ATTITUDES TOWARDS 3D SURFACE TEXTURE SAMPLES DERIVED FROM CONSUMER ELECTRONICS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

İSMAİL YAVUZ PAKSOY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
INDUSTRIAL DESIGN

FEBRUARY 2016

Approval of the thesis:

ATTITUDES TOWARDS 3D SURFACE TEXTURE SAMPLES DERIVED FROM CONSUMER ELECTRONICS

submitted by **İSMAİL YAVUZ PAKSOY** in partial fulfilment of the requirements for the degree of **Master of Science in Industrial Design Department, Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver ______________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Gülay Hasdoğan ______________________
Head of Department, **Industrial Design**

Assist. Prof. Dr. Naz A.G.Z. Börekçi ______________________
Supervisor, **Department of Industrial Design, METU**

Examining Committee Members:

Prof. Dr. Gülay Hasdoğan ______________________
Department of Industrial Design, METU

Assist. Prof. Dr. Naz A.G.Z. Börekçi ______________________
Department of Industrial Design, METU

Assoc. Prof. Dr. Çağla Doğan ______________________
Department of Industrial Design, METU

Assist. Prof. Dr. Aykut Coşkun ______________________
Department of Media and Visual Arts, Koç University

Assist. Prof. Dr. Armağan Kuru ______________________
Department of Industrial Design, TOBB ETU

Date: February 5, 2016

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : İsmail Yavuz Paksoy

Signature :

ABSTRACT

ATTITUDES TOWARDS 3D SURFACE TEXTURE SAMPLES DERIVED FROM CONSUMER ELECTRONICS

Paksoy, İsmail Yavuz
M.Sc., Department of Industrial Design
Supervisor: Assist. Prof. Dr. Naz A.G.Z. Börekçi

February 2016, 137 pages

Inspired by current movements within product design, materials science, production and rapid prototyping technologies, this research explores 3D surface texturization for functional and hedonic product improvement. Developments in Rapid Prototyping and Additive Manufacturing technologies have made the exploration of 3D textures much easier. Designers can now benefit from 3D surface textures on products much more freely in their designs. A research is conducted to determine both the types of 3D surface textures used in current consumer products and what are the usage purposes of these qualities. The research was composed of three studies. The first study involves a survey of textures used on electrical consumer products, which are then classified and analyzed. Based on this analysis, nine types of textures were identified. In the second study, both CAD and Additive Manufacturing tools were explored for 3D surface texture generation capabilities. As a result, nine surface texture were manufactured to be utilized in Study 3. In the third study, these surface texture samples were explored with the Repertory Grid Technique among 30 participants for their both visual and tactual qualities. As a result, 300 elicited attitudes were gathered which were then processed into 17 personal constructs. The thesis finally discusses the implications of these constructs for 3D surface textures.

Keywords: 3D surface textures, computer aided design, additive manufacturing, repertory grid technique, personal constructs.

ÖZ

TÜKETİCİ ELEKTRONİĞİ ÜRÜNLERİNDEN DERLENEN 3-BOYUTLU YÜZEY DOKU ÖRNEKLERİNE KARŞI TUTUMLARIN İNCELENMESİ

Paksoy, İsmail Yavuz
Yüksek Lisans, Endüstri Ürünleri Tasarımı Bölümü
Tez Yöneticisi: Yrd. Doç. Dr. Naz A. G. Z. Börekçi

