases, search engines In-company databases, general available databases (e.g. CAMPUS Plastics), commercial databases (e.g. IDEMAT, Cambridge Engineering Selector www.grantadesign.com), search engines (e.g. Google), trade guides (e.g. yellow pages)	Young product designers remembered that they used general material selection software during their education, but in the 13 companies visited in this study, this kind of software was not available. However, some companies maintain an in-company database. Other sources that assist in selecting materials suppliers and manufacturers are the Yellow Pages or general search engines on the Internet like Google. Mostly product designers use these information sources during the early phases and the embodiment phases of the design project.
Samples collections Samples from former projects (e.g. Tech Box www.ideo.com), commercial sample collections (e.g. Material ConneXion www.materialconnexion.com, Materia www.materia.nl)	Tangible information sources used by the interviewees are different sorts of collections available in the companies. Different types of collections are those of brochures, of products and product parts and of material samples. Product designers use collections to store and recall former design projects, interesting parts 'from the street' or from trade shows. Samples provide information about sensorial properties of materials such as visual and tactile features. Commercial sample collections were not used.
Books, exhibitions Books for inspiration (e.g. Lefteri series (2001-2004)), Exhibitions (e.g. Materials Skills www.materia.nl), seminars organized by material federations	Product designers use material books and lecture notes from the product designers' education to gain general information about which materials are suitable for the design problems they are facing. Exhibitions and seminars are not available on the specific time needed in the project. Product designers use them to build experience.
3. Materials on supply	
In person Customer advisor of material supplier or manufacturer, company visits	Design agencies and their clients often have a selection of suppliers they work with. Experts from suppliers and manufacturers are consulted during the whole project for tips and tricks. In the late phases product designers discuss which materials suit the requirements best, which additives are needed and which colours and effects. Furthermore, they discuss what consequences the materials choices have on other aspects of the design such as on shape. The interviewees consulted manufacturers, for the processing characteristics of materials.
Internet Internet information of supplier, databases, data sheets	The interviewees regularly use online databases of materials suppliers. In addition to the information found on the Internet pages of a supplier, data sheets with more detailed information are requested, as well as custom made material samples and master batch samples.
Samples, brochures Send on request or as advertisements (e.g. a sample box www.plexiglas-magic.com, newsletters)	Materials suppliers and manufacturers send brochures and newsletters as advertisement on their new developments. Sometimes they visit design agencies to show and explain the possibilities with their material portfolio.
Trade shows, magazines Presentation of materials suppliers on plastic fairs, magazines (e.g. Materials Today from Elsevier www.materialstoday.com)	Product designers visit materials trade shows to meet suppliers and manufacturers, to keep up with new developments and to show the company's developments when attending the trade show as an exhibitor. From magazines product designers gather information for future projects.

Appendix 2

Schemes of the materials selection activity cases

The figures on the next pages show the abstract version of the schemes of all projects that were discussed in chapter 5 and 6.

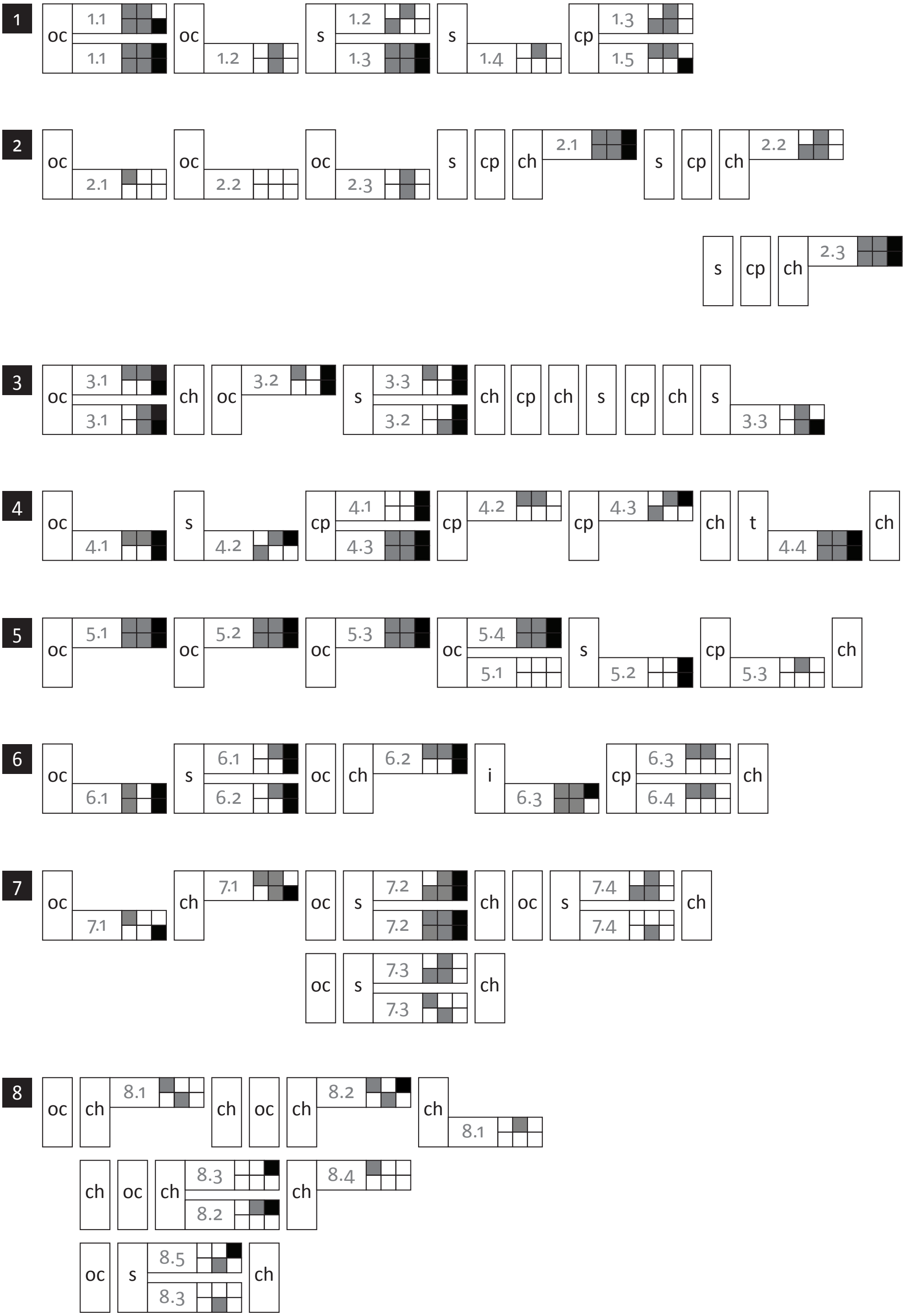
The diagrams represent two kinds of data: 1) the outlines of the materials selection steps in a project and 2) the design aspects that the product designers selected in the questionnaires about indicated data points. The diagrams represent the materials selection steps taken in a project.

