THESIS FOR THE DEGREE OF LICENTIATE ENGINEERING

Affective Surface Engineering for Product Design

Methods to ensure robust production with remained product experience

MARTIN BERGMAN

CHALMERS

Department of Materials and Manufacturing Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

Design research, sensation and perception, hard metrology, emotional functions, semantics, surface roughness, product interaction, core values, total appearance… the list of scientific phrases never ends. Yet, what do they mean and how shall we use it when we are communicating with the industry and our end users? Is it possible to link the product experience to process parameters, put a number onto it? When you can measure spoken needs or even better, implied needs, of a product, and relate that data to the production, it is possible to create advanced products with high interaction stimuli.

By joining engineering sciences (hard metrology) with design science (soft metrology) correlations between customer's product experience (emotional functions) and surface properties (technical functions) can be established.
The research briefly handles an optimization process where the framework from Kansei Engineering (KE) is used to evaluate the semantics issues primarily regarding materials and functional surfaces of products. The basic idea is that; the stakeholder's experience shall be observed already at the phase of ideation in the product development process, which then facilitates the project (in regard to the total appearance) later on when a concept reaches the production stage.

The results presented in this thesis are carried out through a number of case studies together with the industry. The main result and aim of the research is a developed robust approach that links emotional functions with technical functions, which in the next step facilitates the improvement of the total appearance of a product.

Nevertheless, it should be recognized that research is not yet complete. It is an iterative process, which confirms that the loop of the method needs to be complete. The developed method is a toolbox with the fundamental tools and workshops to facilitate the correlation process mentioned above, however the packaging of the final step in the method is not yet complete. The future research outlook will focus on the "independent industry implementation" where the method is used by the industry by guidelines only, thus without researchers support.

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My loved ones: My family and friends who have supported and given me strength as well as their patience, understanding and encouragement. I love you all, to the moon and back!

LIST OF PUBLICATIONS

This thesis is based on (but not limited to) the work contained in the following papers.

Paper A

Bergman M, Rosén B-G, Eriksson L and Anderberg C (2014a) Surface design methodology: challenge the steel J. Phys.: Conf. Ser. 483 011001 doi:10.1088/1742-6596/483/1/012013

Paper B

Bergman M, Rosén B -G , Eriksson L and Anderberg C (2014b) Surface Design Methodology – The Cleanability Investigation KEER2014 Proc. 5th Kansei Engineering & Emotion Research (Linköping Sweden 11-13 June) ed S Schutte

Paper C

Bergman M, Rosén B-G and Eriksson L (2015) Affective Surface Engineering – the art of creating emotional response from surfaces. Proc. 15th Int. Conf. on Metrology and Properties of Engineering Surfaces (Charlotte, USA, 2-5 March) ed C J Evans

Co-author statement

All papers are written by Martin Bergman together with Mechanical Engineering Prof. Bengt-Göran Rosén (Halmstad University) and Industrial Design Prof. Lars Eriksson (Jönköping University).

CONTENTS

GLOSSARY: DEFINITIONS AND TERMS USED IN THE THESIS

Aesthetics; The study of the effect of gestalt design on sensation

Engineering design; Design with particular emphasis on the technical aspects of a product, including both analytical and synthetic activities.

Form; Shape (geometry), dimension, surface texture, structure, and configuration.

Gestalt; A discernible whole; an arrangement of parts so that they appear and function as a whole which is more than the sum of the parts (Monö, 1997).

Industrial design; Design with particular emphasis on the relation between product and man, e.g., semiotic, ergonomic and aesthetic aspects of the product.

Product design; The activities concerning the design of products, including the activities of engineering design and industrial design.

Product; A system, object or service made to satisfy the needs of a customer. *Function* see Product function.

Semantic function; Product function related to the meaning we place, or interpret, into its form. Includes the four functions to describe, to express, to exhort, to identify (Monö, 1997).

Syntactic function Product function related to the structure and configuration of visual form.

Ergonomic function Product function that enables or enhances the use of a product with respect to physical or cognitive ergonomics.

Communicative function Collective term for syntactic and semantic functions.

Form function; Alternative term for Communicative function.

Product semantics; The study of the symbolic qualities of man-made forms in the cognitive and social context of their use and application of knowledge gained to objects of industrial design (Butter and Krippendorff, 1984).

Product function; What a product or an element of a product actively or passively does in order to contribute to a purpose, by delivering an effect. A function is intended or incidental.

Functionality; The combination of all effects, properties, and their behavior, that contributes to making the product useful for its purpose.

Property; Any characteristic of an object, that belongs to and characterizes it (Hubka and Eder, 1988).

Configuration; A system that is designed by selecting existing elements and arranging them into a product.

Structure; Elements and their relations (functional and spatial).

Artifact; A thing made, or given shape, by man (Karlsson, 1996).

Design (object); The result of a design process (Andreasen and Mortensen, 1996).

Design (process); To conceive the idea for some artifact or system and/or to express the idea in an embodiable form (Archer, 1971).

Semantics; The study of the sign's message (the meaning of the sign) (Monö, 1997).

Semiotics; The study of signs (Monö, 1997).

Syntax; The study of the signs relations to other signs and the way it interacts in compilations of signs (Monö, 1997).

System; A system is separated from the surroundings by a borderline, and has a structure consisting of elements and their relations (Andreasen, 1980).

Technical system; A man-made system that is capable of performing a task for a purpose.

User; Any individual who, for a certain purpose, interacts with the product or any realized element (system, part, component, module, feature, etc., manifested in software or as concrete objects) of the product, at any phase of the product life cycle.

Design thinking – A design-specific cognitive activity that designers apply during the process of designing.

Design making – A design-specific practical activity that designers apply during the process of designing.

Desirability; A term for what is needed on the market, the stakeholders requests.

Viability; A term for what is economically justifiable.

Feasibility; A term for how well the product might be developed and manufactured.

Soft Metrology; Usually implemented with qualitative properties, impressions, etc.

Hard Metrology; Usually implemented with quantitative methodology using sensors and metrology methods. All hard metrology is measured with some kind of measurement system.

Total Apperance; The symbiosis of; Physical, Physiological and Psychological aspects regarding a product.

Functional surfaces; Surfaces that somehow affect a products value regarding function and experience.

1 INTRODUCTION

The main topic of this thesis is interaction, communication and functionality in the field of product design, with a specific focus on visual and haptic stimulus of materials and surface textures. It has been implemented through a number of case studies in collaboration with the Swedish industry.

1.1 BACKGROUND

Now, while writing this, the earth's population is reaching 7.4 billion people, each and every one of them experiences their life in a personal way, and how a individual experience different situations depending on a various aspects. The fundamental biological issues matters for instance; fear comes with a tendency to flee, anger with the tendency to attack, and fascination with the tendency to explore, that is a fact no matter where you come from! (Desmet and Hekkert, 2007) However, we are raised in different ways depending on which culture we belong to, what profession we have matters and many other external factors we can't influence. We refer to our past while traveling through life and into new experiences; history versus future and old behaviors might be challenged. Our past interferes with the interaction of new products or services and jeopardizes the experience. (Desmet and Hekkert, 2007)

As a product designer and engineer your job is basically to fulfill stakeholders needs by creating products that work the way they should to facilitate everyday life. The technical functions (functions of shape, materials, surfaces color etc.) of the product should be developed and thought out to match the customer's expectations. If we have cognitive flow in our everyday life, we tend to relax and lower our psychological guard. (Kahneman, D, 2013)

However the experience of using the product also has to be pleasant, the interaction has to be complete between man and machine, otherwise the product will be put aside in favor of other products. Hence, what we call emotional functions (stimuli of the senses creating feelings) of the product also have to be right. (Desmet and Hekkert, 2007)

A product where the technical functions and the emotional functions are developed in a controlled way and correlate will likely create a nice experience for the end user. (Bergman et al. 2016)

In the specific field of material design, the surface appearance is of high importance as it has a major impact on functionality both technical and emotional. A key factor to be able to control the correlation between emotional and technical functions is the development of a novel and robust approach where the material and surface design is measured and verified towards the demands of the emotional and technical functions. (Bergman et al. 2016)

1.2 THE MATTER

Consumer decisions when choosing a product contains a complexity of aspects including experience controlled by our five senses, fulfilling of functional requirements and gestalt, describing the sum of the product properties. The widely implemented ISO 9001 series is based on seven quality management principles where the first is customer focus.

″Sustained success is achieved when an organization attracts and retains the confidence of customers and other interested parties on whom it depends. Every aspect of customer interaction provides an opportunity to create more value for the customer. Understanding current and future needs of customers and other interested parties contributes to sustained success of an organization’’. (ISO 9001, 2015)

Organizations depend on their customers and therefore should they understand past, current and future customer needs, they should meet customer requirements and strive to exceed customer expectations. Here, tools and methods to measure customer satisfaction and link it to physical properties of products are of great interest. Form, color, gloss, material and texture selection are examples of critical product properties; and convey a message from the industrial and engineering design departments to the customer. Well-polished metal surfaces and finely woven clothes may be examples of product properties specially designed to be appealing to the human sense of visual feedback and touch from products aiming at an exclusive high quality market (Nagano et.al., 2013).

Material and manufacturing selection of a car, as an example, is not only about ensuring safety in a construction, ensuring low cost production or optimizing the weight. Zoom into the material beyond what we can see with the naked eye and the microstructure will expose a landscape in the sub millimeter scale affecting us as customers and users in a subtle way.

Surfaces and materials have gradually emerged as competitive design parameters to achieve higher qualities of physical products, both technically and emotionally. Personal experiences from design work in both education and projects together with the industry have contributed to the identification of needs, which have influenced the direction of the thesis work. However, the incentives for this research were the following.

- The need for increased transdisciplinary collaboration between industrial design and engineering design activities for a holistic approach
- The vision to control the total appearance in a process
- The need for a novel and robust approach for material and surface design in regard to soft- and hard metrology
- The need for comprehensive tools for material and surface design

1.3 WHAT IS DESIGN AND DESIGN RESEARCH?

To make the reader appreciate the fundamental idea of product design and design research, but also understand different design terms and definitions, the next chapter is focusing on the basics and the core of what design could be.

Design

Design is about future possibilities; otherwise continuous improvements could cease immediately. Yet, it is not just only about highlighting problems and solving them, but that new products, systems and services will change the conditions for life and business, not just functional but also emotional. (Ullmark, 2004)

Now, the term “design” comes from the Latin word “designare” and basically means to point out or make something. Which we most likely have done long before we knew about what design is, yet also long before we communicated about it as well. However, the term design means different things to people depending on which culture we are in, where culture applies both for geographical culture and business culture. (Yo, 2005)

One definition could be: that designing is the creation of a solution to an addressed problem, where certain purposes, requirements and constrains are identified. Or, it could also be defined as; everything that is built for a purpose and fulfills a need and has a certain function is ‘designed’. (Warell, 2001)

If that definition is true, a cogwheel for a gearbox with high technical demands is to be considered as design. However a piece of canvas art, textile graphics or a glass sculpture for example, which may have social, decorative and affective functions rather than being a solution to a direct technical problem, will immediately be addressed as something else than design. Although, the artist who made it maybe strove for a specific social reaction and expression by adding different materials, textures, shapes and colors, regardless of technical specifications and restrictions from a company for instance. Thus, by accepting the definition of design above then, being an artist described here, is not a matter of design. However being a craftsman like a blacksmith or jewelry smith you are slowly getting closer to being a designer in that manner, you are getting closer to fulfill a need. Now, looking closer at the industry where a product usually is developed with multiple constraints regarding technical requirements, production costs and so forth, definitely is considered as design. Start analyzing product development and you will find many types of design within this topic. (Warell, 2001)

Going back to textile patterns and fabric design; what is the material and the choice of texture of the car seats of an interior design for instance, if not an issue of design, both functional and emotional? Hence to all these discussions, I find it crucial to separate different approaches in design to be able to place the core of the research work made in this thesis.

Industrial Design

Industrial design basically embraces areas treated by industrial designers or persons with similar competence such as aesthetics, semantics, appeal, graphics, product and corporate identity, ergonomics and visual form. (Warell, 2001)

Monö (1997) maintains that industrial design is about “the creation of the gestalt of useful products intended for mass production, with the aim of adapting them to man and his environment”. However, in this thesis the definition of industrial design embodies the description above, nonetheless a little bit more specific: “design with focus on the relation between product and man”.

Product Design

The meaning of product design is difficult to define, hence it could include a lot. It is rather the boundary when product design tends to look like the methodologies of engineering design or industrial design that needs to be defined. However, Warell, (2001) says that product design is ranging from the creation of textiles, glass and ceramic handicraft, to the form-giving activities of the industrial designer, and the engineering activities during product development. One common interpretation of product design is also that; the activities involving the design and development of products, including the activities of engineering design and industrial design, briefly could be interpreted as a hybrid of industrial- and engineering design.

The term ‘product design’ could embrace both physical products and services, and it will probably diverge depending on which profession you are asking, again it might be subjective. The meaning of product design and the words design/designing in this thesis however is aiming at physical and industrial manufactured objects, which then obviously involves the engineering design knowledge for its realization. Therefore, objects of handcraft, literature, Internet services or chemical substances like fuel, are not considered as products in this work.