Şubat 2016, 137 sayfa

Ürün tasarımında, malzeme bilimlerinde, ve üretim ile hızlı prototipleme alanlarındaki gelişmelerin ışığında, bu çalışma 3-boyutlu yüzey dokularının ürün tasarımına olabilecek işlevsel ve işlev ötesi yönlerini incelemektedir Hızlı prototipleme ve eklemeli üretim alanlarındaki gelişmeler 3-boyutlu yüzey dokularının incelenmesini daha kolay kılmıştır. Ürün tasarımcıları artık tasarımlarında 3-boyutlu yüzey dokularını bir tasarım unsuru olarak kullanabilmektedirler. 3-bouytlu yüzey dokularının tüketici ürünlerindeki kullanım amaçlarını nitelikleri üzerinden inceleyen bir araştırma yürütülmüştür. Araştırma 3 çalışmadan oluşmuştur. İlk çalışma, tüketici elektroniği ürünleri üzerinde bulunan 3-boyutlu yüzey dokularını derleyerek analiz etmiş ve sınıflandırmıştır. Bu analize dayanılarak dokuz yüzey dokusu tipi belirlenmiştir. İkinci çalışmada, hem bilgisayar destekli tasarım teknolojileri, hem de eklemeli üretim yöntemleri, 3-boyutlu yüzey dokusu oluşturma yetileri açısından incelenmiştir. Bunun sonucunda belirlenen dokuz yüzey dokusu üretilmiştir. Üretilen örnek yüzey dokuları, üçüncü çalışmada repertuar çizelgesi teknii kullanılarak 30 katılımcı tarafından görsel ve dokunsal nitelikler açılarından değerlendirilmiştir. Sonuç olarak 300 adet tavır derlenmiştir. Bunlar analize tabi tutularak 17 kişisel kurguya dönüştürülmüştür. Tez 17 kişisel kurgu üzerinden örnek dokuların değerlendirmesini ve bu çalışmasnın çıkarımlarını içermektedir

Anahtar Sözcükler: 3-boyutlu yüzey dokuları, bilgisayar destekli tasarım, eklemeli üretim, repertuar çizelgesi tekniği, kişisel kurgu.

Ad Astra Per Aspera

To the stars through difficulties

ACKNOWLEDGEMENTS

First and the foremost, I would like to express my sincere gratitude to my thesis supervisor Assist. Prof. Dr. Naz Börekçi for her patience, understanding, useful comments, remarks, support, attention and motivation. This thesis would not have been possible without her guidance. It was wonderful to have the chance to work with her.

I am also thankful to my initial supervisor Assoc. Prof. Dr. Bahar Şener-Pedgley for introducing me to this topic with the BAP-02-03-2014-001 coded scientific research project. I am grateful for her valuable contributions and feedback. The structure of the literature review for this thesis was prepared under her supervision.

I would like to express my gratitude to each of my jury members, Prof. Dr. Gülay Hasdoğan, Assoc. Prof. Dr. Çağla Doğan, Assist. Prof. Dr. Armağan Kuru, Assist Prof. Dr. Aykut Coşkun for their valuable criticisms and feedback.

I am blessed with my best friends Ümit Bayırlı, Itır Güngör Boncukçu, and Mehmet Erdi Özgürlük and their support in me. I would like to show my indebtedness for their rare friendship.

I would also like to thank all the participants involved in the surveys for allocating their valuable time to participate to the study.

I would like to thank to my family for their endless love and support.

Finally, I am truly grateful to my dearest friend Günsu Merin Abbas for her warm support, motivation and contribution in every step of this process. She was always ready and next to me anytime I needed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AM : Additive Manufacturing

CAD : Computer Aided Design/Computer Aided Drawing

CAM : Computer Aided Manufacturing

CNC : Computer Numerical Control

FDM : Fused Deposit Modelling

METU : Middle East Technical University

PCP : Personal Construct Psychology

RGT : Repertory Grid Technique

RP : Rapid Prototyping

STL : Stereolithography

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation of the Study

Product design process relates many aesthetic dimensions of a product being designed, including colors, shapes, 3D forms, materials, and of course, surface features. Those properties not only define how a product looks but also they determine how it is going to be produced, and how users will experience the products with their multimodal perception systems. Surface feature of a product, which is a very important parameter, influences products in both instrumental and affective ways. In addition, surface textures can differentiate a product from among other equivalent products in the consumer market by the use of pleasure giving features. As a result, surface features are one of the crucial properties of a product in the discipline of product design, which designers should explore, develop and utilize.

Even though surface features have crucial impact on a product, surface textures have been little investigated by researchers in the field of industrial design, as the literature review has shown, unlike the rest of the aesthetic features. The reason behind the lacking of such research might depend on the limited capabilities of conventional manufacturing technologies. However, the use of 3D surface textures in actual products in the markets observed often, as a research subject, 3D surface textures must be exploited deeply.

3D surface texturization is one of the sophisticated form creation opportunities provided by additive manufacturing technologies. When combined with CAD modeling techniques, additive manufacturing gives designers the ability to create organic and complex objects. Nevertheless, 3D surface texturization in product design has not been a topic that is explored deeply and sufficiently. It is actually neglected. However, 3D surface texturization may play a key role in functional and hedonic improvements of consumer products.