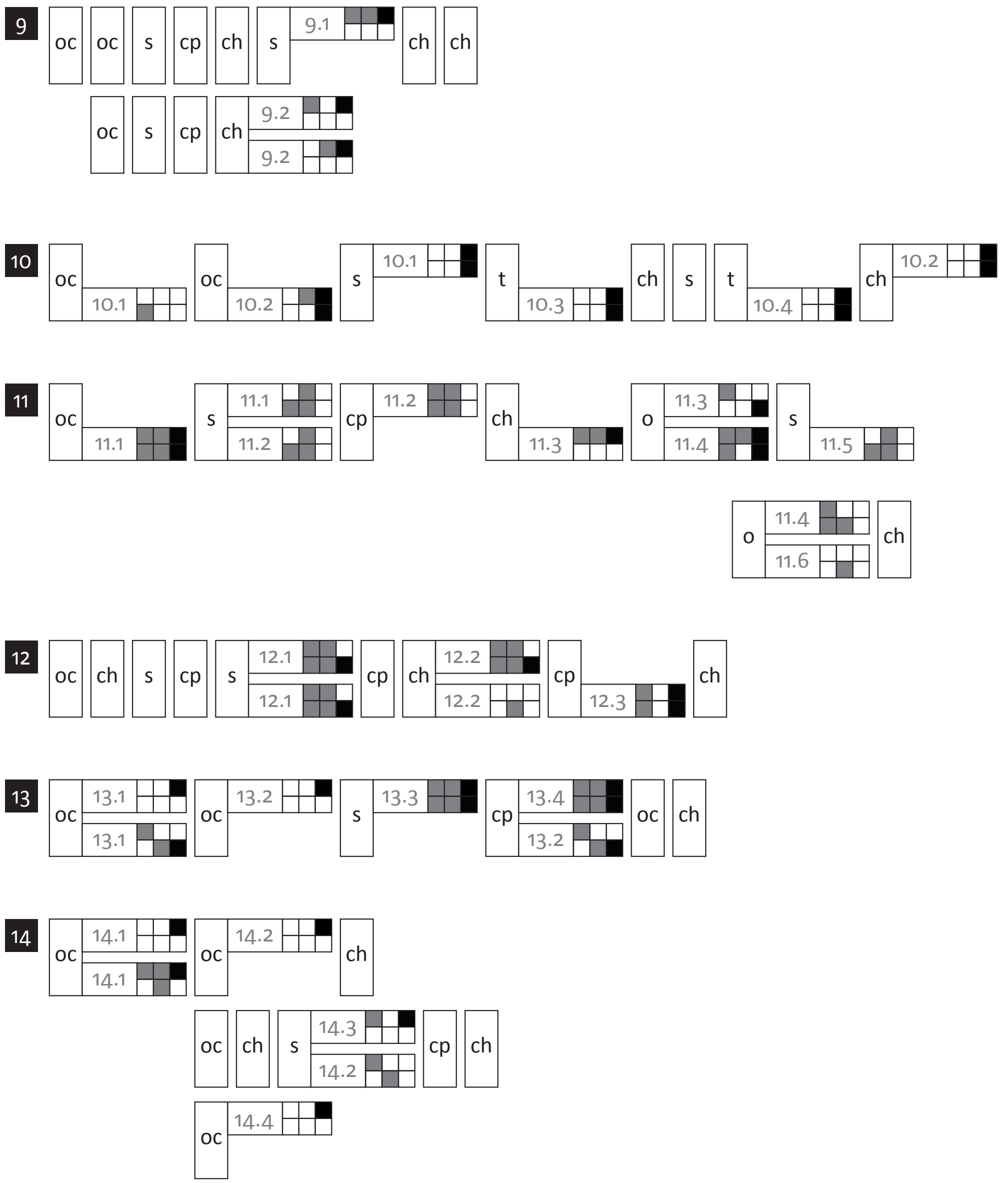
In some projects different product parts were discussed (case 7, 8, 9 and 14). The different product parts are represented in different rows.

The rectangles show letters referring to the activities of the Materials Selection Activities model (chapter 4). For example 'oc' refers to the activity of 'formulating materials objectives and constraints'.

The activities that were marked as a data point show a number and a matrix with six boxes. The *top line* shows the data points marked at the moments that the product designer indicated having used the formulated *criteria*. The *bottom line* shows the moments the product designers indicated having gathered *information* and marked that as a data point.

The numbers refer to the case number and the sequence number of the data point. The six boxes represent the design aspects from the MSC model (as introduced in section 2.2) that the product designers could select in the questionnaires. The legend of the figure shows which aspect refers to which box. A black or grey box indicates that this aspect was considered at the data point. The technology aspects are shown in grey, the user-interaction aspects are shown in black.


1
oc 1.1 1.1
oc 1.2
s 1.2 1.3
s 1.4
cp 1.3 1.5
2
oc 2.1
oc 2.2
oc 2.3
s cp ch 2.1
s cp ch 2.2
s cp ch 2.3
3
oc 3.1 3.1
ch
oc 3.2
s 3.3 3.2
ch cp ch s cp ch
s 3.3
4
oc 4.1
s 4.2
cp 4.1 4.3
cp 4.2
cp 4.3
ch
t 4.4
ch
5
oc 5.1
oc 5.2
oc 5.3
oc 5.4 5.1
s 5.2
cp 5.3
ch
6
oc 6.1
s 6.1 6.2
oc
ch 6.2
i 6.3
cp 6.3 6.4
ch
7
oc 7.1
ch 7.1
oc
s 7.2 7.2
ch
oc
s 7.4 7.4
ch
oc
s 7.3 7.3
ch
8
oc
ch 8.1
ch
oc
ch 8.2
ch 8.1
ch
oc
ch 8.3 8.2
ch 8.4
oc
s 8.5 8.3
ch



Materials Selection Activity

s

oc = objectives and constraints
s = making a set
cp = comparing
ch = choosing
t = testing
i = gathering information
o = other

Datapoints

12.1 using the formulated critera

12.1 gathering information about materials

Considered aspects

F	M	PP
S	MP	U

F = function
M = materials
S = shape
MP = manufacturing
PP = product personality
U = use

Appendix 3

Information sources per materials selection activity

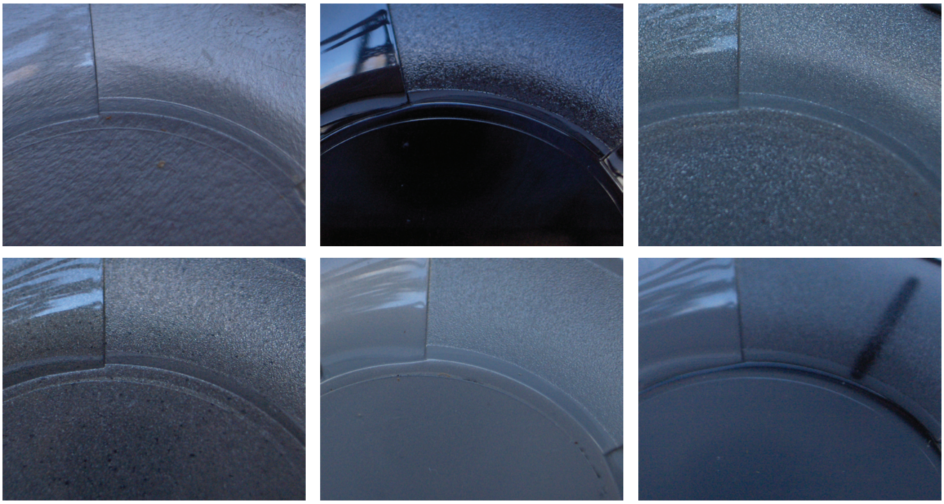
Section 5.3 on page 73 describes the main information sources that were mentioned in 15 design projects. The sources are here categorized in the activities of the MSA model.