Engineering Design

Engineering design is normally interpreted as an activity by specially trained developers that normally are employed within the field of machine elements, solid mechanics, and calculation of strength of materials, aerodynamics, fluid dynamics, hydraulics, electronics engineering, software engineering, system engineering, quality engineering, industrial economics and human factors engineering. No matter which area the engineering designer is working in, the engineering aspects, the technical functions, are usually in focus in the development process. (Warell, 2001)

Design Research

So, how about design research? Research or science and design are emotionally loaded concepts. While research and science have a long history in the public arena, design is fairly new. However, design is closer to the public nowadays and the concept appears more frequently in books, magazines and media. Design is generally associated with innovation, care and increased competitiveness although sometimes also with oversupply and overconsumption by countries around the world. (Ullmark, 2004)

Research and science nearly have got an inviolable position in the society, and are most often not criticized or questioned. However, despite the strong position in the general discussion, research/science and design are just two of many professional activities giving imprints in the society. In general, research is a collaborative activity in which each input is contributing in an incomplete chain of knowledge. Previous research results must be reliable and significant for other scientists to be able to continue working within the area, and these requirements affects the whole working approach. The scientist has to be aware of and challenge multiple possible options and objections to be able to state it as true fact. This way of working is time consuming and requires a lot of resources, which results in a limited share of society's knowledge production. Otherwise, we have to rely on already proven experience, although the research contributes by the fundamental understanding of structures, methods and criteria for reliability testing. (Ullmark, 2004)

Design and research approaches differ in several ways in terms of objectives and conditions. The design approach is usually a result of unique situations that need to be handled; in contrast, research is more focusing on a universal solution to an addressed issue. (Raster and SVID, 2007)

In general, design as a strategy can not delimit the addressed problem to make it manageable, which research usually does to be able to implement a project with significant results in regard to science norms. So how should we relate to design research? How much of the traditional design will influence the research, and vice versa? Well, if design research holds on to descriptions and analysis of an existing reality and makes predictions about it with proven methods, then probably nothing special will occur. However, turning that information into practice and into a traditional design process makes it more valuable for the end user. Now, a narrowly defined focus in the design research facilitates the research efficiency but also reduces the risk of being questioned. Yet, when that result shall be converted into practice, uncertainty might arise as a consequence of the research project boundaries. (Raster and SVID, 2007)

1.4 COMPREHENSIVE VIEW OF DESIGNING

This research is so far about product design mainly from a Swedish point of view. However when talking about design and designing from a Swedish perspective approaching the needs, objectives and activities, the word 'design' in Swedish normally represents the appearance and the aesthetic aspect of products. Such products could concern fashion design (fabrics/textiles), glassworks, jewelry, and furniture for instance. (Warell, 2001)

Yet, in this thesis the terms 'product design' and 'designing' are aiming for a wider sense of use, as described earlier in this thesis.

Hence, product design could be considered as a hybrid or balanced combination of industrial design and engineering design; the two different approaches of industrial- and engineering design should be presented.

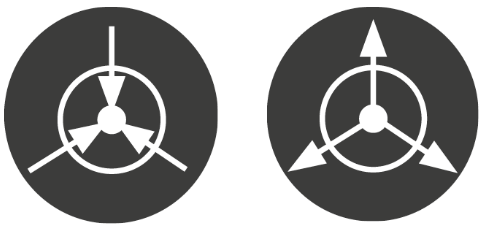

Figure 1, Illustration of the Engineering approach (left) and the Industrial design approach (right).

Basically, the two approaches are antonyms to each other (figure 1), yet not impossible to combine. The engineering-oriented designer usually starts by designing the different parts of the product, then from the parts focusing on the whole design of the product. In opposite, the industrial-oriented designer initially focusing on the design of the whole, the gestalt, then concentrating of the parts the product is assembled of, focusing on cultural and social aspects. (Warell, 2001)

Different approaches into the design issue usually result in different perspectives of looking at the product. This means that; depending on which approach that is implemented, different prioritizations are made during the project. The traditional engineering oriented designer relies on scientific methods and knowledge in regard to material and form behavior as well as technical functionality for example. The industrial designer on the other hand, relies on the experience working in the field; the subjective knowledge and personal views and principles are controlling the approach. (Warell, 2001)

The difference between the two approaches appears as fairly clear however complex to deal with, and they are! Engineering designers and industrial designers have been working side by side in projects limited to communicate their needs with each other for decades. However, this way of categorizing the two approaches and the way of work is outdated and counterproductive, and the product designer will likely need a comprehensive view and approach to be able to handle the complexity of product development in the future.

2 SCOPE OF THE RESEARCH

In this chapter the reader will be aware of the objective of the research and the delimitations that have been set to be able to implement the cases and projects.

2.1 OBJECTIVES OF THE RESEARCH

The main objective of this paper is to present the importance and context of ‘affective engineering’ and to give example of the application for engineering surfaces to support the discussion of continued research in the field - addressing the problem of the absence of a current joint approach to affective surface engineering in general. This is done by means of a developed novel and robust approach to be able to modify an implementation of what is called “Kansei Design” (“emotion design”), towards materials and surfaces. The approach is based on the proven method Kansei Engineering, which has its roots in Japan. It is not about generalizing a feeling/experience or interaction of a product; it is rather about framing the experience of the stakeholder towards a certain product and optimizing the total appearance. This is done to be able to improve that product in regard to the stakeholder’s needs and expectations in terms of both technical and emotional functions. Hence, to be able to implement such an approach a need arose; a need for a robust model/framework to relate to, which is the core in this thesis.

The main objective of the thesis is divided into the following sub-goals.

- Study the influence of the material/surface properties in regard to the total appearance and the experience.
- Study the sensation and perception of materials and surfaces, the semantics, focusing on visual and haptic stimuli.
- Investigate the correlation of technical- and emotional functions.
- Create a model for designing and analyzing materials and surfaces in regard to point 1-3.

2.2 RESEARCH QUESTION

In the very beginning the main research question was vague, and difficult to verify. The underlying aim was then to control the stakeholder’s feelings or experience and the question was as follows;

“Is it possible to put a number on feelings?”

However when the research went on and the first case studies were implemented and the attitude of the issue matured, the question changed. The focus went from the willing of controlling the stakeholder’s subjective experience to the willing of control of the “total appearance” of which the stakeholders interact with, the core of provoking those experiences.

“Is it possible to measure, verify and modify total appearance?”

2.3 APPROACH

The research approach so far has been the implementation of case studies in collaboration with different disciplines in the industry. The main common core in all cases on the other hand has been the evaluation and improvement of the material and surface total appearance. The total appearance has been evaluated differently depending on which case and company that has been in focus, hence the different cases aim has varied towards material and surface design.

2.4 DELIMITATIONS

The focus in the research work so far is to create an understanding of the impact of using the "Affective Surface Engineering" approach presented in this thesis. The main purposes have been to improve the framework and the approach in regard to material and surface design towards the senses of sight and touch. This means that other design parameters such as shape and color have not been in focus, as well as the other senses of hearing, smell and taste.

2.5 THESIS STRUCTURE

This thesis is organized into seven main sections.

Section 1
An introduction to the research work; is a section where the reader can get an idea of the background and the incentives for the research.

Section 2
The scope of the research; is a section where the reader will be introduced to the main objective and the research question of the research.

Section 3
The theoretical frame of references; is a section where the reader will get a deeper understanding about the theories and core within the research.

Section 4
The result – the method; is a section where the reader could learn about the method created for Affective Surface Engineering.

Section 5
Research conclusions; is a section where the reader is getting into the final discussion about the research and future work within the area.

Section 6
References

Section 7
Appended papers.

3 THEORETICAL FRAME OF REFERENCES

The intention of describing a theoretical frame of references is to establish the fields of knowledge, which contribute to the understanding of the field of study.

3.1 WHAT IS A PRODUCT AND ITS DOMAIN?

One reasonable definition is that; a product is anything that can be offered to the market and that might fulfill a need. Yet, it is easy to believe that products are only a composition of physical parts from the industry, yet they are not. Talking about products also includes services, applications to smartphones and so forth as well. The products domain could be explained as the cognitive content – the sum of what has been perceived, discovered, or learned by the product. (Warell, 2001)

3.2 WHAT IS A CONTEXT OR ENVIRONMENT?

A context or environment is place or a space where a domain is used. The context supports the user to understand what otherwise could be difficult to comprehend with a product. It is a necessary assistant, helping users define unknown facts and make sense of external information. Briefly, the context supports the domain-to-user interaction. (Warell, 2001)

3.3 TOTAL APPEARANCE

What a designer is trying to do when designing physical products from the visual point of view is the controlling of the total appearance of the product.

Appearance is according to American Society for Testing and Materials (ASTM), ASTM E284 (2002), defined as "The aspect of visual perception by which objects are recognized". The visual appearance of an object is a result of the interaction between the object and the light falling upon it. Color appearance is a result of the light reflection and adsorption by the pigments. Gloss is created by the reflection of light from the surface, and translucency is a result of the light scattering while the light passes through the object (fig. 2). The described complexity of the object's appearance causes different measurement technologies and instruments to be employed when attempting to quantify it, Pointer (2003). Texture is a complementary component of the visual appearance and also needs to be considered. The concept of total appearance has been introduced to extend the concept of the appearance of an object. The total appearance, however, would require a description of the shape, size, texture, gloss and any other objects' properties possible to detect by our 5 senses (visual, haptic, smell, sound and taste) and interpreted by the brain as a "total appearance" of an object, Pointer (2003) and McKnight et al. (1997).

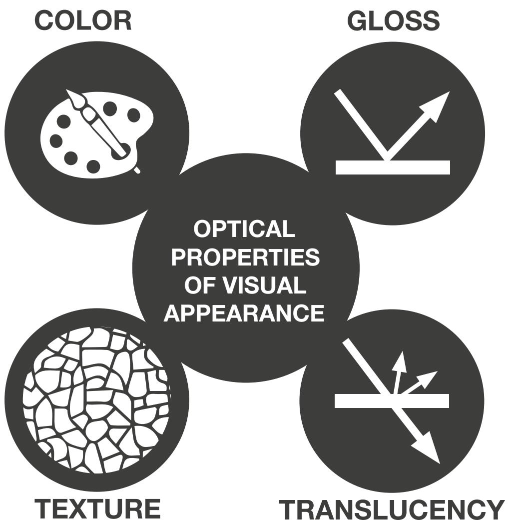

Figure 2, Visual appearance is one aspect of the total appearance. Here, the four basic optical properties (color, gloss, texture and translucency) of visual appearance are grouped together. (Rosén et al. 2016)

The total appearance (fig above) could also be described as a combination of three aspects of appearance:

- Physical (physically by our senses detectable object properties modified by the surrounding, properties of the illumination, individual factors like ageing, handicap, etc., affecting our sensibility)
- Physiological aspect (the neural effect when human receptors are subjected to the physical stimuli and convey signals to the cerebral cortex), creates a sensation
- Psychological aspect created when sensations are interpreted by the cortex, recognized as an object and combined with inherited and taught response modifiers (Memory, Culture, Fashion, Preferences). Figure 3 below summaries the factors affecting the total appearance resulting in two appearance images.

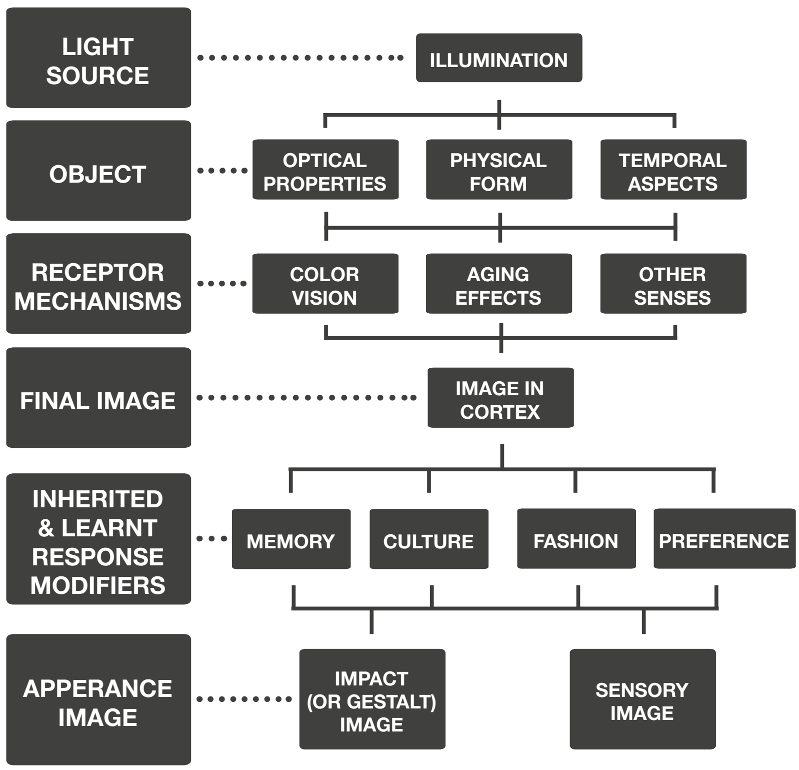

Figure 3, the concept of total appearance. (Pointer, 2003)

The impact image, and the sensory image; the impact image is the initial recognition of the object or scene (the gestalt), plus an initial opinion or judgment. For the sensory appearance image, three viewpoints are used to create the total appearance, sensory, emotional and intellectual. The sensory viewpoint describes thoughts associated with the colors, gloss etc. of the object. The emotional viewpoint associates the emotions connected with colors, gloss, etc. while the intellectual viewpoint covers other aspects associated to the object and situation rather than sensory- or emotional associations, Hutchings (1977) and Hutchings (1995).

Total appearance is closely related to the models of Intended product communication, and the Perceptual Product Experience (PPE) framework and could be used when quantifying customer perception and satisfaction using soft metrology to correlate physical- and human factors contributing to products appearance images.

3.4 SOFT METROLOGY, A WAY OF MEASURE TOTAL APPEARANCE

Soft Metrology, defined as "the set of techniques and models that allow the objective quantification of certain properties of perception, in the domain of all five senses". (Pointer, 2003) Soft metrology addresses a broad range of measurement, outside of the traditional field of physical metrology (Pointer, 2003):

- Psychometric measurement or perceived feeling (color, taste, odor, touch),
- Qualitative measurements (perceived quality, satisfaction, comfort, usability),

- Econometrics and market research (image, stock exchange notation), sociometry (audience and opinion),
- Measurements related to the human sciences: biometrics, typology, behavior and intelligence.

The ideal would be to perform physical measurement using sensors applied to a subject placed in a test situation and the establishment of useful measurement scales correlating human responses and physical metrology, i.e combining traditional physical "hard metrology" (geometry-, color-, gloss-, taste-, smell-, noise- and tactile properties) to enable increased understanding of the influence of physical product properties on human responses, see figure 4 below.