There are several reasons why 3D surface textures have not been explored deeply in current products. Among the reasons are hygiene, durability and limitations of conventional production methods. When it comes to hygiene, textured surfaces may catch more dirt than clean/non-textured surfaces. As for durability, textured surfaces may be less durable and prone to fraction more than the ones that are not textured.

There may be kinds of 3D surface textures that are not possible to produce with conventional manufacturing technologies, but can be produced with additive manufacturing technologies. This thesis investigates 3D surface textures used on consumer products from the perspective of their inherent qualities and how additive manufacturing technologies can contribute to their development.

1.2 Aim of the Study

This study aims to explore 3D surface textures on products, particularly consumer electronics, in order to understand the ways in which they are used, and their qualities that elicit a variety of attitudes in users. It is seen that, 3-D surface textures are used on such products for both their functional (e.g. better gripping, indicating contact region on the product) and their hedonic (e.g. visual or tactile pleasure, utility beyond function) qualities.

By employing additive manufacturing (AM) technologies, digital tools (CAD systems) that form surface textures will also be explored to constitute better design practices for creating geometries of these surface features. It is also important to understand how users respond to various types of surface textures. Therefore, a study will be conducted to elicit user attitudes.

1.3 Research Questions

The thesis tries to find answers to the questions below.

3D surface textures

- How can the definition of 3D surface texture can be elaborated within the context of product design?
- For what purposes and how have 3D surface textures been used on consumer products?
- How can these textures be categorized in Consumer Electronics Products in terms of their resemblance relations?
- How can 3D surface textures be parameterized in terms of their physical characteristics?

3D surface texture generation and manufacturing tools

- What are the techniques used on CAD software to generate 3D surface texture samples?
- What are the capabilities of currently available digital tools (hardware/software) for creating 3D texturing?

Evaluation of 3D surface textures

- How do users evaluate various types of surface textures?
- What are the implications of these evaluations in terms of consumer electronics products?

1.4 Definition of Terms

In this thesis the terms below will be frequently mentioned:

3D surface textures: It is defined as a set of geometric features made in three dimensions on the surface of an object (Jee & Sachs, 2000). 3D surface texture is not a feature that is inherited from the material quality or coating process. It is purposefully designed and placed on the surface of a product for a particular reason.

Additive Manufacturing (AM): In this thesis, the term additive manufacturing used to mention the manufacturing of an object by adding materials on successive layers, which works in the way of rapid prototyping machines by employing CAD based rapid prototyping systems. The term is not only used for rapid prototyping aims but also for manufacturing finished parts or products for end use, which will take place on the shelves of the markets.

1.5 Structure of the Thesis

The thesis is composed of six chapters. Following Chapter 1 Introduction, Chapter 2 provides a review of the literature covering the topics of 3D surface textures. A proper definition is set as a basis of the research. Properties of textures, senses towards 3D surface textures and discussion of examples within the findings on literature. Additive Manufacturing is also introduced in this chapter. Figure 1.1 represents the diagrammatic representation of the thesis structure.

Following Chapter 2, Chapter 3 introduces the survey of 3D surface textures found on consumer electronics products. It describes the methodology, analysis procedures and outcomes of the survey. As an outcome, nine types 3D surface textures were identified and handed over to be manufactured in Study 2 which is described in Chapter 4.

Chapter 4 describes the second Study of this thesis where tools and methods to create 3D surface textures were explored. 3D surface texture generation tools are utilized to create digital versions of identified 3D surface textures in the previous study. These sample textures were then manufactured using the MakerBot Replicator 5th Generation 3D printer to be utilized in Study 3 described in Chapter 5.

Chapter 5 includes the surveying of previously manufactured 3D surface texture samples using the Repertory Grid Technique (RGT). RGT is explained as a method, and utilized to find out elicited attitudes of participants towards sample 3D surface textures. The chapter describes the methodology and the outcomes. The findings are presented.

Chapter 6 is the Conclusion chapter, where the findings and their implications are discussed, and the research questions for this thesis are answered.