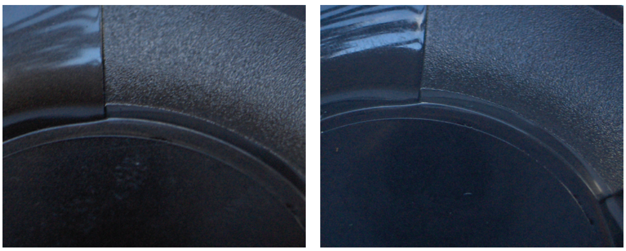
Source	**Materials selection activity**						
	Criteria	Set	Comparing	Choosing	Testing	Other	All
Client	27	10	4	11	2	7	61
Supplier	5	24	10	4	3	0	46
Manufacturer	4	11	10	7	10	7	49
Other expert	2	7	5	0	3	0	17
Users	17	1	1	0	13	0	32
Model	1	0	4	2	14	0	21
Group	5	10	10	3	4	9	41
Trade show	0	4	1	0	0	0	5
Internet	0	2	3	0	0	0	5
Other source	15	8	8	7	0	7	45
Subtotal	*76*	*77*	*56*	*34*	*49*	*30*	*322*
No information	58	25	9	29	3	13	137
Total	**134**	**102**	**65**	**63**	**52**	**43**	**459**

Appendix 4

Material profile study

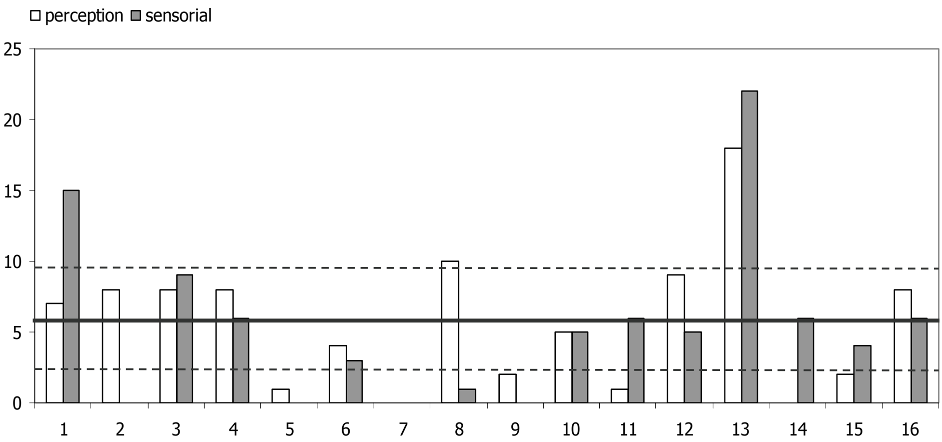
A small study provided insight into the assumption that formulating the required user-interaction aspects as sensorial properties leads to a uniform selection of materials. People with different backgrounds selected materials based on two different material profiles. The first profile was written in perception terms and the second in sensorial terms. The aim was to find out which profile leads to a higher consistency of selected materials. When a profile is formulated in sensorial terms, it was expected that people more often selected the same materials than when formulated in terms of perceptions.



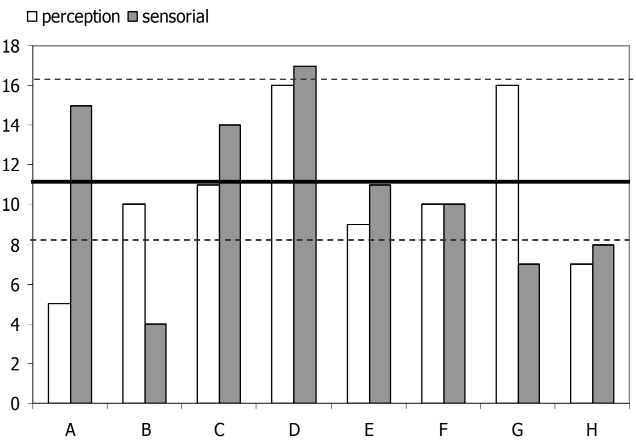


Samples used in the set of material variations

Profile	Instruction
Perception terms	The appearance of the materials should fit the modern camper; high tech, comfortable, durable and sturdily
Sensorial terms	The materials should be opaque and glossy, do not scatter or be flexible, but do contain a texture



Number of times a sample was selected from a set of 16 different materials after reading the perception or sensorial profile. The black line represents the mean number of possible picks. The space between the two dotted lines shows the picks that were not significantly related to the instructed profile ($p < 0.05$)



Number of times a sample was selected from a set of 8 variations of a material after reading the perception or sensorial profile. The black line represents the mean number of possible picks. The space between the two dotted lines shows the picks that were not significantly related to the instructed profile ($p < 0.05$)

Thirty people (11 product designers, 10 material experts and 9 consumers) were asked to select 3 materials from a set of 16 different materials (e.g. wood, steel, plastic or textile; see appendix 8) and thereafter 3 materials from a set of 8 variations of the same material (all plastics with different visual effects; see the previous page) based on the perception profile. They were asked to do the same for the sensorial profile. The materials were provided as pictures of the samples in an on-screen document.

Per profile was counted how many people selected every single material from the set. These numbers were compared with a binominal probability distribution test in SPSS (PDF.BINOM). This test reveals whether the selection of a sample could be contributed to the instructed profile or whether it was randomly selected. The more samples that are randomly selected, the less consistent the participants are in their selection based on a specific profile.

When people are asked to choose materials from a set of different materials, the terms used in the instruction given do not influence the outcomes. The participants' interpretations of both profiles lead to the same number of significantly selected materials. Only the number of materials that is not selected at all from the set is larger after the sensorial instruction. This means that the sensorial profile makes the solution space a bit smaller than the perception profile.

Although the interpretations of the different profiles do not affect the selection from a set of different materials, it does affect the selection of material variations. The sensorial profile leads to more significantly selected materials compared to the perception profile. The perception terms were thus interpreted differently by the different people, although they select the same materials from the set of different materials. At a later stage, when more detail is required and the set to select from consists of material variations, these differences in interpretations leads to different selections. As a consequence, the proposed material variations might not fulfil the expectations of the client.