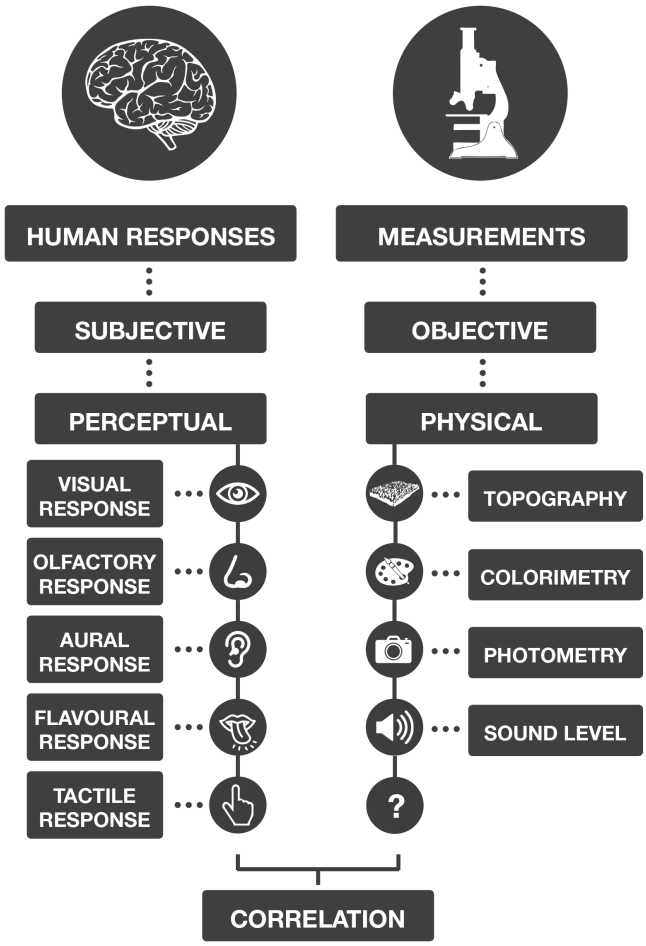

Figure 4, Soft metrology, correlating the objective physical measurements to human subjective perceptions. (Pointer, 2003)

Here the human would be considered as a measurement system defining sensitivity, repeatability and reproducibility and comparing the results with those obtained by methods from traditional "hard" physical metrology. The notion of subjectivism can of course be discussed further related to figure 4 above. Parts of what is described as subjective human responses in the figure above can actually be described as general perception, though subjective. For instance, the Bouba-kiki effect, in which the subjective perceptions are shared by all respondents, and therefore can be seen as a general perception, and not notified as a personal opinion of what is perceived. The area of soft metrology has got a lot of attention and departments was formed both at the standards institutes NIST in USA and NPL in England, Pointer (2003), Krynicki (2006) and Eugéne (2008) a European project - Measuring the Impossible (MINET) 2007-2010 with 22 partners from Europe and Israel including industries and academia as well as the national standards institutes in Great Britain, NPL and in Sweden SP, European Commission (2007). In 2013 also L. Rossi published her doctoral thesis – "Principle of Soft Metrology and Measurement procedures in humans" stating the importance of the field, Rossi (2013).

3.5 THE GESTALT - FUNCTIONS OF THE DESIGN ELEMENTS

In product design we are usually talking about physical products and the primary design elements are form (as geometry/shape), color (as hue, saturation, whiteness and blackness), material (as chemical substance or raw material, isotropic or anisotropic, structure and strength) and surface (as texture, gloss, haze, isotropic or anisotropic).

In the field of design the physical creation of form, color, saturation and material could be considered as the 'gestalt'. The 'Gestalt' is a discernible whole, an arrangement of parts that appears and functions as a whole, which is more than the sum of the parts. (Monö, 1997)

Form

Form is the design element of an aesthetic structure that provides the related properties of the visual. Different forms generate different expressions and different experiences. "Takete" and "Lumumba" in figure 5 is a fundamental example where different form provokes different experiences. (Monö, 1997)

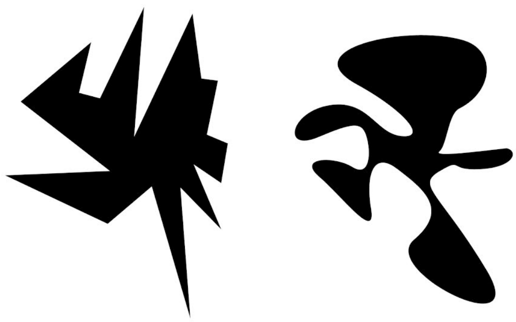

Figure 5, illustration of Takete and Lumumba.

However, to start looking at more complex forms (with "Takete" and "Lumumba" in mind) creates a deeper understanding of the complexity in the selection of form. This is even more important when different geometric volumes starts intersecting with each other and creating different proportions. Figure 6 illustrating an example of two different Volvo cars with different proportions and joined forms in regard to the upper part (A), the lower part (B) and the tires (C) of the body, one SUV and one sports car. The proportion illustration is a bit extreme, however the theory behind it is clear, a sports car has got a lower profile closer to the road for a more stable drive at high speed. As a result of the low profile the cockpit is also closer to the ground, which results in a more narrow upper part (A). The SUV or terrain vehicles in general on the other hand, need a higher ground clearance to be able to manage more difficult terrain. Yet, also the cockpit is located higher for several reasons; firstly it could be a result of desired ground clearance and secondly because you traditionally need a broader view when driving with a SUV, which is why the windows of a SUV/terrain vehicle usually are bigger in comparison as well. (Monö, 1997)

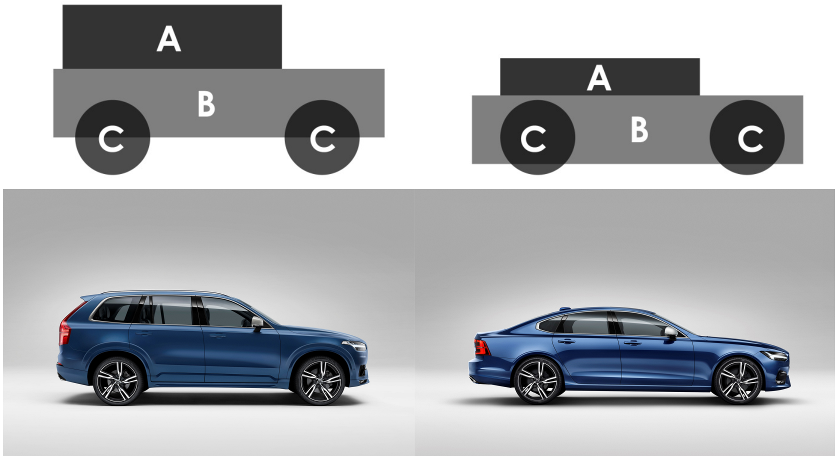

Figure 6, illustration of different shapes and proportions.

Cheryl Akner-Koler talks more about the importance of form and proportions in her thesis "FORM & FORMLESSNESS". (Akner-Koler 2007)

Color

Color is a complex design element; yet is the design element that usually is defined by the end user by a personal choice. Color is fairly dominant as a design parameter and can be used as an index, an iconic sign as well as a symbolic sign. (Klarén, 2008) However, what is perceived by the beholder could vary depending on the external light and the receptors in the eye, it is a visual stimulus, we can't experience color by haptic stimuli. (Wolfe et al. 2012) What in everyday life is called light is perceptually; something the beholder perceives by sight. Hence, color is basically light with different wavelengths of electromagnetic radiation, which the brain converts to an experience of the light. Color can appear different also depending on light temperature, a warmer tone of external light (3500-4500K) could give a color the appearance of being more yellow-ish, and in opposite; blue-ish if the external light is colder (5500-7000K). (Klarén, 2008) There are a lot of different color systems trying to create a standard or a model for mapping variation in colors; NCS is one of the largest international languages of color communication, and it is a perceptive color system. Figure 7 illustrates the function of the NCS system with its color map. (Hård, 1981) Now, the NCS color system is depending on the external light to be "correct"; if the chosen color should be placed outside on the wall on a building, the color should be chosen and evaluated in the same light temperature as it is outside (5000-6500K). (Klarén, 2008)

Figure 7, illustration of the NCS system color palette and the structure.

There are objective ways of defining the color in a numerical way. The exact value could be determined by use of an instrument known as a spectrophotometer. The physical difference between the various regions of the spectrum is wavelength; the wavelength varies continuously from one end of the spectrum to the other. The unit of length that is commonly used for specifying the wavelength of visible radiation is the nanometer (nm). In terms of this unit, the spectral areas include approximately the following ranges of wavelength (MacAdam, 1981), figure 8 shows an example of how a color analysis spectrum could look like:

- Violet 400 - 450 nanometers
- Blue 450 - 490 nanometers
- Green 490 - 560 nanometers
- Yellow 560 - 590 nanometers
- Orange 590 - 630 nanometers
- Red 630 - 700 nanometers

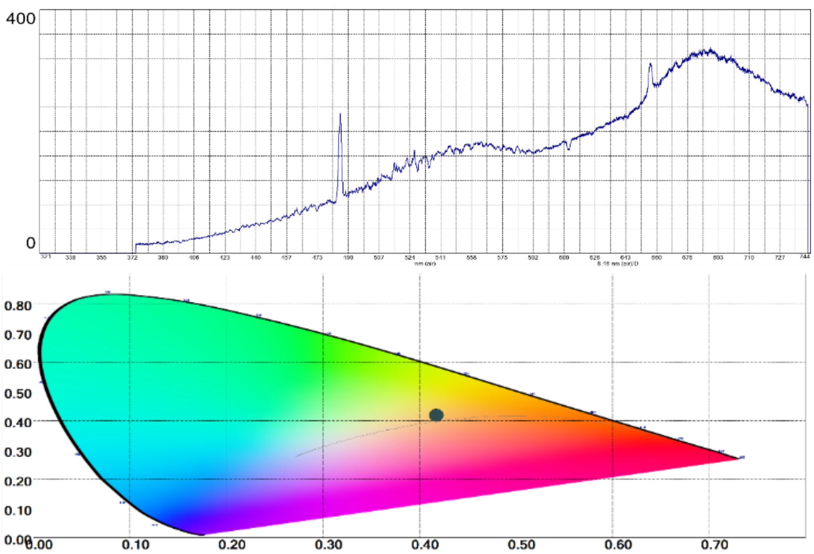

Figure 8, illustration of how a color analysis spectrum could look like with the use of a spectrometer. The upper graph illustrates the dominating wavelength of the analyzed color, which in this case is around 590 - 630 nanometers (orange).

Material

Material is the substance or substances of which a thing is made or composed. A material can be recognized with structure and strength, however not form, and a material could appear as a solid, liquid or gas. Materials are composed of different combinations in either a crystalline structure, amorphous structure or a mixture of them both. Crystalline material consists of atoms that are well arranged; in contrast to amorphous that is disordered. There are a massive amount of different materials on the market, raw materials and alloys as well as hybrid materials. Steel, concrete, glass, rubber, metal, petroleum, plastic, stone, textile, wood and tissue are just a few examples of basic material groups used in products and other applications. Products today however are commonly made of composites. Composite materials mainly represent an evolution of the science and technology of materials, essentially because they blend the best properties of several materials resulting from the most up-to-date technologies, which empower them with outstanding physical and mechanical properties. (Brigante, 2014)

Each material requires an optimized manufacturing process, and that process needs to be taken into consideration as early as possible. There is a danger to become detached from manufacturing processes as a product designer. Different manufacturing processes comes with different machines and procedures, and it is usually the material selection that determines the way of producing the product, or vice versa (Thompson, 2007). The manufacturing process, the material and the products construction determine the strength and the durability as well as the total appearance of a product. The material selection is one of the most important processes in a development project. The material discussion and selection should therefore be implemented as early as possible in a project to stay cost efficient. (Ashby et al. 2010)

In this thesis materials are usually already set as a defined parameter as the topical company has a distinct production line, however the surface design of the material usually varies. However there are many different ways to do a material selection. By defining key material parameters such as hardness or flexibility; material selection software or databases could give the first indication of which material group to start with. Some databases even propose new innovative hybrid materials depending on which material parameter that are in focus. Ashby (2016) material selection is one famous and efficient way of implementing a material selection. As another example, Thompson (2007) describes in his book “Manufacturing processes for design professionals” several different manufacturing processes such as forming, cutting, joining and finishing functions for different materials.

Material is, together with support by the surface structure, the design elements that primarily provide the sense of touch. By the haptic stimuli the user will experience thermal conductivity, weight, and roughness for instance (Wolfe et al. 2012) and (Ashby et al. 2010).

Surface

A surface is briefly, a two-dimensional topological manifold, either isotropic or anisotropic. A surface is the design element where the microstructure has a major impact on the total appearance, initially primarily the visual sense, however also the tactile sense with support by the material properties. The surface also has a great impact on technical requirements, such as e.g. high friction, which is possible to measure, adjust and control in a process.

The surface total appearance and technical functions is depending on manufacturing process, during machining and manufacturing the surface of the component becomes more or less deformed – no matter which production process that is used (Sander, 1991). What also matters is the finishing phase of a material and surface; is it sand blasted, polished, painted, coated, anodized or is just a raw surface? The total appearance and technical functions of a surface will vary depending on the finishing of the surface as well. However, the spaces we are navigating and living in consist of thousands and thousands of surfaces of different kinds, and we are affected by them whether we want to or not.

Looking at surfaces in the micro scale focus is primarily on parameters from ISO 25178, table 1. When quantifying parameters from the ISO-standard different measurement methods could be implemented such as stylus methods, optical methods, pneumatic methods and liquid methods (Sander, 1991). For further reading about measurement techniques; read the section *'What is a function?'* later in the thesis.