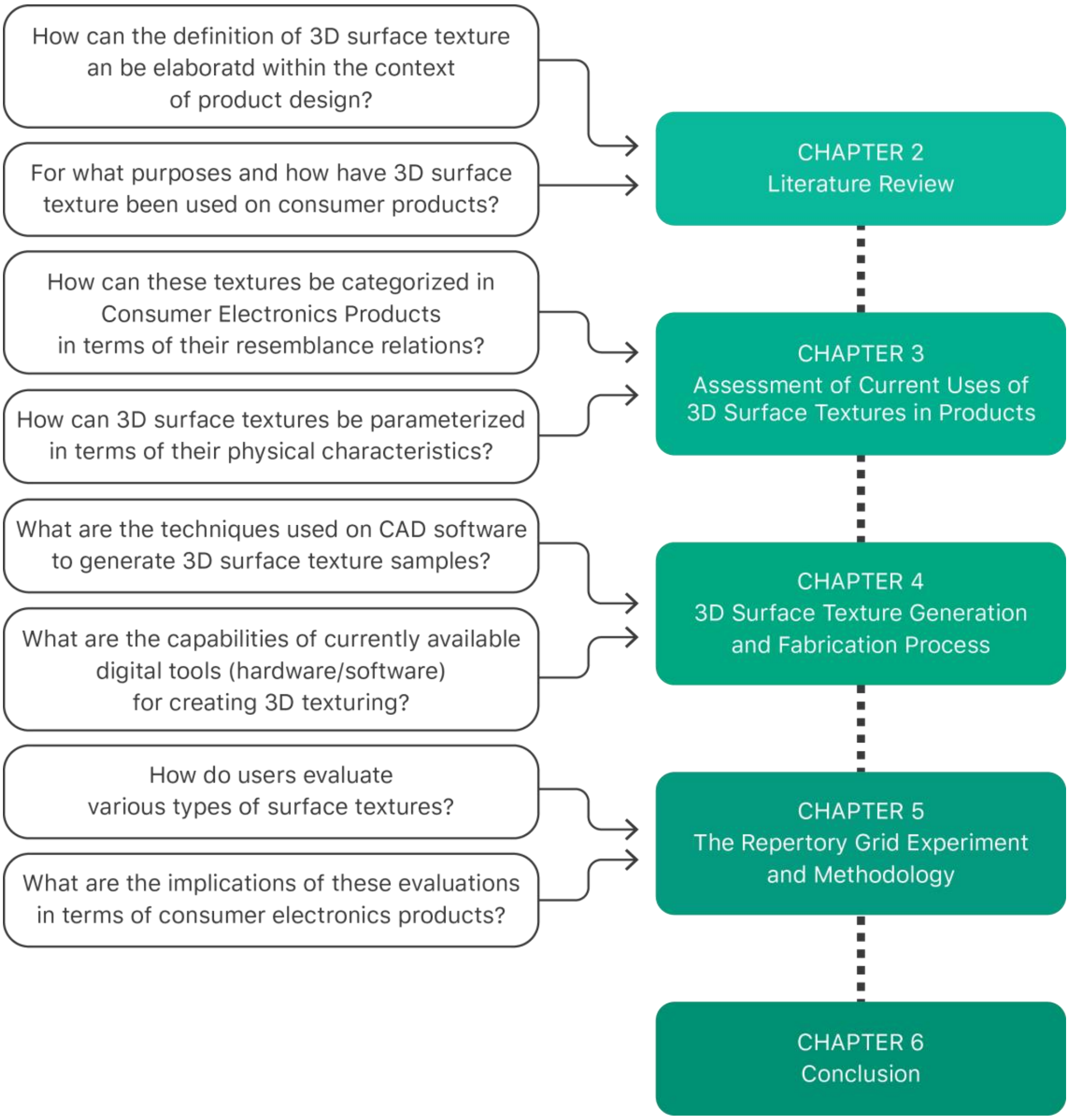


Figure 1.1 Diagrammatic Representation of the Thesis Structure

CHAPTER 2

LITERATURE REVIEW

This chapter covers the studies relevant to 3D surface textures, its manufacturing limitations/opportunities and its involvement with the senses. Definitions of texture and surface texture are reviewed, Additive Manufacturing (AM) techniques are evaluated in accordance with 3D surface textures. Senses regarding user-product interaction are covered to create a basis for evaluating 3D surface textures.