The results of the study show that it is likely that a profile described in sensorial terms requires less interpretation during the materials searches and thus leads to a clear set of criteria about the required user-interaction aspects of the product.

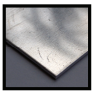
Appendix 5

Picture tool

LIVELY

- high-gloss
- hard
- cold
- full of colour

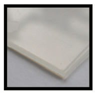
Sample: aluminum



INTERESTING

- semi-transparent
- full of colour
- hard

Sample: plastic



UNTIDY

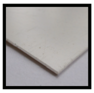
OBTRUSIVE

CHEERFUL

MiPS - TUDelft

- high-gloss
- light bright colours
- smooth
- warm

Sample: plastic



SILLY

MiPS - TUDelft

- transparent
- flexible
- full of colour
- gloss

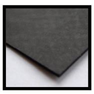
Sample: plastic

EASY GOING

MiPS - TUDelft

- full of colour
- flexible accents
- opaque
- glossiness accents

Sample: rubber

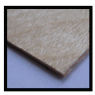


CHILDISH

MiPS - TUDelft

- one material
- multiple colours
- full of colour
- gloss

Sample: wood

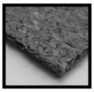


HONEST

MiPS - TUDelft

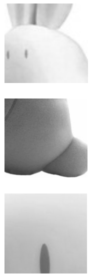
- warm
- irregular texture
- changeable colour
- pattern

Sample: cork



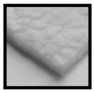
CUTE

MiPS - TUDelft



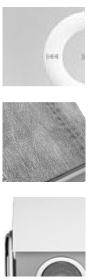
- matt gloss
- light colours
- soft
- warm

Sample: plush



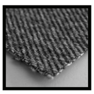
MODEST

MiPS - TUDelft



- matt gloss
- light colours
- semi-transparent details

Sample: textile

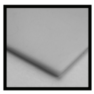


RELAXED

MiPS - TUDelft

- matt gloss
- semi-transparent
- soft
- warm

Sample: plastic

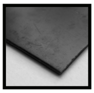


ALOOF

MiPS - TUDelft

- one material
- one colour
- dark
- matt gloss

Sample: plastic

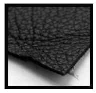


BUSINESS LIKE

MiPS - TUDelft

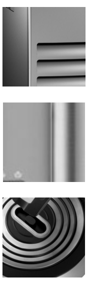
- matt gloss
- one material
- colourless
- regular texture

Sample: leather



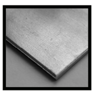
DOMINANT

MiPS - TUDelft



- silk gloss
- combination grey/ RVS/ black
- regular texture

Sample: steel

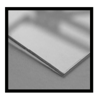


OPEN

MiPS - TUDelft

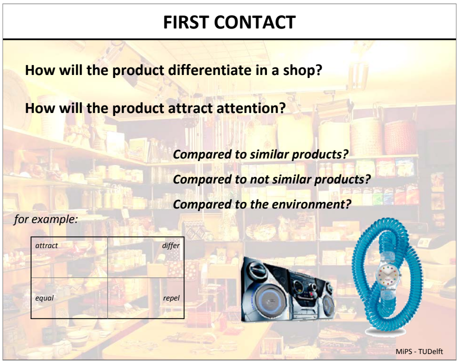
- light
- transparent, reflective
- cold
- colourless

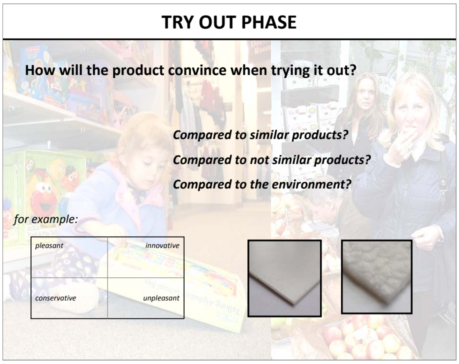
Sample: plastic

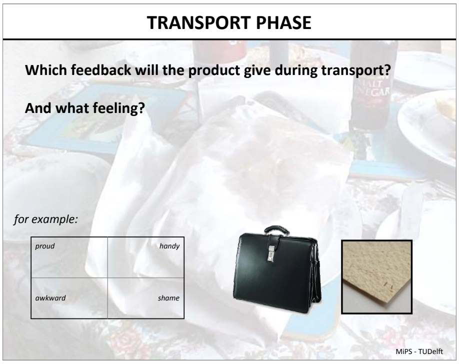


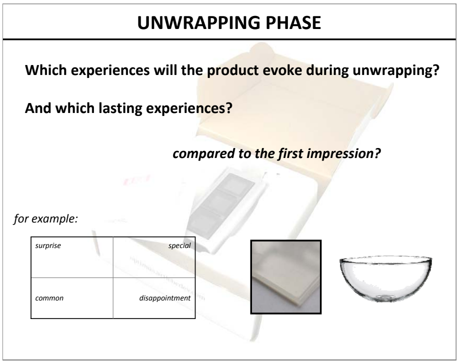
Appendix 6

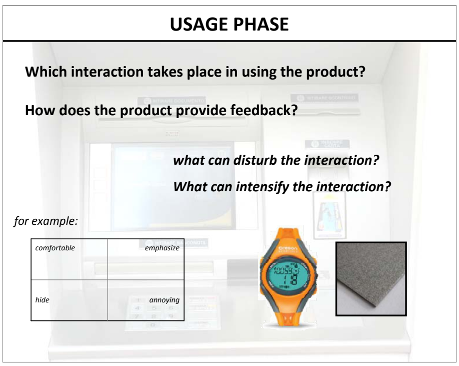
Questions tool

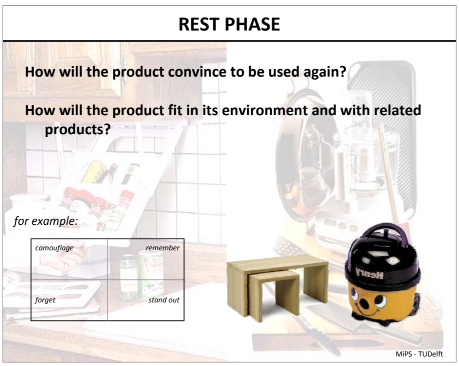












FIRST CONTACT

How will the product differentiate in a shop?

How will the product attract attention?

Compared to similar products?

Compared to not similar products?

Compared to the environment?

for example:

attract	*differ*
equal	*repel*

MiPS - TUDelft

Which materials aspects play a role in the first contact with the product?

VISUAL
reflection
glossiness
transparency
scattering
roughness
texture
light intensity
hue of colour
multiple colours
intensity of colour
darkness of colour
durability of colour
pattern

AUDITORY
dampening
pitch
loudness

SMELL AND TASTE
intensity of odour
fragrance
taste

TACTILE
denting
softness
dampening
porosity
flexibility
plasticity
brittleness
weight
stickiness
wetness
oiliness
roughness
warmth

Appendix 7

Checklist with sensorial properties

Together with the questions tool a checklist with sensorial properties was developed (section 8.2). In the table below, the English and Dutch versions are provided. The checklist and the relation sheet in appendix 9 use the same list of properties.