Table 1: *Classification of surface roughness parameters.*

Family	Symbol	Parameters description
Height Parameters	S_q	Root mean square height
	S_{sk}	Skewness
	S_{ku}	Kurtosis
	S_p	Maximum peak height
	S_v	Maximum pit height
	S_z	Maximum height
	S_a	Arithmetical mean height
Spatial Parameters	S_{al}	Auto-correlation length
	S_{tr}	Texture-aspect ratio
	S_{td}	Texture direction
Hybrid Parameters	S_{dq}	Root mean square gradient of the scale limited surface
	S_{dr}	Developed interfacial area ratio of the scale limited surface
Feature Parameters	S_{pd}	Density of peaks
	S_{pc}	Arithmetic mean peak curvature
	S_{10z}	Ten point height
	S_{5p}	Five point peak height
	S_{5v}	Five point pit height
	S_{da}	Closed dale area
	S_{ha}	Closed hill area
	S_{dv}	Closed dale volume
	S_{hv}	Closed hill volume

Family	Symbol	Parameters description
Functional Stratified parameters	S_k	Kernel roughness depth (roughness depth of the core)
	S_{pk}	Reduced peak height (roughness depth of the peaks)
	S_{vk}	Reduced valley depth (roughness depth of the valleys)
	S_{mr1}	Upper material ratio
	S_{mr2}	Lower material ratio
	S_{vq}	Dale root mean square deviation
	S_{pq}	Plateau root mean square deviation
	S_{mq}	Material ratio
	$S_{mr\ (mc)}$	Areal material ratio of the scale-limited surface

One good example of surfaces that most people can relate to is the cleanability of kitchen surfaces, figure 9. However it is well known that stainless steel surfaces are demanding to keep clean in everyday use, in regard to the total appearance, especially grease stains and fingerprints. This is mainly because of the glossy surface, the texture and the color of the material and its surface. (Bergman et al. 2014a) and (Bergman et al. 2014b)

Figure 9, illustration of surface design from macro to micro scale in a stainless steel design product.

As an example of challenging the stainless steel in the kitchen above, a previous result from a case study is illustrated in figure 10, where other materials with similar, or better, surface design for the application of “cleanability” are exposed. In this study stainless steel was used as a reference surface to be able to compare potential competing materials for the same application. The case study was handling sterilization units for the health care industry, however in this case the result also fits the principle with the kitchen above. (Bergman et al. 2014a) and (Bergman et al. 2014b).

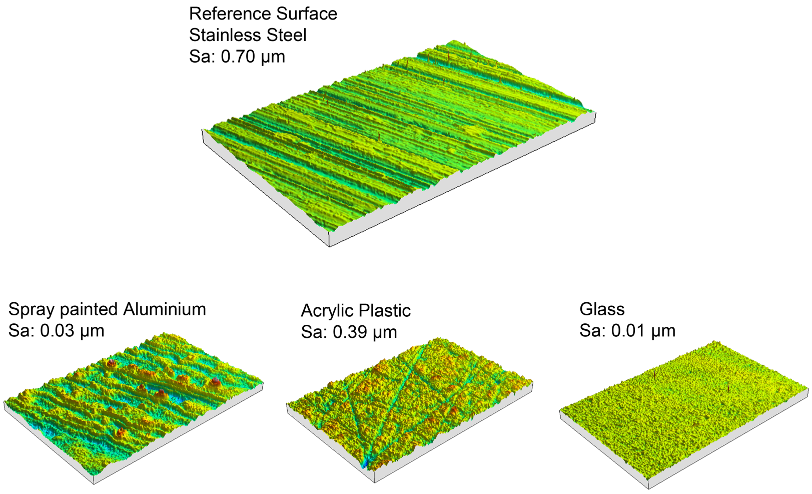

Figure 10, Coherence scanning interferometer measurements of 0.1×0.1 mm areas of three candidate materials for replacing stainless steel (upper left). Areal arithmetic mean height amplitude (the Sa parameter) of the surfaces varies from 10 nm to about 0.7 µm - a factor of 70.

The surface structure supports the product functions in many ways, both emotionally and technically; product brand recognition is one important aspect or e.g. the "cleanability" of a surface could also be important for some products. Different materials and surface textures will give various results in cleanability. A surface with a rough texture is probably more difficult to keep clean than a surface with a smooth texture for instance. In a previous case study this theory was tested through a cleanability test, where different surface roughnesses were evaluated against each other. Artificial blood was used as surface contamination and different solvent as well as wiping materials were used to find the optimal solution for significant cleanability. (Bergman et al. 2014a) and (Bergman et al. 2014b)

Figure 11 illustrates seven examples (among many) of how the surface could look like after one swipe with the wiping material together with a solvent. What were evaluated on the surfaces after the wiping test were *'The Spot', 'The Ring'* and *'The Leftovers'*. Different combinations with various wiping materials and solvent generated different results for the different surface textures. This is one way of evaluating surfaces micro structural properties in a typical usage of an existing product. However, the surface does not only need to appear clean after wiping the surface, it also has to be uncontaminated all the way down in the microstructure. Hence, the surface design in the micro scale is of great interest and importance when it comes to the technical functions. (Bergman et al. 2014a) and (Bergman et al. 2014b)

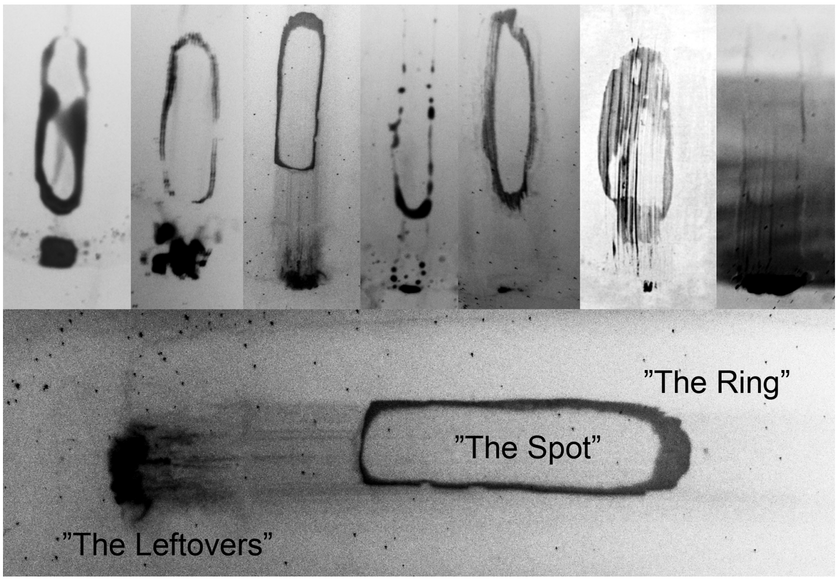

Figure 11, the top picture illustrating examples from the wipe test of surfaces from a case study handling materials for the health care industry. The lower picture is illustrating what elements of the surface contamination were evaluated; *'The Spot'*, *'The Ring'* and *'The Leftovers'*.

Yet, the idea with implementing a new material in the first place, was partly finding more hygienic materials and partly finding materials that could stimulate the stakeholders emotional functions in a wider range then before. The full study could be found in the appended papers in this thesis.

By means of using the surface total appearance as a gate into a development project dealing with product design, finding and defining the product functions could be completed. Especially when dealing with the visual and tactile stimulus in combination with technical functions such as durability and so forth.

As a result of challenging the steel in a kitchen, towards e.g. glass, the design of products in the kitchen will look and function differently. Figure 12 illustrates an example of how the total appearance of a product in a kitchen changes with another focus of the material design.

Figure 12, picture illustrating a ventilation product in a kitchen mainly covered by glass surfaces.

3.6 WHAT IS A FUNCTION?

Talking about product design a function could be considered as something physical, a technical function that is measurable and adjustable. However a function could also be considered as emotional, like a cognitive function. In product design the ultimate solution would be a hybrid function of them both together, the relation between the technical- and the emotional functions.

In this thesis both the technical- and the emotional functions are of great interest, since to be able to control the emotional functions you need to be capable to measure and adjust the technical functions.

Technical functions

In this thesis technical functions are used as a term for the design elements different properties that are measurable, adjustable and possible to control in a process.

Narrowing this down, the technical functions so far are mainly focusing on surface topography, which is measured with “hard metrology” using acknowledged methods and measuring instruments. The typical measurement instruments for surface topography can be divided into two groups; contact- and noncontact measurements. (Flys, 2016)

The *‘Contact Measurements’*-group includes measurements techniques as *‘The Stylus Profiler’* (figure 13)*, ‘Scanning Probe Microscope’* and *‘Atomic Force Microscope’*. (Flys, 2016)

Figure 13, picture illustrating a *'The Stylus Profiler'* in action.

'The Stylus Profiler' is the most common technique which determines the surface characteristics by means of a stylus measurement system. The stylus is moved horizontally across the surface and records different variations in amplitude by means of a so-called transducer, and the signals are converted into height data, figure 14. The stylus tip is usually made of a hard material (e.g. diamond) and has a radius of 0,5-50µm, and because of its hardness it could scratch the surface sample during the measurement. (Bennett and Dancy, 1981), (Bennett and Mattson, 1989), (Bennett et al., 1991) and (Al-Jumaily et al., 1987)

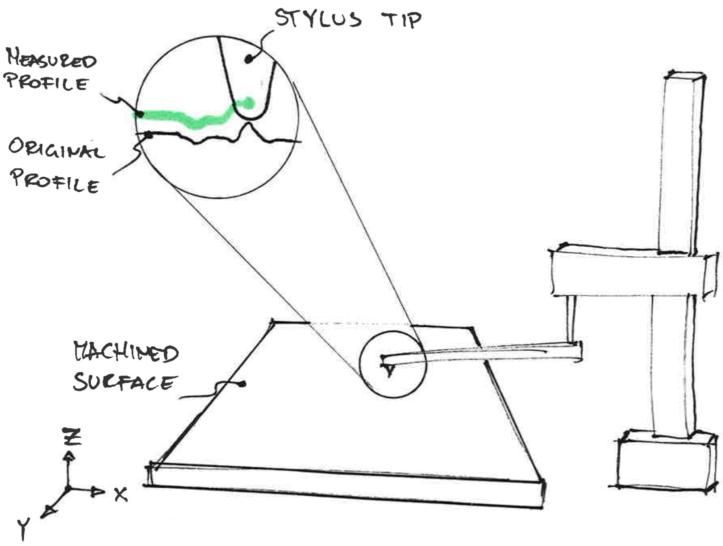

Figure 14, picture illustrating the principle of *'The Stylus Profiler'*.

In the area of contact measurements; *'The Stylus Profiler'* is the one regularly used in this thesis and in the case studies. For further reading and understanding about contact measurements; Mironov, (2004) is showing *'Scanning Probe Microscope'* (SPM) and Flys, (2016) describes *'Atomic Force Microscope'* (AFM) in more detail in her thesis *'Calibration Procedure and Industrial Applications of Coherence Scanning Interferometer'*.

Further, the *'Noncontact Measurements'*-group includes measurements techniques as *'Scanning Electron Microscope', 'Confocal Microscopy', 'Phase shift interferometry', 'Coherence Scanning Interferometry'* and *'White light interferometry'* (figure 15). (Flys, 2016)

Figure 15, picture illustrating a *'White light interferometer'* in action.

'White light interferometry' is a method used for surface height measurement and uses the broadband illumination of a white light source and overcomes some limitations typical in single and even-multiple-wavelength methods. The method is broadly used for measurements of e.g. engineering- and machined surfaces. It is usually limited in the vertical scan axis and constrained by how far the reference mirror can move, however theoretically, the vertical scan axis is unlimited. Figure 16 is illustrating the principle of the *'White light interferometry'*. (Flys, 2016)

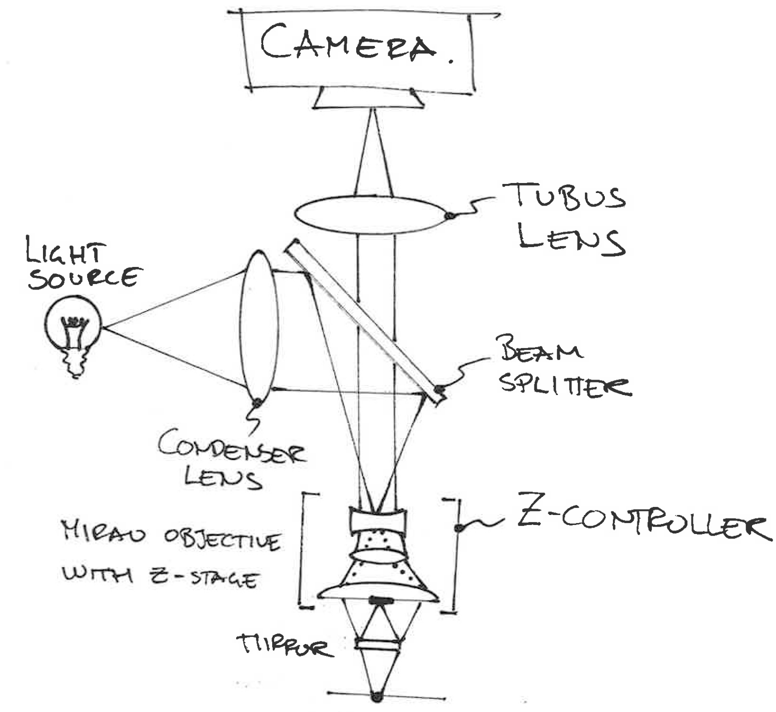

Figure 16, picture illustrating the principle of *'White light interferometer'*.

In the area of noncontact measurements; *'White light interferometry'* is the one mainly used in this thesis and in the case studies. For further reading and understanding about noncontact measurements; Flys, (2016) describes *'Scanning Electron Microscope', 'Confocal Microscopy', 'Phase shift interferometry', 'Coherence Scanning Interferometry'* and *'White light interferometry'* in more detail in her thesis *'Calibration Procedure and Industrial Applications of Coherence Scanning Interferometer'*.

Emotional functions

The emotional functions are used as a term for the interaction between the user and the domain evoking different experiences of the user. It is handling sensorial and psychological issues, conscious and unconscious psychological processes. The emotional functions are measured with "soft metrology" using workshops with focus groups and questionnaires. (Bergman et al. 2015)

Soft Metrology, is defined as "the set of techniques and models that allow the objective quantification of certain properties of perception, in the domain of all five senses" (Pointer, 2003). Soft metrology addresses a broad range of measurement, outside of the traditional field of physical metrology (NPL report):

- Psychometric measurement or perceived feeling (color, taste, odor, touch)
- Qualitative measurements (perceived quality, satisfaction, comfort, usability)

- Econometrics and market research (image, stock exchange quotation), sociometry (audience and opinion)
- Measurements related to the human sciences: biometrics, typology, behavior and intelligence.