2.1 Definition of Textures and 3D Surface Textures

Texture is one of the most important surface characteristic we use to identify and recognize the objects. It is also highly involved in user-product interaction.

The Longman Dictionary defines texture as;

> "something composed of closely interwoven elements or an organization of constituent particles of a body or substance; and the visual or tactile surface characteristics and appearance of something (e.g. fabric)."

Alternatively, the Merriam-Webster Dictionary offers a more specific definition:

> "the way that something feels when you touch it; the way that a food or drink feels in your mouth."

The second definition stresses the body contact with texture; instead of defining the actual texture features on the surface, it points out the feelings derived from the texture. Also, the attention in terms of senses is given to tactual and gustatory senses, which is contrary to the notion that visual senses are the most important when it comes to textures. These senses will be covered in the following sections.

The term surface texture, or simply texture, may refer to the image of a textured surface, which means the texture may be derived from luminance or color variations, 2D albedo variations, surface height variations or even relief geometries (Eng, 2003). It is important to note that reliefs are generally used to represent figures or textual information. Surface relief usually refers to the topology of a 3D physical surface in which only surface height varies whereas surface albedo refers to surface markings or surface reflectance.

As one might expect, *3D surface textures* are the ones that have variations in height at a certain level. The term is used for surface textures, which are in-between 2D surface textures and macro textures, which are part of the macro form of the product. All these concepts are illustrated in Figure 2.1.

Naturally, these distinctions between surface texture concepts do not imply that they cannot overlap. For instance, a surface texture can mimic natural textures, at the same scale of the original natural texture. In addition to inspirations from nature, which usually does not have repeating patterns, designers also use computer-generated textures, which are based on geometrical patterns. These geometrical patterns can be made by adding height to elements of 2D texture.

Figure 2.1 Examples of Different Surface Texture Concepts (Images derived from the Internet).

Despite the lack of a universally agreed definition of 3D surface texture, some researchers attempted to define it in respect to their working area. Jee and Sachs (2000) define 3D surface textures as a set of geometric features made in three dimensions on the surface of an object. According to the definition, 3D surface texture is not a feature that is inherited from the material quality or coating process. Dana and Nayar (1999) define 3D textures as height variations on the surface of an object which should not be confused with 2D surface textures, which are composed of color or albedo variation on a smooth surface. Hoogs, Collins, and Kaucic (2002) also point out that there has to be significant 3D geometry, which they imply it should not be originated from material property or some other involuntary factors.

When defining textures of foods, Bourne (2003, pp15) comes with the following definition; "The textural properties of a food are that group of physical characteristics that arise from the structural elements of the food, that are primarily sensed by the feeling of touch, are related to the deformation, disintegration and flow of the food under a force, and are measured objectively by functions of mass, time and distance". According to this definition, surface textures have great influence on sense of touch. However, senses other than touch also have influence in the perception of surface textures.

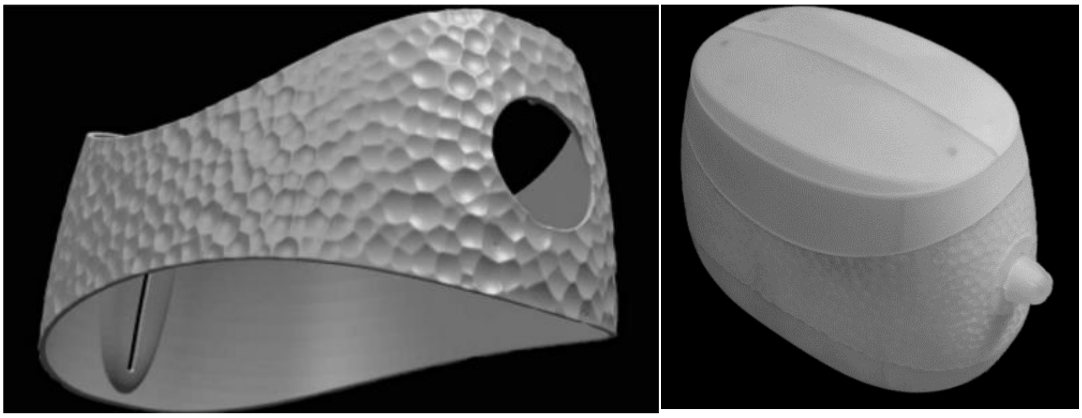


Figure 2.2 Right: Toaster design with "hammered" 3D surface texture middle. Left: Molding. Right: Final model (Evans, 2005, pp157).