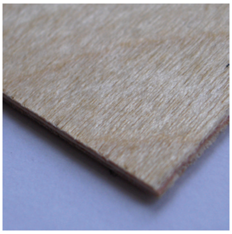
ENGLISH	DUTCH
Light reflection	**Reflectiviteit**
Reflection *(reflective - not reflective)*	Spiegeling *(spiegelend - niet spiegelend)*
Glossiness, scattering *(glossy - matt)*	Glans, verstrooiing *(glans - mat)*
Trancparency *(transparent - translucent - opaque)*	Transparantie *(transparant - melkachtig - ondoorzichtig)*
Brilliance *(no - brilliance)*	Schittering *(geen – schittering)*
Roughness *(rough - smooth)*	Ruwheid *(ruw - glad)*
Texture *(regular - irregular)*	Textuur *(regelmatig - onregelmatig)*
Light radiation	**Luminiscentie**
Luminescence *(low - high)*	Lichtintensiteit *(laag - hoog)*
Colour	**Kleur**
Hue of colour	Kleursoort
Intensity of colour *(colourless - full)*	Intensiteit van de kleur *(kleurloos - vol)*
Grayness *(light - dark)*	Grijsheid van de kleur *(licht - donker)*
Durability of colour *(durable - changeable)*	Veroudering *(duurzaam - veranderlijk)*
Colourfulness *(monochrome - multicolour)*	Kleurrijkdom , chroma *(eenkleurig - veelkleurig)*
Pattern / structure	Patroon / structuur

Pressure	**Druk**
Hardness *(denting - not denting)*	Hardheid *(indeukbaar - niet indeukbaar)*
Softness *(soft - hard)*	Zachtheid *(zacht - hard)*
Dampening *(fast - slow)*	Demping *(snel - langzaam terugverend)*
Compactness *(massive - porous)*	Compactheid *(massief - poreus)*
Manipulation	**Manipulatie**
Stiffness *(stiff - flexible)*	Stijfheid *(stijf - flexibel)*
Ductility *(ductile - tough)*	Vervormbaarheid *(kneedbaar - stug)*
Brittleness *(brittle - tough)*	Broosheid *(broos - taai)*
Weight *(light - heavy)*	Gewicht *(licht - zwaar)*
Friction	**Wrijving**
Stickiness *(sticky - not sticky)*	Kleverigheid *(kleverig - niet kleverig)*
Wetness *(wet - dry)*	Vochtigheid *(vochtig - droog)*
Oiliness *(oily - dry)*	Vettigheid *(vet - droog)*
Smoothness *(rough - smooth)*	Gladheid *(stroef - glad)*
Texture *(regular - irregular)*	Textuur *(regelmatig - onregelmatig)*
Temperature	**Temperatuur**
Warmth *(warm - cold)*	Warmte *(warm - koud)*
Sound	**Geluid**
Dampening *(muffled - ringing)*	Demping *(gedempt - resonerend)*
Pitch *(low - high)*	Toon *(laag - hoog)*
Intensity of the sound *(soft - loud)*	Intensiteit van het geluid *(zacht - luid)*
Smell	
Fragrance	Geursoort
Odorous *(natural - odorless - fragrant)*	Geurig *(natuurlijk - geurloos - geurig)*
Taste	**Smaak**
Flavour	Smaaksoort

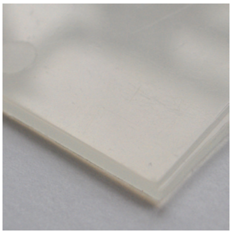
Appendix 8

Sample tool

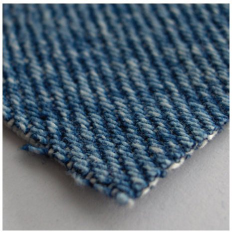
Wood



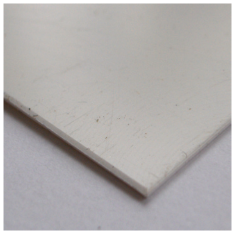
Plastic



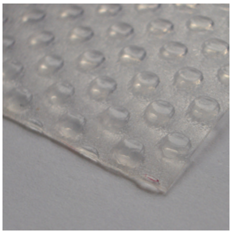
Textile



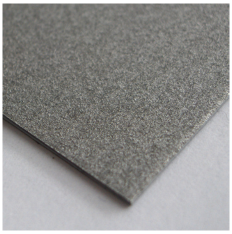
Plastic



Plastic

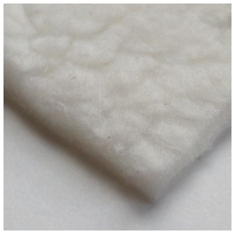


Metal

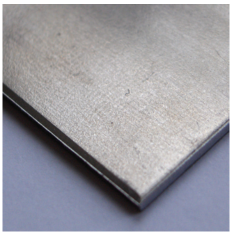


Cork

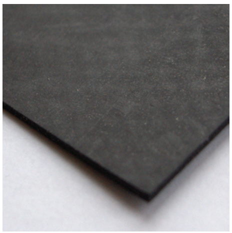
Textile



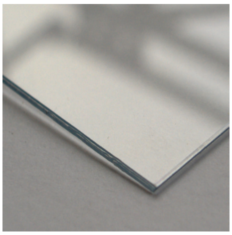
Steel



Rubber

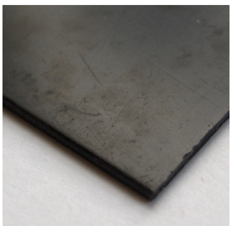


Plastic

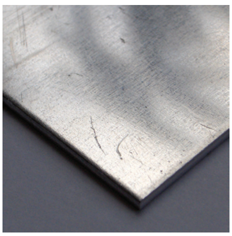


Paper

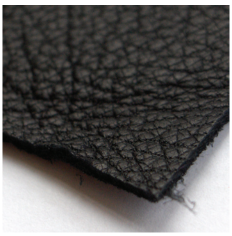
Plastic



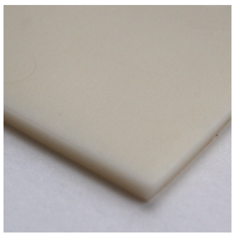
Aluminium



Leather



Plastic



Appendix 9

Properties relation sheet

The sheet below presents the sensorial and related physical properties that can guide the materials searches. The explanation of the properties can be found in section 8.3.