Syntactic function

"Form follows function" is a common expression in product development, yet the opinions whether it is true or not could differ depending which profession you ask. However, form (in regard to the design elements) and product function do relate to each other. Now, the syntactic function is basically how the product function is related to the structure and configuration of the visual form, the gestalt. Briefly, it is about how the function of the product and the aesthetics relate to each other. This is product specific, and it cannot be explained as a general model. However, if the aesthetics support the function of the product, the semantic functions of the product are easier to communicate. A collective term for the relationship between the syntactic- and the semantic function is the 'Communicative function', which basically handles the moment of interaction between the user and the product. (Monö, 1997)

3.7 WHAT ARE PRODUCT UNDERSTANDING, IDEAESTHESIA AND PRODUCT SEMANTICS?

Product understanding could basically be described as; the way stakeholders understand a product. Product understanding is directly linked to the gestalt, the design of the product, including form, color, material and surface parameters.

Ideaesthesia could be defined as the phenomenon in which activations of concepts result in an experience. Creating ideaesthesia is a complex task involving both physical metrology and perceptual evaluations. An example of ideaesthesia is the experiment made by the psychologist Wolfgang Köhler in 1929, showing correlation between the visual shape of an object and the speech sound (see figure 5) named the 'bouba/kiki' effect. (Köhler 1929)

The bouba/kiki effect, which later became the lumumba/takete effect, can be explained as a case of ideasthesia (Gómez 2013). In the example in figure 5, the design element of form was possible to correlate to both the sensoric visual and sound experience of the adjective pair takete (hard) and lumumba (soft).

Now, a tool used frequently within the discipline of industrial design and strongly related to ideaestathesia, is 'semantics', the study of meaning and the relation between signifiers, like words and symbols towards products, and what they stand for. Now, design is about making sense of things, and to be able to make sense of products the theories about semantics are essential. Product semantics could be considered as cognitive ergonomics and handles the process of product understanding, the meaning of the product. (Krippendorf, 2006)

Product semantics concerns the relationship between the user and the product as well as the importance that the artifacts have in use and in the social context. Affordance provides strong clues to the operations of things. The product is the sender of information and the user needs significant feedback to succeed in the usage of the product. (Monö, 1997)

There are sub functions in product semantics that are important, the semantic functions;

- DESCRIBE – Facts, its function, mode of action, purpose and handling (practical function and technology).
- EXPRESSION – The nature, characteristics and qualities, for example. Stable, lightweight, compact and sporty.
- INVITE – To the reaction, use caution and accuracy for instance.
- IDENTIFY Type of product, purpose, origin, nature (affinity with the system, family, range, categories, etc.).

An object can be so much more than just a convenient object for the user. There are a lot of parameters that influence the choice; social values, the desire to belong to a certain group, personal experiences and memories, emotional functions and so forth. These factors are sometimes more important than the technical functions. However it is important that the product is designed so the user understands how to use it, good product semantics. (Monö, 1997)

Briefly, product semantics handles the communication between the user and the product; Expression – Impression – Effect

3.8 WHAT IS EXPERIENCE?

The majority of people on earth navigate through life using their impressions, perception and feelings, and the confidence of our intuitive religion and preferences; often with a decent result (Kahneman, D, 2013).

Perceptions involve any or all of the five senses in symbiosis. Understanding the theories of sensation and perception facilitates the process when product developers create new concepts for a predicted user experience. The framework of perceptual product experience (PPE framework) considers perceptual product experience as composed of three core approaches: *the sensorial mode including* perceptions of stimuli experienced with any of the receiver senses; *the cognitive mode*, where we understand, organize, and interpret and make sense of what we perceive; and finally *the affective mode* concerns itself with experiences that are affective: feelings, emotions and mood states, as a result of product perceptions. (Warell 2008) and (Monö 1997)

The PPE model in figure 17 illustrates a framework for product communication between the producer and the consumer, e.g. how product developers intended the product message (the semantics) is expressed as core values, adjectives and converted into measurable design elements with controlled properties (total appearance) creating consumer experience.

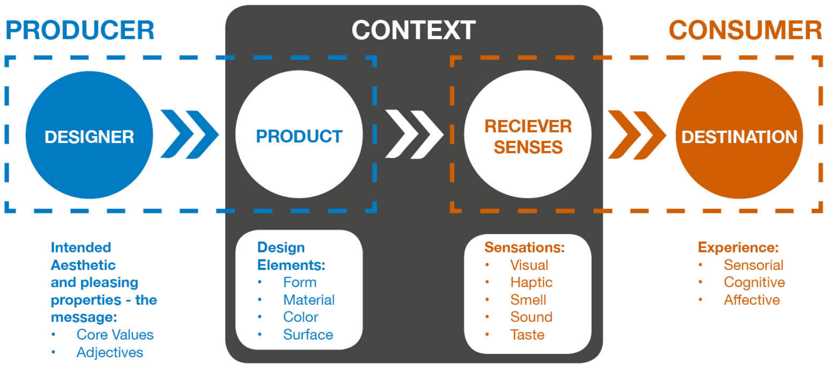

Figure 17, illustrating model for intended product communication linked to the PPE framework. (Rosén et al. 2016)

One could define "experience" as the process of doing and seeing things such as an activity on a vacation, or the fact of having been affected by or gained knowledge through direct observation or participation of some sort. Another could define “experience” as the skill or knowledge that you get by doing something, e.g. the length of time that you have spent on a particular job.

In this thesis “experience” is directly associated with the understanding and the cognitive knowledge, obtaining information from external stimuli.

As mentioned in the beginning of this thesis the fundamental biological system matters for the experience and how one interprets it. However there are more underlying functions that matter for all of the interaction we as users are exposed to in daily life. Figure 18 shows a structure of the human interpreting system, where the general and fundamental interpretation system creates the foundation of the pyramid.

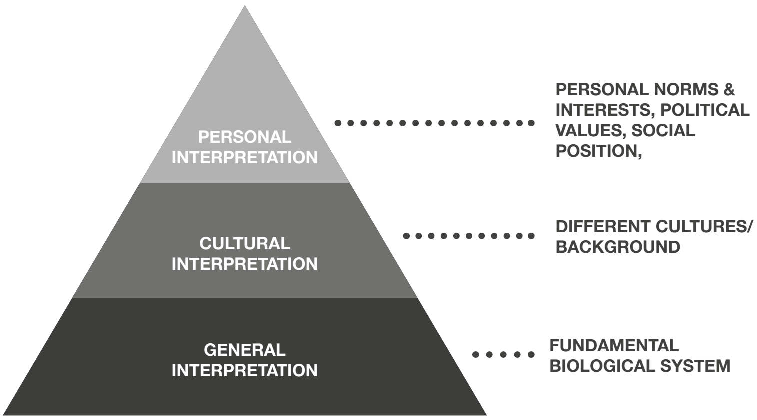

Figure 18, illustration of the interpretation mapping. (Monö, 1997)

General interpretation is controlled by the fundamental biological system, which in turn is controlled by the brain, nerves and hormones, which are responsible for our thoughts, feelings and actions. (Wolfe et al. 2012) However, humans have fundamental needs that could interfere with how we experience new products for the first time. One recognized example of human needs is Abraham Maslow’s theory the ‘hierarchy of needs’. Maslow means that there are five levels of motivation; biological and psychological needs, safety needs, belonging and love needs, esteem needs and self-actualization. (Maslow 1943)

Cultural interpretation could be described in many ways, and in this thesis 'culture' is used as a term for people with different backgrounds in several ways. One way of describing 'culture' could be the fact that we as humans are born and raised at different places on earth in different nations with varying conditions. Another way of describing 'culture' could be the fact that humans are active within different occupations for instance.

Personal norms, political values, social position, interests and so forth mainly affect personal interpretation. It is usually difficult to design products that fulfill the requirements of each of each all the personal interpretation levels for all of the many people, since they are highly subjective. Yet, designing products that match the two first levels (the normal distribution) is both easier and more efficient. However, products that allow a final personal choice, as e.g. various colors or materials, probably stimulate the personal interpretation in a wider range than if it would be excluded. (Bergman et al. 2015)

Sensation and Perception

We interact with our environment, and with objects in a certain context, through our five senses; hence the physical measurements that are most relevant for sensory science are those relating to the parameters that are sensed through our sensory transducers. (Berglund et al. 2012)

In psychology and social science, sensation and perception are stages of processing of the senses in the human systems. Sensation is the function of the low-level biochemical and neurological events that begin with the impinging of a stimulus of the receptor cells of a sensory organ. It is the detection of the elementary properties of a stimulus. Without sensation we will not be able to experience external stimuli. Sensation is the process that allows our brain to take in information via our five senses, which then can be experienced and interpreted by the brain. The five senses are sight, touch, hearing, smell and taste. Perception on the other hand, is the mental process or state that is reflected in statements like "I see a green forest", representing awareness or understanding of the real-world cause of the sensory input. (Wolfe et al. 2012)

In the scenario presented in figure 19, all of the five senses are working together creating an experience. It is an example of how a warm spring day in the park eating ice cream sitting on a warm wooden bench could look like. It might appear to be a pretty general and ordinary scenario, however there are a lot of things that happen in the space of just a minute. Lets divide the scenario into sub situations:

The person is using the sense of touch when leaning against the wooden bench at the same time as he is holding the ice cream with the other hand feeling the wafers shape and the structure with the fingertips. Maybe some of the ice cream is dropping down over the hand creating a short moment of coldness. The visual sense is stimulated by the surrounding nature with different lights and colors, animals running and flying and so forth. The birds are singing songs stimulating the hearing sense as well as the sound of the leaves moving thanks to the wind. The flavors of the ice cream are stimulating the taste and the flowers, nature and the ice cream are stimulating the smell and so forth. The complete interaction is creating the subjective experience of this moment for the person in the scenario. Again, it is a lot of sub situations that provide an experience (positive or negative), and it might not always be what we think. Was it the ice cream or the birds singing that provide the strongest feeling of the summer approaching?

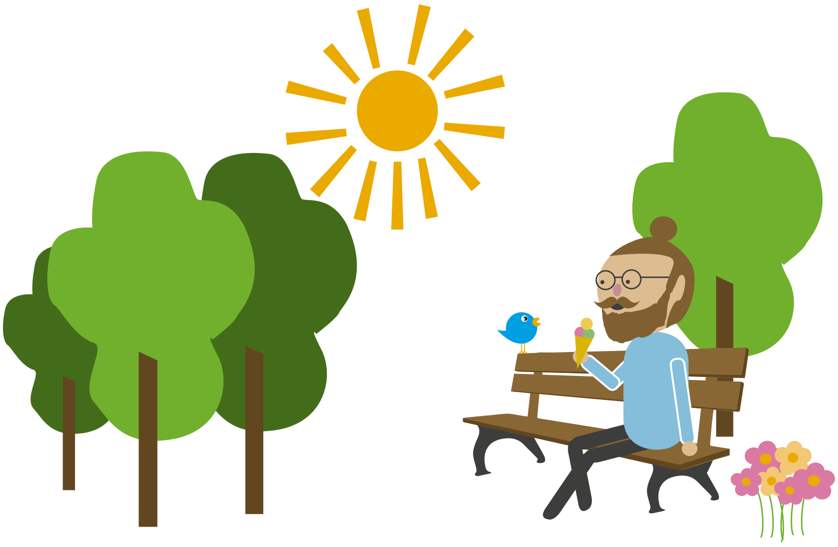

Figure 19, illustration of a scenario example where the five senses are stimulated in different ways.

However, what happens when we as human beings experience different scenarios in life and how does it affect us? Stimuli from the environment are transformed into neural signals, which are then interpreted by the brain, through a process called transduction. Transduction is the physical process of converting stimuli into biological signals that may further influence the internal state of the organism, including the possible production of conscious awareness or perception. (Wolfe et al. 2012) Lets start with our physical features and how we as humans pick up information through our senses.

The visual sense (the system of sight) transfers light energy that occurs naturally by wavelengths into neural messages through our eyes. This process is known as visuoreception. The very fine qualities of the wavelengths (height, width and frequency) are detected by different structures inside our eyes. As a consequence of those differences, we experience different intensities of light, colors, shapes and textures. (Wolfe et al. 2012) and (Berglund et al. 2012)

Our sense of touch is supported by something called mechanoreception. Receptor cells underneath the skin are constructed to sense the slightest amount of force. This helps us humans to perceive the smoothest wind breeze for example. We also have thermo receptor cells underneath the skin, which are constructed to detect temperature, and convert that data into information the brain can use. This helps us humans to perceive the heat in a candle flame within the time of a millisecond, which then triggers a reflex of pulling the hand away for instance. (Wolfe et al. 2012) and (Berglund et al. 2012)

The sense of hearing (the auditory system) works similarly to the visual system; sound is transferred in the atmosphere in the form of wavelengths, e.g. different amplitude – different loudness. Comparable to the wavelength of light the quality of the auditory wavelength will define the quality of sound that is perceived in the brain. The sound wave is entering the ear and once the wavelengths are reaching the middle ear, auditory structures transform the wavelengths to vibrations. The vibrations in turn, are transferred into neural impulses that are sent to the brain, this process is also supported by the mechanoreception. (Wolfe et al. 2012) and (Berglund et al. 2012)

The sense of taste is responsible for transferring information from our mouth to our brain via chemoreception. This procedure is supported by chemical receptors in our tongue, called taste buds. Chemicals in what we eat contain a quantity of different characteristics and qualities, which are picked up by the receptors (taste buds) and transferred as information to our brain. Hence, it is the brain that determines what the food tastes like, not the taste buds. The sense of taste can detect; salty, sweet, bitter, sour and umami. (Wolfe et al. 2012) and (Berglund et al. 2012)

The sense of smell is operating with chemoreception as well. We detect smell via receptor cells that are lying inside of the nasal cavity, which are responsible for transmitting the particular information to our brain. Unlike the sense of taste, which can only detect 5 different tastes, the sense of smell can detect any smell we are exposed to. However the intensity of the odor will determine if we are going to smell it or not. (Wolfe et al. 2012) and (Berglund et al. 2012)

Briefly, the goal of sensation is detection of the signals around us and the goal of perception is to create useful information from the sensation information (information of the surroundings). In other words, sensations are the first stages in the functioning of senses to represent stimuli from the environment, and perception is a higher brain function about interpreting events and objects in the world. (Wolfe et al. 2012)

The combined sensation of a products surface gloss, color, haptic properties like friction, elasticity, hardness and temperature create an intended message to the customer received as stimuli (R) by the human five senses, transformed to psychological sensation (S). Psychological sensation (S) was expressed in *Fechner's law* as

$$S = k \log R \qquad (1)$$

where k is a constant and the sensation S follows a logarithmic function where small differences in stimuli create a larger variation of sensation than for changes of stimuli at higher values. (Fechner 1897)

Later S S Stevens at Harvard developed a similar model - *Stevens' power law* - sensitive to the fact that different types of stimuli follow different curve shapes to psychological sensation:

$$S = aI^b, \qquad (2)$$

where a is a constant, b is a stimulus exponent varying with the type of stimulation (visual, haptic, smell, taste, or audio) and I is the stimulus energy related to stimuli (R), Fechener's law in equation (1) above (Stevens 1957). So to convey a message strong enough to the customer, limits for the lowest detection level of changes in stimuli and the function relating the stimuli to psychological sensation are important to understand. Questions that need to be answered related to surface engineering are *the minimum roughness* of a handle the customer can sense and *the differences of texture roughness* allowing a handle with two textured parts to be perceived as having the same haptic roughness sensation, i.e. defining thresholds for texture sensation and tolerance in relation to customer expectations and satisfaction.