To give an example, Evans's (2005) toaster design may be presented as a product which has 3D surface textures. The middle mold of the toaster has 3D surface texture (Figure 2.2).

In parallel to these definitions, it is useful to set a definition of 3D surface textures for this study. 3D surface textures are;

- Geometrical features made on the surface of an object,
- Made in three dimensions, which creates height variations on a surface,
- Not inherited from coating process or some other material attribute,
- Perceivable by multimodal sensory receptors,
- Created to have a specific function or some other use beyond-function (i.e. hedonic or symbolic use).

2.2 Properties of 3D Surface Textures

In these days, many consumer products offer same functionality, reliability performance and price (Coskun, 2014). For instance, in consumer electronics store, when one chooses a product, he/she would have hands on experience with competing products. While interacting with products, people look for functional properties; which one does the job best, how would these products enhance their lives, what value does it provide according to its price, etc. Along with this evaluation, people also look for how it feels to look at it, hold it and use it. These feelings are involved with **hedonic** properties which greatly affect decision making behavior. Sometimes hedonic properties, which may also be called **pleasure related** properties, dominate functional ones. Obviously, 3D surface textures are one of the features to enhance products in terms of both functional and hedonic properties.

Based on the literature review in the marketing area, consumers’ attitudes towards products and brands during decision-making process are decomposed into two different concepts; **utilitarian** and **hedonic**. Unlike earlier measurement method that has single dimension, which is called evaluative semantic differential (SD), consumer attitudes are bidimensional (Batra & Ahtola, 1991). According to Crowley, Spangenberg and Hughes (1992), this decomposition is made to measure and evaluate values of products more validly.

According to Batra and Ahtola (1991), there are two basic reasons for consumers to purchase goods and services and perform consumption behaviors: "(1) consumatory affective (hedonic) gratification (from sensory attributes), and (2) instrumental, utilitarian reasons concerned with 'expectations of consequences' (of a means-ends variety, from functional and non-sensory attributes)". Also Chitturi, Raghunathan and Mahajan (2008) define 'hedonic benefits' as aesthetic, experiential, and enjoyment related benefits while defining 'utilitarian benefits' as functional, instrumental and practical benefits of consumption offerings. Furthermore, Chitturi, Raghunathan, and Mahajan (2008) propose that exceeding a hedonic expectation evokes delight, while exceeding a utilitarian expectation merely evokes satisfaction. In addition, they claim that while failing to meet a utilitarian expectation evokes anger, failing to meet a hedonic expectation evokes dissatisfaction.

Since hedonic properties are highly related with 'pleasure', 'happiness' and 'joy', it is favorable to define those words. Demirbilek and Sener (2003, pp1350) give general definitions of those terms as;

- "Pleasure: the agreeable emotion accompanying the expectation, acquisition, or possession of something good or desirable. Related word: bliss, felicity, happiness, and thrill."
- "Happiness: a state of well-being and contentment."
- "Joy: a pleasurable or satisfying experience; the emotion evoked by well-being, success, or by the prospect of possessing what one desires."

Functional properties of products are more and more taken for granted in products, which means it is not enough for users who are looking for more, where hedonic properties come to play a great role. Demirbilek and Sener (2003) claim that usability and functionality are simply not enough to convey pleasure and happiness to users. These positive emotions come into stage in decision-making, motivation and social interaction.

Figure 2.3 Citrus juicers manufactured from four different material families: front to back, ceramic, glass, metal, and plastic. © 2013 Owain Pedgley. (Karana et al, 2013; pp339.)

Hassenzahl (2001) suggests that enjoyment and usage purposes are increased with the inclusion of hedonic components. That is why fun and enjoyment are part of the user experience, which contribute to overall user satisfaction with a product. Furthermore, these positive emotions simulated by product features do not necessarily increase user efficiency and effectiveness. It is also proposed that a product's hedonic quality is the main trigger for positive experience, despite not being necessary for task fulfillment (Diefenbach & Hassenzahl, 2011).