VISUAL PROPERTIES	**PHYSICAL PROPERTIES**	
Light reflection		
Reflection *(reflective - not reflective)*	• Reflection coefficient • Surface roughness • Light absorption Above properties are wavelength specific (UV, IR, visual light)	Tuning by • Surface treatment • Geometry • Additives External influences • Light source spectrum • Light source intensity Alternative • Surface layer
Glossiness, scattering *(glossy - matt)*	• Reflection coefficient • Surface roughness • Orientation of pigments • Index of refraction Above properties are wavelength specific (UV, IR, visual light)	Tuning by • Surface treatment External influences • Light source spectrum • Light source intensity Alternative • Surface layer
Transparency *(transparent - translucent - opaque)*	• Transparency (light transmission per thickness) • Index of refraction Above properties are wavelength specific (UV, IR, visual light)	Tuning by • Surface treatment • Geometry External influences • Light source spectrum • Light source intensity Alternative • Surface layer

Brilliance *(no - brilliance)*	• Local reflection in absorbing matrix • Compound shape (plates, balls)	Tuning by • Surface treatment • Geometry • Reflection properties • Glossiness properties • Transparency properties External influences, • Light source spectrum • Light source intensity Alternative • Surface layer
Roughness *(rough - smooth)*	• Surface roughness • Homogeneity of macro structure	Tuning by • Surface treatment Alternative • Surface layer
Texture *(regular - irregular)*	None (designed surface roughness)	Tuning by • Surface treatment • Deposition techniques • Manufacturing techniques Alternative • Surface layer
Light radiation		
Luminescence *(low - high)*	• Light emission (energy) efficiency • Delay time between absorbing and reemission of light Above properties are wavelength specific (UV, IR, visual light)	Tuning by • Additives • Surface wavelength • Background materials Alternative • Surface layer
Colour		
Hue of colour	• Typical material colour • Colour dye or pigment type • Coherence between pigments	Tuning by • Bending technique (pixels or mixed colour) External influences • Light source spectrum Alternative • Surface layer
Intensity of colour *(colourless - full)*	• Colour dye or pigment concentration	Tuning by • Light reflection properties External influences • Light source spectrum • Light source intensity Alternative • Surface layer

Grayness *(light - dark)*	• Concentration of black/white dyes or pigments in combination with colour	Tuning by • Light reflection properties External influences • Light source spectrum • Light source intensity Alternative • Surface layer
Durability of colour *(durable - changeable)*	• UV resistance • Water, fluids, gasses absorption • Crazing in surface • Adhesion between pigment and material	Tuning by • Light reflection properties • Surface treatment • Additives External influences • Light source spectrum • Light source intensity Alternative • Different pigments • Surface layer
Colourfulness *(monochrome - multicolour)*	• Number of differentiating colours	External influences • Light source spectrum • Light source intensity Alternative • Surface layer • Layered pigments
Pattern / structure	• Organization of colours	Alternative • Surface layer

TACTILE PROPERTIES	**PHYSICAL PROPERTIES**	
Pressure		
Hardness *(denting - not denting)*	• Hardness	Tuning by • Geometry
Softness *(soft - hard)*	• Elasticity Modulus • Hardness	Tuning by • Geometry • Roughness properties • Texture properties
Dampening *(fast - slow)*	• Response time of elasticity	Tuning by • Geometry
Compactness *(massive - porous)*	• Relative density	Tuning by • Geometry

Manipulation		
Stiffness *(stiff - flexible)*	• Elasticity Modulus	Tuning by • Geometry
Ductility *(ductile - tough)*	• Uniform strain • Yield strength	Tuning by • Geometry
Brittleness *(brittle - tough)*	• Elongation at break • Fracture toughness	
Weight *(light - heavy)*	• Density	Tuning by • Volume
Friction		
Stickiness *(sticky - not sticky)*	• Adhesion • Roughness	Alternative • Surface layer
Wetness *(wet - dry)*	• Water expulsion under load	Tuning by • Surface treatment • Warmth properties • Softness properties
Oiliness *(oily - dry)*	• Surface fat concentration	Tuning by • Additives • Surface treatment
Smoothness *(rough - smooth)*	• Friction coefficient	Tuning by • Roughness properties • Surface treatment • Manufacturing techniques Alternative • Surface layer
Texture *(regular - irregular)*	None (designed surface roughness)	Tuning by • Surface treatment • Deposition techniques • Manufacturing techniques Alternative • Surface layer
Temperature		
Warmth *(warm - cold)*	• Heat flux • Thermal diffusibility: combination of thermal conductivity and specific heat	Alternative • Surface layer

AUDITIVE PROPERTIES	PHYSICAL PROPERTIES	
Sound		
Dampening *(muffled - ringing)*	• Loss coefficient • Internal coefficient of friction	Tuning by • Additives • Geometry (hollow or massive)
Pitch *(low - high)*	• Damping spectrum: combination of elasticity modulus and density	Tuning by • Stress state • Geometry (hollow or massive)
Intensity of the sound *(soft - loud)*	• Sound absorption parameter • Extent of resonance	Tuning by • Geometry (hollow or massive) External influences • Applied power

SMELL AND TASTE PROPERTIES	PHYSICAL PROPERTIES	
Smell		
Fragrance	• Typical material odour • Type of fragrance compounds	Alternative • Surface layer
Odorous *(natural - odorless - fragrant)*	• Concentration of fragrance compounds • Delay time	Alternative • Surface layer
Taste		
Flavour	• Typical material taste • Release of compound particles under saliva and manipulation	Alternative • Surface layer

Appendix 10

Usability study of the tools

The material terms used in the profiles that the participants made before and after using a tool were grouped into the different property categories (table 8.9). We looked per tool which categories were found in the profiles made after using the tool. If one category was mainly found, we added a “1” in the table below. If more than one category was found we divided “1” with the number of categories and gave each category a fraction of 1. We focused on the categories used by the designers, because they need these terms for the materials searches. Finding the sensorial category was expected, because this is the category the tools aim at. Especially finding the perceptual category is unwanted because the tools are designed to translate perceptions into sensorial properties.

The tables on the right page show a summary of the questionnaire answers given by different groups that used the tools in the study described in section 8.4.

STUDENT product designers

	perception	use	sensorial	technical	materials	total
Own method	2 7/12	1/4	3/4	1 7/12	5/6	6
Picture tool	3	0	2 1/2	0	1/2	6
Sample tool	1 1/4	3/4	2 1/4	3/4	1	6
Questions tool	1	0	3 1/2	1/2	0	5

PROFESIONAL product designers

	perception	use	sensorial	technical	materials	total
Own method	1 7/10	19/20	1 19/20	7/10	7/10	6
Picture tool	3 1/6	1/3	1 1/6	1	1/3	6
Sample tool	2	1	2 2/3	1/3	0	6
Questions tool	1 1/3	2/3	3	1	0	6

The groups are professional product designers (PPD), professional clients (PC), student product designers (SPD) and student clients (SC).