The experience is partly provoked by functions of the aesthetics appealing to our five senses. It could be explained as the human perception of beauty. Philosophers have discussed hidden factors controlling appreciation of beauty since the Ancients. However one way of measuring the appreciation of design parameters linked to the total appearance is by using semantic differential scales, figure 20. A semantic differential scale could be composed of polar opposite adjective pairs separated by a five to seven point rating scale. For example, a customer could rate the attitude to a product by grading adjective pairs (rough to smooth, cold to warm, dark to bright) on seven grade scales. Or it could also be from being not satisfied to satisfy, see example in figure 20. Semantic scales could then be evaluated using e.g. principal component analysis (PCA), to draw general conclusions of attitudes. (Osgood 1943)

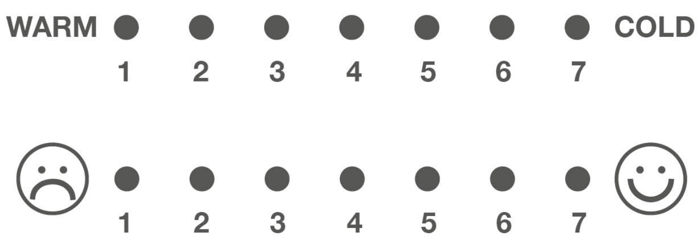

Figure 20, illustration of different types of semantic differential scales.

In addition, one important component affecting the attitude to the products is the stakeholder's need or motivation. If the psychological sensation (S, in equation 1) triggered by the physical stimuli matches the consumer expectation at the present motivation level, the attitude to the product would be considered as positive in regard to the hierarchy of needs mentioned earlier. (Maslow 1943)

4 THE RESULT – THE METHOD

There are many methods dealing with qualities correlated to functions. After Osgood's publications more methodologies, e.g. quality function deployment (QFD) and the Kano model were developed with similar motivation (Akao 1994) and (Kano et al. 1984). Those methods are qualified for dealing with psychological sensation however not as capable when it comes to translating the subjective sensation into design parameters.

Thus, the result of this thesis is the developed research approach that has its roots in the proven development method Kansei Engineering. Professor Mitsou Nagamachi (Hiroshima International University) had a vision about improving products on a more detailed level than before. Hence, he developed the method Kansei Engineering (KE) in the 1970's which has its roots from the Japanese concept of Kansei, ("intuitive mental action of the person who feels some sort of impression from an external stimulus") (Nagamachi and Lokman 2011) and (Lokman 2010). According to Professor Nagamachi the Kansei concept includes; "a feeling about a certain something that likely will improve one's quality of life". KE can also be defined as a customer-oriented approach to product development (Nagamachi 1997), (Nagamachi 2002), (Frisk and Järlskog 2002) and (Hedberg 2004).

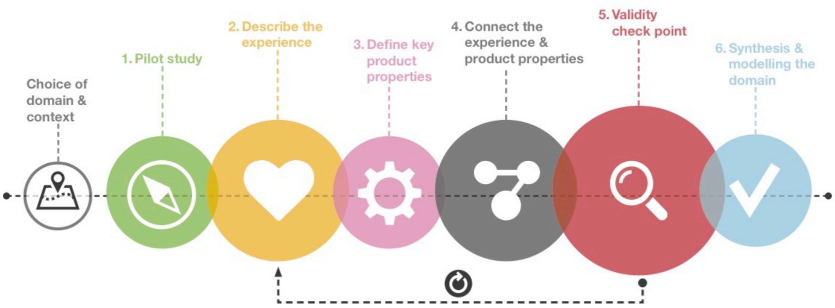

Figure 21, illustration of the developed affective engineering method.

The 6 phases range from the pilot study where the product or service is defined including specification of the product and market, to synthesis and modeling of the result of the given study.

1. Pilot Study – Defining the product domain, market and users.
2. Describing the Experience – Collect adequate adjectives, expected by the user from the domain.
3. Define Key Product Properties (Span the space of properties) – In this phase it is important to find physical product properties that affect the user.
4. Connect the Experience to Product properties.
5. Validity Check point by establishing correlations
6. Synthesis and Modeling the Domain – Design and validation of a "prediction model".

4.1 PILOT STUDY

In the Pilot study there are a lot of questions to be answered and it is crucial to navigate efficiently in the right direction from the beginning in a development project. Product designers in general have got a good internal navigation and relation to the design process, however sometimes the lack of communication in a project could result in endless discussions of WHAT the aim is for WHOM and so forth. D.School at Stanford University also talks about this in their book Bootcamp Bootleg. (Stanford, 2016)

However, to be able to pursue continuous improvements in product development and design in a structured way "The Design Compass" was developed. "The Design Compass" works as an external stimuli tool and guideline in the process of Affective Engineering to facilitate the workflow. By focusing on the primary questions (what, who, why, where, when and how; the compass tool, figure 22) major in the pilot study but also during the design phases (define, explore and refine); deeper levels of observation and a higher level of understanding is obtained by the designers and project participants. This task also allows the team to move from concrete observations to a more abstract emotional state of mind in particular situations. With a wider understanding and the knowledge about these questions as a starting point; it is probably easier to navigate through the design process. IDEO and d. school Bootcamp Bootleg also confirms similar methods.

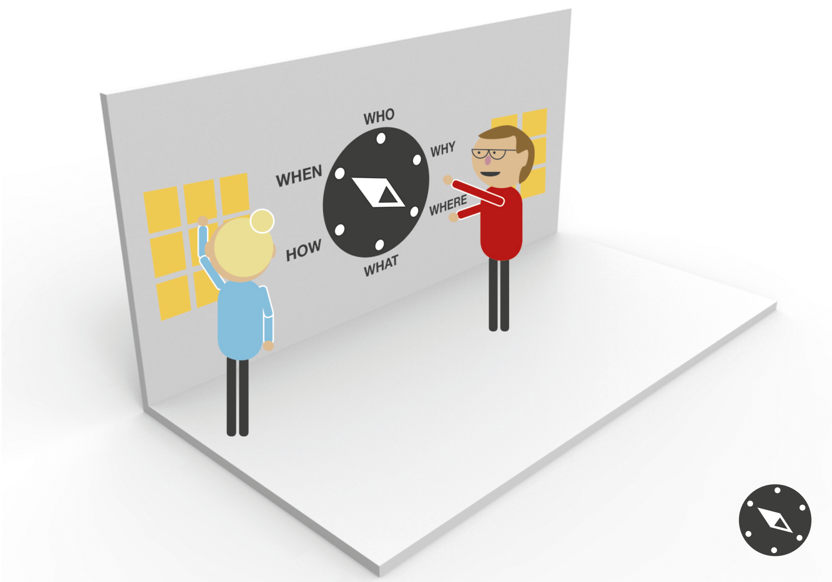

Figure 22, illustration of the workflow with the compass tool.

Further the design compass works as a tool to framing in the stakeholder's needs and expectations of the new product.

4.2 DESCRIBING THE EXPERIENCE

The idea of describing the experience is about framing in the emotional functions, framing the needs of a future solution. Shütte (2013) added to the discussion of needs of the customer the pleasures of motivation by Jordan's four pleasures: *physio* – to do with the body and the senses; *psycho* – to do with the mind and the emotions; *socio* – to do with relationships and status; and *Ideo* – to do with tastes and values. Jordan's four groups complete Maslow's five steps in the hierarchy of needs mentioned earlier. (Jordan 2002)

However, to be able to frame the emotional functions there is a need to scan the semantic space, collect the expressed "feelings" of the product. In this thesis it is about collecting adequate describing words, which the user expresses when interacting with the product. By using describing words it is possible to find appropriate expressions for a product or service, which in itself facilitate the project later on in the design process evaluating the experience. When the project is implemented the selected describing words could be evaluated towards the company´s vision to verify the outcome. (Bergman et al. 2012) and (Bergman et al. 2014a)

To be able to map the experience the result of the previous work (the compass) shall be taken into consideration, hence that result is the foundation of how the user will experience the new product. Different words have different meanings speaking of experience; Takete/Lumumba is a good example of this statement. Therefore, the choice of describing words is crucial, adequate words should be chosen. (Hedberg, 2004)

Figure 23, illustration of the workflow with the word game tool.

The collection of words was from the beginning implemented with post-it notes where words were ideated. Today, the collection phase is optimized to be able to offer a more cost efficient process with a higher significance. The *"Word Game"* was developed to serve as a physical tool for designers to be able to set high quality core values for a product or service in a structural way, and also faster than before. Instead of implementing questionnaires, a focus group is participating in a physical word game where the intensity and the level of ambition usually end up being very high. Figure 23 illustrates a schematic view of the word game implementation. By having different "filters" (figure 24) as e.g. domain, context and culture the amount of collected adjectives are reduced and validated in a structural way. By doing it this way the result becomes more significant than with e.g. post-it notes and the amount of words can be collected faster, which indicates that this phase is more efficient than before. (Bergman et al. 2012)

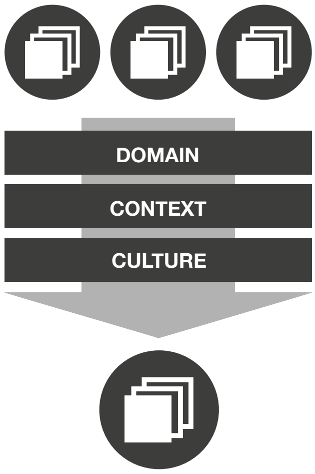

Figure 24, illustration of the different filters that are used implementing the *"Word Game*. (Bergman et al. 2012)

The *"Word Game"* is implemented, and initially, the focus group sort out ambiguous words which do not fit in the domain and context. Preferably, it could be three different groups when this step is implemented; one "yes"-, "maybe"- and "negative"-group. The words that are sorted out obviously do not advance into the next level. Now, the cluster division takes place and the focus group starts with the "yes"-group (followed by the "maybe"-group if necessary). The main purpose with this step is to find synonyms among the describing words, or words that could be directly connected to each other, e.g. the words "Modern" and "Stylish" could be directly connected to each other even though they are not synonyms. The amount of words is reduced during this part of the project. If two or more words are very similar; the most appropriate word shall be used. Focus should be on finding words that are used in the everyday language and that are easy to understand, to avoid any confusion about a certain word. The selected words should be related to the domain and context as well. When this part of the game is implemented there should be about 150 describing words distributed equally in 10 clusters (the amount of words and clusters could vary). The last part of this game is to reduce the amount of words one more time. Instead of erasing ambiguous words, the top five descriptive words shall be selected from each group and form a new group. This reduction results in 50 describing words distributed equally in ten clusters (this amount could vary). (Bergman et al. 2012)

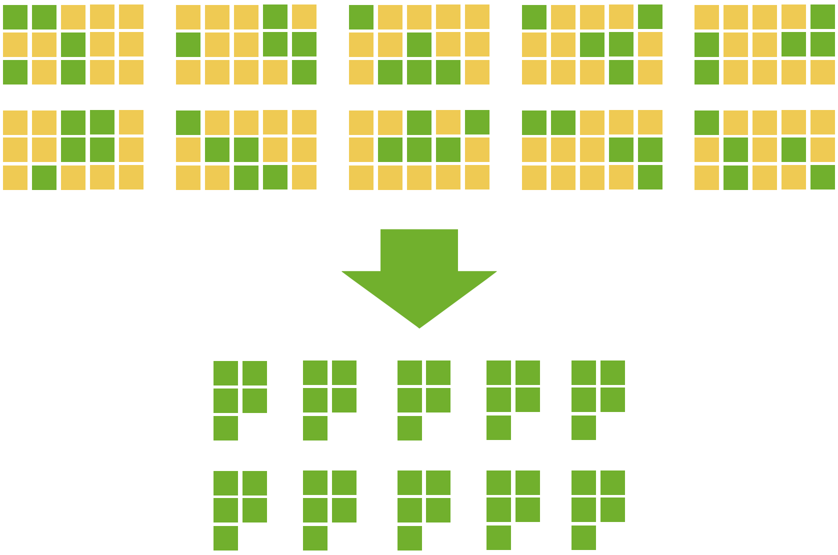

Figure 25, illustration of the word game reduction procedure.

The implementation of the *"Word Game"* results in 50 potential descriptive words towards the domain and context. As the next step, the company should be invited to choose one word from each cluster, which would be considered as the core values for the next generation of products in the context. Wikström, (2002) says that it is of great importance to involve the company in an early stage to be able to correspond to the focus groups result. (Bergman et al. 2012)

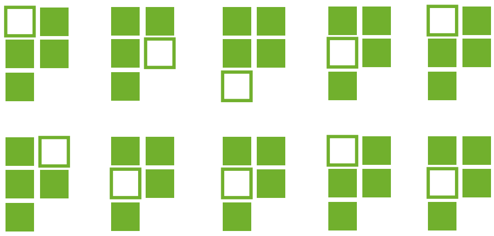

Figure 26, illustration of the word game reduction procedure.