USABILITY TOPICS	Own method	Pictures tool	Samples tool	Questions tool
Efficiency of the tool (little to much time)	PPD, PC: a bit more time than average SPD, SC: average SPD, SC: high variation	PPD, PC, SPD: less than average SC: least time	PPD, PC, SPD, SC: a bit less than average SPD, SC: high variation	PPD, PC, SPD, SC: more than average
Duration of getting familiar with the tool (little to much time)	PPD, PC, SPD, SC: less time than average. PPD, SPD: high variation	PPD, PC, SPD, SC: less time than average	PC, SPD, SC: a bit less time than average PPD: less time than average PC, SPD, SC: high variation	PPD, PC: average SPD, SC: more time than average PPD, SC: high variation
The tool's contribution to the understanding of the other party (better to worse)	PPD, PC: a bit worse than average SPD, SC: a bit better than average PPD, PC, SPD, SC: high variation	PPD, SPD: better than average PC, SC: a bit better than average. PPD, PC, SC: high variation	PC, SPD, SC: a bit better than average PPD: better than average PPD, PC: high variation	PC, SPD, SC: a bit worse than average PPD: a bit better than average PPD, PC, SPD, SC: high variation

CREATIVITY TOPICS	Pictures tool	Samples tool	Questions tool
More inspiration? (hardly to very much)	PPD, PC, SPD, SC: much inspiration	PPD, PC, SPD, SC: inspiration	PPD, PC, SPD: just a bit inspiration SC: hardly inspiration
Creativity restricted by the tool? (hardly to very restricted)	PPD, PC, SPD, SC: hardly to a bit restricting	PPD, PC, SPD, SC: hardly to a bit restricting	PPD, PC, SC: high variation SPD: very restricting
The tool was directing? (hardly to very much directing)	PPD, SPD, SC: around the middle PC: very directing	PC, SPD, SC: a bit directing PPD: hardly directing PPD, PC, SPD, SC: high variation	PPD: hardly directing SPD: very directing PPD, PC, SPD, SC: high variation

Appendix 11

Instructions for the tools in the evaluation study

The developed tools were evaluated by four product designers in their own projects (chapter 9). The instruction they received in the research diary is the following (translated from Dutch):

The MiPS tool is used during a meeting with the client and aims at making a materials profile for the materials searches. This material profile contains the desired sensorial aspects of materials of the new product.

The **set of questions** helps to discuss the different phases of the user- product interaction (first contact, try out, transport, unwrapping, usage and rest phase). On every card some example questions and terms are provided. The questions and terms can be used to start a discussion about the desired interaction.

The other sets can be used during the discussions to clarify ideas about the desired interaction. The **example products** help to find the desired interaction. Some material characteristics of these products are given on the backs of these cards. Every card has a materials sample associated with it. The set of **materials samples** represent a wide variety of sensorial aspects. The samples are used to find the desired aspects, not to select the materials itself. A combination of samples can show the desired sensorial aspects.

Parts of the MiPS tool
6 cards with questions
16 cards with product examples
16 material samples
a checklist with material aspects that influence the sensorial experiences with a product
An overview of the relations between the sensorial aspects of material and the physical material properties

The sets can be used to your own preference, for example as shown in the picture. Selecting a small number of cards or samples is important, because by doing this, the options are reduced.

Discussing the aspects that are mentioned on the backs of the cards helps to clarify what both parties expect from the materials. It identifies how both parties think the materials aspects contribute to the desired interaction.

The **checklist** with material aspects can help to summarize the meeting and to put the agreements in the materials profile. This profile contains the desired sensorial aspects of materials such as glossiness, hue of colour, texture and warmth. The aspects do not need to be defined in full detail in the profile. The aim is to know the most important aspects that create the desired user-interaction and which variables are less important while looking for material candidates.

The **relation sheet** of sensorial aspects and material properties can help to find suitable materials.

Which materials aspects play a role in the first contact with the product?

VISUAL
reflection
glossiness
transparency
scattering
roughness
texture
light intensity
hue of colour
multiple colours
intensity of colour
darkness of colour
durability of colour
pattern

AUDITORY
dampening
pitch
loudness

SMELL AND TASTE
intensity of odour
fragrance
taste

TACTILE
denting
softness
dampening
porosity
flexibility
plasticity
brittleness
weight
stickiness
wetness
oiliness
roughness
warmth

Example of the aspects in the checklist

Curriculum Vitae

ilsevankesteren@gmail.com

Ilse van Kesteren was born on June 14, 1977 in Haarlem. After finishing the HAVO in 1993 and the VWO in 1995, she started studying Industrial Design Engineering at the Delft University of Technology. During her education she had her internship at the National Bicycle Company in Dar es Salaam, Tanzania, in 1999. After coming back from this journey, she joined the organization committee of the Research Trip to California and Mexico in the summer of 2000, during which over 25 companies were visited. After a year break, to run the financial matters of the Student Association *i.d*, she received her Masters degree in 2003.

After graduation, she worked as a researcher and subsequently started her PhD project at the Design Engineering department of the Faculty of Industrial Design Engineering. During the PhD project, she supervised students both in Bachelor and Master courses and was a faculty representative for the PhDs for a year. In 2005, she was an accompanying teacher of a student trip to Copenhagen, Oslo and Gothenburg. She presented parts of her work at various research conferences and trade shows during the PhD period.

Besides the work for the university, she is an active member of the program committee Material Design, which organized over ten successful lectures and discussions for designers and material scientists, since 2004. For the Dutch Society of Material Knowledge, she co-organized, in 2006, their first event for young material scientists 'Meeting Materials', with lectures, speed dating materials and excursion at Corus, in IJmuiden.

Publications

Journals and proceedings

Kesteren IEH van, Bruijn JCM de, Stappers PJ. (2007, in press) **Evaluation of materials selection activities in user-centred design cases.** Journal of Engineering Design

Kesteren IEH van, Stappers PJ, Bruijn JCM de (2007, in press) **Materials in Products Selection: a tool for including user-interaction in materials selection.** International Journal of Design. December issue

Kesteren IEH van, Kandachar PV, Stappers PJ. (2007) **Activities in Selecting Materials from the Perspective of Product Designers.** International Journal of Design Engineering. Vol. 1 (1) page 83-103

Kesteren IEH van. (2008) **Product designers' information needs in materials selection.** Materials & Design. Vol. 29 (1) page 133–145

Kesteren IEH van, Stappers PJ, Bruijn JCM de. (2007) **Defining user-interaction aspects for materials selection: three tools.** Proceedings of the Nordic Design Research Society, May 27-30th 2007, Stockholm, Sweden. www.nordes.org

Kesteren IEH van, Stappers PJ, Kandachar PV. (2006) **Activities in selecting materials by product designers.** In: Su D, Zhu S (eds). Proceedings of the International Conference on Advanced Design and Manufacture. Nottingham: ADMEC, page 145-150

Kesteren IEH van, Stappers PJ, Kandachar, PV. (2005) **Representing product personality in relation to materials in a product design problem.** In: Mazé R (ed). Proceedings of 'In the making': 1st Nordic design research conference, Copenhagen 2005

Kesteren IEH van, Kandachar PV. (2004) **Commercialization of new materials in consumer goods.** In: Redmond J, Durling D, de Bono A (eds). Futureground, Proceedings of the Design Research Society International Conference 2004. Melbourne: Monash University

Kesteren van IEH, Stappers PJ, Bruijn JCM de (submitted) **Product designers' approaches of integrating user-interaction aspects in materials selection.** Design studies

Co-authored proceedings

Holper, MPR, Meij, M van der, & Kesteren, IEH van (2006) **Product personality considerations in materials selection** In: Proceedings of International Future Design Conference on Changing Places of Digi-log Future. Seoul, South Korea, page 494-507

Karana E, Kesteren IEH van (2006) **Material effects: The role of materials in people's product evaluations** In: Karlsson MA, Desmet P, and van Erp J. (eds). Proceedings from the 5th Conference on Design and Emotion 2006, 27-29 September, Göteborg, Sweden

Dutch publications

Kesteren IEH van (2007) **Gebruiksinteractie en materiaalkeuze** (User-interaction and material selection). Product. 2007 (2) page 22-24

Kesteren IEH van, Ludden GDS. (2006) **Beleving vertaald in kunststoffen: de glitters van deze tijd** (Experiences translated into plastics, the sparkles of current time). Kunststof Magazine. Vol. 17 (2) page 16-18

Ludden GDS, van Kesteren IEH. (2006) **Het ontwerpen van productbeleving – luisteren naar ijsjes** (Designing product experiences - listening to ice creams). Kunststof Magazine. Vol. 17 (1) page 16-18

Kesteren IEH van, Ludden GDS. (2005) **Productbeleving: voelen, ruiken en zien van kunststoffen** (Product experiences, feeling, smelling and seeing of plastics). Kunststof Magazine. Vol. 16 (9) page 18-20

Kesteren IEH van (2005) **Communiceren over kunststof: hoe productontwerpers tot nieuwe materiaal ideeën komen** (Communication about plastics: how product designers come to new material ideas). Kunststof en rubber. Vol. 58 (1) page 32-35

Kesteren IEH van, Poelman W. (2004) **Materiaalontwerpers, een brug tussen materiaal en ontwerpen** (Material designers, a bridge between materials and designing). Product. 2004 (6) page 4-6

Ludden GDS, Kesteren IEH van, Saakes DP, Sonneveld MH. (2003) **Het ontwerpen van kunststof consumentenprodukten; van technisch functioneren tot belevenswaardig** (The design of plastic products, from functioning to experiencing). Kunststof en rubber. Vol. 56 (12) page 16-18

Acknowledgements

Thank you all! For the opportunities, insight, trust, critical notes, discussions, information, cooperation, time, fun, (free)hugs and everything else I needed to start, go through and finish this thrilling project.

Thank you! Promoters, for your guidance and support. Prabhu Kandachar, for starting the project, and for giving me the space to do it in my own way. Pieter Jan Stappers, thank you for your hospitality, your creative feedback on my proposals, papers and above all for giving back my trust in the times I needed it. Hans de Deugd, thank you for teaching me about the complexity of the project and the different viewpoints involved. Thank you, Sjef de Bruijn, for jumping into the project and your enthusiastic commitment in the last years. Your constructive criticism on my work helped me to get to this point.

Thank you! Colleagues and friends at design engineering and Studiolab! It would have been a lot less fun without you. Geke, writing together, promood, coffees and trains, thank you for sharing our PhD experience! Thank you, Kirill and Elvin, for being the office mates and being that famous special Delft Materials Girls team :-) ! Ruben, writing mate, chapter for chapter, we got there. Miguel, Daniel, Froukje, Arnold, Jasper, Edit, Cha-Joong, and all the other colleagues, thank you, for the discussions, lunches and coffee breaks.

Thank you! All the people that offered me their time to discuss materials selection. Special acknowledgements for the participants in the different studies. The value of this thesis comes from you: Amber Leeman, Anne Hulshof, Bas Bruinig, Bert Jan Pot, Bruno Ninaber van Eyben, Costas Papaikonomou, Eric Tempelman, Fred Montijn, Gerard Kool, Gerben Pakkert, Hans Antonissen, Hans Blaak, Helle Ullerup, Henk Crone, Jaap van Grinsven, Jan Eek, Jean-Paul Niellissen, Jeroen Verbrugge, Joline Karelse, Joop Onnekink, Joop van Tuil, Joost Alferink, Kasper van der Wiel, Kees van Lede, Koen van Niekerk, Liesbeth Bonekamp, Marcelle van Beusekom, Marije van der Laan, Marjolein Min, Michelle Kuipers, Peter Wigman, Pim Jonkman, Rene van Geer, Rob Zweerman, Sander Nieuwveld, Sandra van den Berg, Sophie Krier, Stephan Boom, Sue van de Giessen, Tom Kieboom, Willem Mees van der Bijl and Wim Altena.

Thank you! For letting the written words become a thesis. Karen for the English editing, Sytse for the amazing work on the cover and illustrations and all the others that gave comments on the chapters, propositions and lay-out.

Thank you! Students, for the sparkling ideas you gave me: Annette Voesenek, Antonno Versteeg, Arjen van Spronsen, Bert-Jan Pastoor, Bregje Nabuurs, Chrystal Lieuw On, Clemens Simons, Coen ten Herkel, Daan van Tulder, Eelke Dekker, Frouke van den Berg, Gerard Dekker, Heleen Buijs, Hugo van Loenen, Jill Roelofs, Kittin Tang, Laura Klauss, Marije Nieuwenhuis, Marjoleine van der Meij, Michiel Holper, Nina Pander, Patricia Slingerland, Patrick Koppes, Reinier Jaarsma, Remco Bakker, Sarah Stuijfzand, Sören Blomaard, Stefanie Tumewu and Wouter Robers.

Thank you! Wim Poelman, head of the Materials Design program committee. We organized up to 10 well attended ‘De beleving van … ‘ - evenings together with Mick Eekhout, Ton Hurkmans, Lucie Huiskens, Charlotte Lelieveld, Marieke Hoppenbrouwer and recently also with Peter Legierse, Daan Rietbergen and Ilse Mater. The organisational meetings and the evenings itself always inspired me. They provided me with a continuous reminder of the questions, difficulties and chances existing in the design and materials fields. Thank you, Menno van de Winden, board member of the Bond voor Materialenkennis, for initiating Meeting Materials. Together with Alwin Knijnenberg and Barbera Keukens we organized the first one-day event for young material scientist in the Netherlands. What a great team!

Thank you! For supporting me, not only throughout the PhD, but throughout life. My parents, Ine and Harry, my brother, Wouter, you form the fundaments of who I am. Thank you for always being enthusiastically proud about me. You have taught me to appreciate the creative things in life and to be curious about people, all over the world. Joop, Annelies, Maaike and Anne, thank you for always being so warm-hearted. Maaike, thank you for the relaxing weekends, long talks, walks and coffee. You are my best friend. Boukje and Barbera, I would not dream of it standing there to defend my thesis without you! Our friendship will always last, wherever we are. Sophie, do you remember our first step in Delft, sharing the passion for design? Kamiel, Jaap, Marcelle, and all my other dear friends, THANK YOU!, for everything.

Thank you! Sytse, lief, a thesis full of words, but none are adequate to describe my gratitude to you. Met jou kan ik alles!