The group of negative words is usually not used in the project although it could be used to e.g. express what a product should not express. To ensure the selected core values match the company's vision about the product they are compared to the first core values from the discussion with the company. It is possible that some of the core values are the same or placed in the same cluster, which is to be considered as good. (Bergman et al. 2012)

Case specific

As an example, figure 27 is illustrating a focus group in the middle of an implementation of the *"Word Game"* for a research project in collaboration with the industry. Focus was the perceived experience of the interaction with sheet metal surfaces for building exterior design. The resulting adjectives that were used in the development process were; organic, dynamic, sleek, elegant, innovative, stylish and robust. The selected adjectives were then analyzed and verified in collaboration with the topical company and the adjectives were used in the following material evaluation process to find materials and surfaces that matches the experience of the total appearance of future facades. (Rosén et al. 2011)

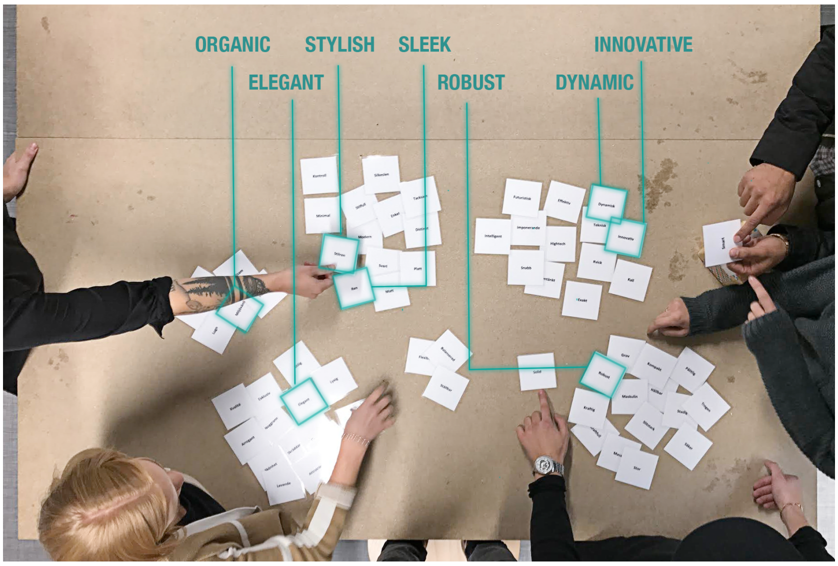

Figure 27, picture illustrating a focus group implementation of the *"Word Game"* in a research development project together with the industry. The words in the upper part of the picture are the selected adjectives for further implementation.

4.3 DEFINE KEY PRODUCT PROPERTIES

When the identification of the product characteristics is made, the main purpose is to generate properties of the existing product that can be controlled and affect the product. These properties can also be called design elements. In product design the primary design elements are form (as geometry/shape), color (as hue, saturation, whiteness and blackness), material (as chemical substance or raw material, isotropic or anisotropic, structure and strength) and surface (as texture, gloss, haze, isotropic or anisotropic), in accordance with ISO25178-2:2012. The design elements are compared later on in the process with the selected describing words (or also known as core values). This is made to systematically obtain specific words that seem to affect the experience (the semantics) of a product. The design elements should be appropriately measurable using standardized methods and parameters like the surface texture field, stratified and feature parameters in accordance with the acknowledged ISO 25178 series of standards. The surface appearance could be described in further detail e.g. polish and structure which facilitates the process when analyzing the surface appearance later on.

Now, the correlations between the experience and feeling (psychological requirements) and the functional requirements (physical requirements) have to be established as well. For instance, the adjectives clean and hygienic, expressing stakeholders psychological demands for a surface in a environment of the medical healthcare, which also are connected to demands on: cleanability, thus related to chemical resistance against stains and cleaning agents; and scratchproofness to resist harmful wear and cleaning effects on the surface (Bergman et al. 2014a) and (Bergman et al. 2014b).

An ASME standard (ASME 2009) connects today's requirements of hygienic surfaces to texture average arithmetic amplitude (Ra) according to ISO 4287:1997 and it is considered sufficiently smooth when the Ra value for a given surface is <0.8 μm (Bergman et al. 2014a) and (Bergman et al. 2014b).

Here the ASME standard defines the surfaces' texture mean amplitude as the design element controlling the feeling and psychological requirements on clean and hygienic. Figure 10 shown earlier in this thesis is an example of four surface variants exhibiting different areal texture average arithmetic amplitudes possessing different levels of cleanability and hygienic properties (Bergman et al. 2014a) and (Bergman et al. 2014b).

However, in this article the design elements will be illustrated as pictograms, illustrated in figure 28.

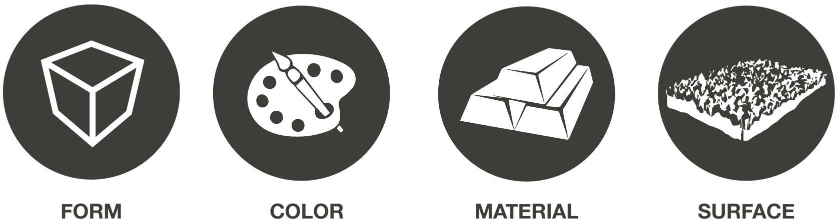

Figure 28, illustration of the design element pictograms.

In the specific field of material design, the surface appearance is of high importance as it has a major impact on functionality both technical and emotional. Hence, from this point, the surface appearance together with the material will be in focus in this thesis.

The reader already knows what a surface really is, hence to the description earlier in this thesis. However, surface appearance is experienced mainly through the senses of sight and touch. In this thesis the visual and the haptic senses have been in focus when analyzing the surface total appearance.

Now the surface appearance is depending on a number of sub design elements itself, which mainly are described as; gloss, haze, roughness and texture (figure 29). Those sub design elements are directly linked to the surface standard ISO 25178, which contains several parameters describing the surface design in the micro and Nano scale.

Figure 29, illustration of surface sub design elements pictogram.

However, to be able to connect the sub design elements parameters to the industry and their process control, the correlation between the sub design elements and the process parameters is also important. Process parameters could be, material temperature, cycle time, processing speed and pressure as a few examples (figure 30).

Figure 30, example illustration of production process pictograms.

When all the technical functions for the design elements and the process elements are set and defined, the connection between the product properties and the experience could be implemented.

Case specific

As an example, figure 31 is illustrating a picture from a project with the automotive industry where a material for interior design was evaluated. The material was chrome plated plastic components and the topical company wanted to evaluate the possibility to find robust measurement- and verification methods for the technical functions for the surface sub design elements; gloss, haze and color temperature of the surfaces. One aim in this research case study was also to find out if there were unknown correlations in-between the parameters that unconsciously affected one another when modifying e.g. the haze in a surface. (Bergman et al. 2016)

Figure 31, picture illustrating the chrome plated plastic component in the interior design for the topical research project. Gloss, haze and color temperature were the sub design elements that were in focus for the surface evaluation.

4.4 CONNECT THE EXPERIENCE TO PRODUCT PROPERTIES

This phase is basically where the users start to interact with the topical product and its domain. If the product properties somehow could connect to the experience the possibility to control the semantic message and the total appearance increases. The ideal would be to perform physical measurement using sensors applied to a subject placed in a test situation and the establishment of useful measurement scales correlating human responses and physical metrology, i.e. combining traditional physical "hard metrology" (geometry-, color-, gloss-, taste-, smell-, noise- and tactile properties) to enable increased understanding of the influence of physical product properties on human responses, see figure 32. Here the human would be considered as a measurement system defining sensitivity, repeatability and reproducibility and comparing the results with the one obtained by methods from traditional "hard" metrology.

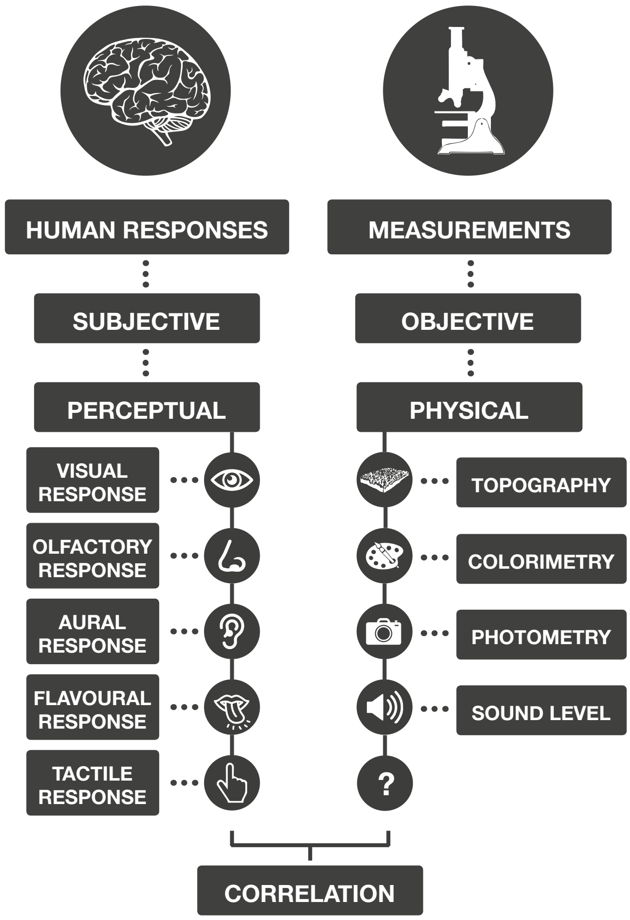

Figure 32, illustration of the soft- and hard metrology theory. (Rosén et al. 2016)

Measurements with people involve human perception and interpretation for measuring complex holistic quantities and qualities, which are perceived or generated by the human brain and mind. This is obviously important to take into account when using focus groups. (Berglund et al. 2012)

However, by using qualitative studies on focus groups or statistical methods like multi variation analysis a connection in-between human responses and physical measurements is possible. The first step is to create a focus group within the actual context or create a real-world environment. If the context for some reason is inaccessible and it is difficult to achieve a good replica of it, then the tests should be implemented in an environment with as little external stimuli as possible. There are other theories about the implementation of a focus group as well, such as the physical environment design (e.g. the size of the room) and also the distance in-between the participants. (Wibeck 2010)

Now, our motivation for and how we perceive a product are strongly linked to the customer´s buy judgement. In product development the methodology nearly always aims at creating this motivation and pleasurable product experience including meaning and message for the stakeholder. (Monö 1997), (Krippendorf 2006) and (Vihma 1995)

A key factor to be able to control the correlation between surfaces appearance with the other design element was the development of a robust tool where the design elements are evaluated and verified. In the research work a tool like that was created to facilitate the implementation, that tool is called *The Affective Engineering Equalizer* (EQ), figure 33. (Bergman et al. 2012)

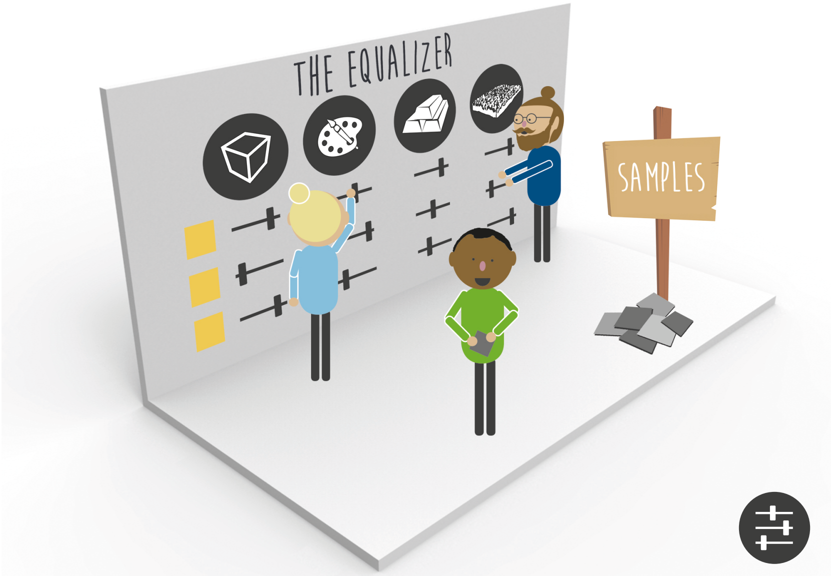

Figure 33, illustration of the workflow of equalizer tool.

The EQ is basically an improved tailor made evaluation tool for designers. The EQ is a dynamic tool owing to the possibility to evaluate design elements as e.g. the form, material, color and surface towards a number of core values in the same questionnaire. By implementing the evaluation this way correlations between the design elements are obtained as well. Does the positive influence of an "Aerodynamic" FORM change if the SURFACE appearance changes for instance? By receiving this specific information about a certain product or service facilitates the development process later on as well as serving as a reference when discussing the product or service with the company for example. Osgood (1943) means that Semantic differential scales work as a tool for evaluation of adjectives, and this is also the basis of the *The Affective Engineering Equalizer*.

Case Specific

In one of the research cases where stainless steel was challenged, the main topical materials for evaluation were glass, spray painted aluminium and acrylic plastics. The focus group got in contact with the challenging materials and the material evaluation the very first time in a typical environment at the sterilization department at Halmstad hospital. The main topical adjectives for analyzing and evaluating the materials were; *robust, warm, sleek, elegant,* *resistant,* and *clean*. Figure 34 illustrating how an implementation could look like in a typical health care environment. (Bergman et al. 2014a)

Figure 34, a picture illustrating a focus group in the middle of the implementation of a material evaluation of material and surfaces for the health care environment. (Bergman et al. 2014a)

4.5 VALIDITY CHECKPOINT

When the connection phase is implemented and the data collection of the interaction is established, the correlation between the technical- and the emotional functions are of great interest in regard to the surface appearance. The validity checkpoint is important, due to the information it could reveal about the properties of the domain. The main idea with the validity checkpoint is to find the underlying data and relationships between the properties and the experience, which affect the total appearance of the product. If those properties are located it will be a lot easier to control the total appearance of the product in the development process. (Bergman et al. 2016)

Now, with the knowledge of how the senses of touch and sight respond for the surface properties and further, which parameters from the ISO-standard affect the surface properties; the surface appearance can be controlled. However, when we say control, we refer to the industry process control, hence it is usually the industry manufacturing the pieces. Therefore, the surface properties should also be correlated to relevant process parameters. (Bergman et al. 2016)

In the affective surface engineering method, a connection between Kansei words and surface texture parameters describing the micro- and Nano topography is made. In a study handling wall panels for hot bath sauna interiors (Rosén et al. 2011), three test panels of 10 people with experience from general product development, specific sauna product development and general sauna bathing, graded the 11 surface textures on a seven grade scale against the eight emotional Kansei words and three design element-related surface areal texture property parameters from the ISO 25178-2:2006. (Rosén et al. 2011)

The Sq, Str and Sdq parameters (texture average amplitude, texture ratio and texture slope) had a significant correlation with the Kansei words beautiful, stylish, and attractive. In this case the soft metrology adjectives are proven to correlate to 'hard' metrology measurable surface texture parameters, i.e. the example validates the principle that Kansei adjectives can be linked to ISO standardized measurable parameters, thus defining geometrical features controllable by manufacturing engineering and possibly to use to specify product requirements. (Rosén et al. 2011) Briefly; with the knowledge of how the tactile and the visual senses respond for the surface properties and further, which parameters from the ISO-standard affect the surface properties; the surface design can be controlled within a manufacturing process, figure 35.

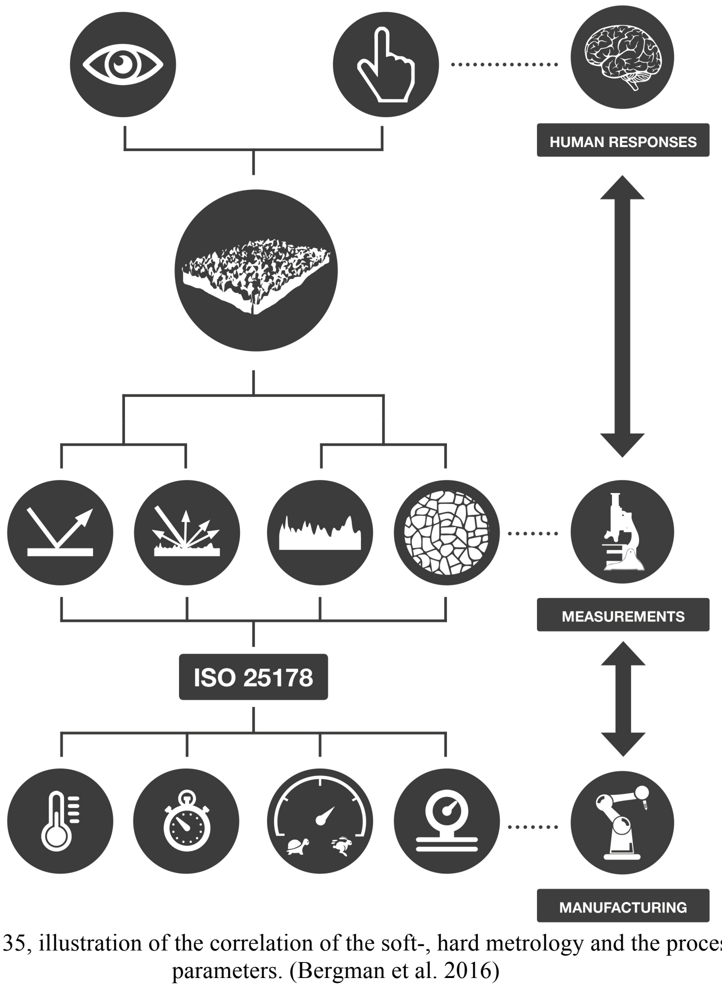

Figure 35, illustration of the correlation of the soft-, hard metrology and the process parameters. (Bergman et al. 2016)

Case Specific

In the case; Affective Surface Engineering for Total Appearance - *Soft Metrology for Chrome Surfaces in Car Interior Design* 2016 by (Bergman et al. 2016), the links and correlations in-between the total appearance and the process window was the main task. It is a good example of when the industry could use the developed method to achieve robust repeatability in a process for higher perceived quality in regard to total appearance in a product. The main result from this study was the established link in-between the process parameters and the perceived quality of the topical product, figure 36. It is important that the material and surface choice by an e.g. color and trim department is taken for real. The intended message will change if the manufacturing process is not optimized. The topical company´s sub supplier needs to know what parameters affecting the surface and the material negatively, and by that also know how to implement a robust manufacturing process. Hence, this step is not to question the designer's choice of materials, but ensure that his intended message is possible to verify and control for repeatability. So, by framing in what correlations gloss, haze and color temperature of chrome plated plastic components had to each other, it was possible to establish links in-between the total appearance and key product properties. (Bergman et al. 2016)

Figure 36, picture showing the aim and the ideal relationship between process control a material and surface design in regard to total appearance. (Bergman et al. 2016)

4.6 SYNTHESIS AND MODELING THE DOMAIN

The final step in the process is to create a model that combines and describes the results in the previous steps. Hence, to assemble the entire project in such a model a link between the technical functions and the emotional functions has to be established. Which means that; this step does not look the same each time; it is all depending on the project structure and its objectives. To create an approach that links the technical functions and emotional functions in general is nearly impossible, hence the Affective Engineering approach can be applied in many different contexts and projects. Therefore, tailor-made relationships are developed for the topical project.

In a previous project with a sauna manufacturer, a design manual was made on request of the company. The design manual basically linked surface geometrical properties (the significant design elements and properties) to the adjectives (core values). In practice this resulted in designer rules collected in a physical booklet for the context of sauna wall panels, establishing that:

- A low average roughness (Sa) and low surface slope (Sdq) increase the stylish and attractive emotions of a sauna wall texture,

- The same surface combinations together with increased texture anisotropy, e.g. a directional pattern, will also affect the beautifulness of the surface.

This fulfills the need for a product development tool for the sauna company to facilitate the material and surface design of their products connecting to the needs and expectations of the stakeholder. (Rosén et al. 2016)

In several cases it is a need to quantitatively formulate models describing the relation between design elements and the desired soft metrology as a complement to the design manuals with qualitative designer rules. In a previous study by (Bergman et al. 2015) and (Rosén et al. 2013) about the haptic appearance of tissue paper, a complex model was created using eight constants (A–H), three material properties (layer type (DL), stiffness, elasticity (stretch)) and four areal ISO 25178 surface texture properties (peak material volume (Vmp), core height (Sk), maximum height (amplitude, Sz), autocorrelation length (repeating wave length, Sal)). (Rosén et al. 2016)

$$\begin{aligned}&\textit{'perceived haptic roughness'}=A-B*DL\\&+C*Vmp+D*Sal+E*Sk\\&+F*stiffness-G*stretch-H*Sz\end{aligned}$$

In the equation above, the product design properties DL, Sz, and stretch have a negative regression coefficient sign (-), showing that an increase in the parameter value results in a decrease in perceived haptic roughness. The coefficients for Vmp, Sk and Sal were positive (+), hence positively correlated with increased (improved) perceived haptic roughness, i.e. increased texture peak material volume, core height, autocorrelation length and decreased maximum texture height improve the stakeholder's haptic perception of tissue products within the context of the performed study. (Rosén et al. 2016)

The designer rules and the equation above are examples where affective engineering and soft metrology results are synthesized into tools able to predict customer perception and aspects of total experience supporting organizations' possibilities to maintain customer focus and competitive improvements. (Rosén et al. 2016)

5 RESEARCH CONCLUSIONS

The concluding chapter is divided into a number of subheads; firstly a discussion about the research result and the synthesis, secondly about the novelty and value of the research result and last the outlook for future work.

5.1 DISCUSSIONS

Now, I would like to start this discussion by focusing on the research question and also the needs presented in the beginning in the thesis, yet also the objectives.

First of all, the research question;

"Is it possible to measure, verify and modify total appearance?"

The answer is; yes.

Now about the needs; In regard to different approaches within design it is clear that we need a holistic approach to be able to cover the variety of different focus in development projects. Diversity in a project group with different approaches is usually needed, however it is of great interest and importance to obtain and take advantage of the variety of professions in an effective way to have a novel and robust development process.

A product's technical functions need to be developed and optimized to fulfill the users expectations about the product, yet also to support the total appearance. When talking about total appearance we mainly refer to the experience of the aesthetics of the product. The total appearance is necessary to be able to control; hence products have got requirements regarding the emotional functions as well as the technical functions, they are both playing a central role in the experience of the product.

In this thesis the material/surface properties influence on the total appearance and the experience has been in focus, and in regard to the result it is obvious that the surface design matters. The awareness that a manufactured piece from the industry could be experienced differently depending on the surface quality needs to be handled in a professional way, and not neglected. Even the slightest difference in surface appearance on a plastic piece in a car interior for instance, could result in a negative experience for the user. The technical functions are directly correlated and affecting the sensorial and perceptual system and with that also the emotional functions. However different properties of the surface design correlate with different parameters of the appearance, this need to be handled highly accurately as the sensorial systems are extremely sensitive. This means that if the sensorial system picks up signals that could interfere with the original message of the product, the cognitive message could fail and the experience of the product becomes negative.

Now, the synthesis of this matter is basically; by understanding the user and the needs of the emotional functions, the technical functions can be optimized, figure 37. So if we are able to adjust the critical parameters affecting the emotional functions, we basically could control a products total appearance.

Now, there is a major difference in controlling the total appearance of the product in comparison to measuring the experience of the same product. We will most likely not be able to 'control' the experience as it is highly subjective. However we will be able to influence the experience of the product on the other hand, by knowing how to control the total appearance. Briefly, by improving the conditions of the products interaction with the user, the experience will be affected.

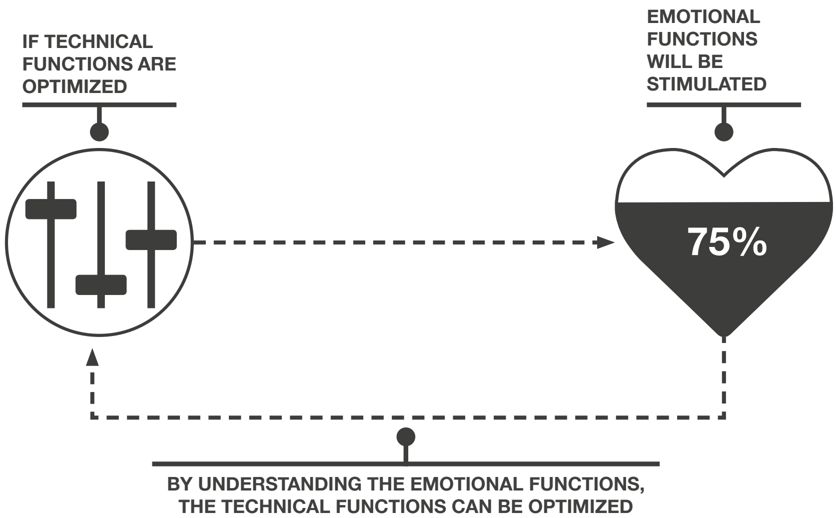

Figure 37, illustration of the synthesis loop in regard to the technical- and the emotional functions.

Now, how should designers (industrial-, product- and engineering design) adapt to this fact, and how could they cooperate with each other but also with the process technician at the industry floor manufacturing those pieces? What do the different professions need to succeed in the translation of their properties of interest into something usable for a successful manufacturing process while maintaining the total appearance?

Well, first of all we as designers need to slightly tone down our pride within our topic and accept that our approaches are different and that our focuses will differ as well. We should use each other's differences effectively by converting soft metrology to hard metrology and vice versa. This could be achieved through a method 'forcing' the participant's to implement 'design thinking' and 'design doing' outside of their comfort zone.

Secondly it is crucial to know about the links between the soft metrology, hard metrology and the manufacturing processes. If everybody of concern in a process could agree that various processing on a manufactured plastic piece for instance, could change the surface design parameters (and by that also the total appearance); we could effectively approach those various links. Now, one phase of the method handles the optimization of surface parameters from the ISO 25178 towards surface appearance, which admits that the link between surface design and process control is established. The big question now is rather about repeatability and how to verify the total appearance in something like an; ‘in line control station’.

Now, the developed method for ‘affective surface design’ is working as intended, yet the content and the implementation will always be project specific and will end up in unique results. The structure of the method obliges the awareness of both technical- and emotional functions, however also how to approach the implementation of combining it in an effective way.

5.2 NOVELTY AND VALUE OF RESEARCH RESULTS

The discussion about novelty and the value of the research is partly depending on time and trends in the topical research field. The evaluation should, in regard to time and trends, be seen as a continuous, ongoing process during the course of research and the future work. Implementing research without regularly reflecting on significance, novelty and value for the stakeholders would be navigating blindfolded. Questions as; “Where did I start my research, what is my current position, in which direction am I heading, and what obstacles will I face?” are important to be able to evaluate if the research is (or not is) novel and valuable.

One of the main objectives was to “create a model for designing and analyzing materials and surfaces in regard to emotional- and technical functions”. Since there were no acknowledged methods or models presented in that area before and parts of the industry had expressed a need for framing in experiences, I wanted to develop a method and framework in this topical area.

Now, the results that are carried out through the research so far are implemented with that objective, the developed method, which is based on a method (Kansei Engineering) that has been proven as an acknowledged approach. There are a minority of researchers and companies worldwide that continuously works with Kansei Engineering in the field of product development as a leading strategy, and even less who developed it further for a topical research field. With that in mind the research work and the developed method presented in this thesis could be considered as novel to the market. The developed method could, in regard to the discussion above, also be considered as valuable in future development projects because it enhances a new way of approaching an addressed issue.

5.3 OUTLOOK

So far the research result, the developed method, is based on the results from the case studies in collaboration with the industry. However the final step is to make the method independent of me as an expert in the implementation. The aim is to introduce the method in a workflow introduction, so the company later on can prosecute the implementation on their own towards their internal objectives. This is not yet possible, hence the final step, *‘Synthesis and modeling the domain’*, is not fully developed to cover a general model. This means that the final step needs to be implemented and tested in future work to be able to be optimized. Preferably, this should be done through a number of case studies where the topical company receives a package solution in the end of the project, with the aim to operate iteratively.

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