Karana, Pedgley, and Rognoli (2013) use juicers to give an example in which they claim that functional user needs may be associated with material-influenced product experiences (e.g. effective extraction of juice and easily cleaned surfaces) while hedonic user needs may be associated with visual unity when stored adjacent to other kitchen utensils and satisfying sound of juice dripping into the container (Figure 2.3).

In this study, these two dimensions will be referred to ‘functional’ instead of utilitarian, pragmatic or instrumental; and ‘hedonic’ properties which are non-instrumental and beyond functional ones.

2.3 Senses and 3D Surface Textures

Before discussing senses with 3D surface textures, it is necessary to understand the senses in human-product interaction. The main function of the human senses is to gather information about the world and identify what is bad or harmful or what is good or contributes to our survival (Hekkert, 2006). There are five sensory systems, visual, tactual, auditory, olfactory, and gustatory, for people to communicate through sensorial information during their interaction with products around them (Coskun, 2014). Desmet and Hekkert (2007) claim that the starting point of the aesthetic level of product experience is sensorial data coming from the products’ aesthetic features. Also the aesthetic information that comes through different sensorial channels varies in terms of type and amount in human product interaction.

Aesthetic values refer to a product’s capacity to please different sensory systems during interaction (Desmet & Hekkert, 2007). It is also defined as ‘sensory gratification’ (Hekkert, P. Schifferstein, 2008) that a product has to offer.

Hekkert and Schifferstein (2008) suggest that even though the way people interact with a product surely depends on the product, they always use their senses to perceive it. They use their motor system and their knowledge to operate or communicate with it, and during the interaction, they process the information they perceive, they may experience one or more emotions, and they are likely to form an affective evaluation of the product. Figure 2.4 illustrates the model of human-product interaction. Cognitive capacities, motor skills, sensitivity and concerns gradually develop into goals, purposes and preferences as user interacts with an environment (Hekkert, P. Schifferstein, 2008).

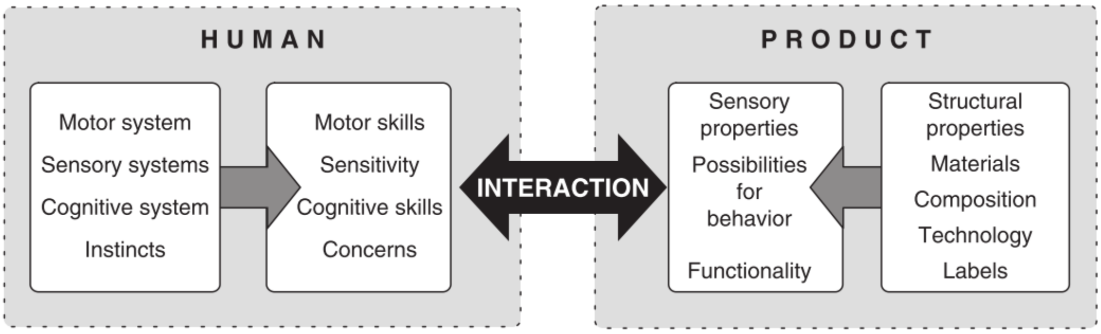


Figure 2.4 Model of Human-Product Interaction (Schifferstein and Hekkert, 2008, pp 3).

Surface textures can be perceived by sight, hearing, and touch, they also influence sound and are also reflected in feeling the texture of a fruit or food by taste and smell (Karana et al., 2013). According to Balaji, Raghavan, and Jha (2011), products are often perceived through vision and touch, which are the most dominant sensory experiences. In the scope of this study, surface textures will be evaluated in terms of their visual and tactual uses, which means only visual and tactual components of human sensory system will be covered with respect to human-product interaction. These two sensory systems are mostly used in human-'product with 3D surface texture' interaction.

2.3.1 Vision

Our environment is full of things, when looking around, we have to interpret what it is we see, what the shapes of things are, what kind of materials they are made of, and what their potential uses and dangers are. In addition to aesthetic values, meanings and affordances, our visual system perceives essential properties including shape, size, texture, graphics, position, lightness, and glossiness (Nefs, 2008).

Furthermore, it is essential to introduce the three concepts of *affordances, constraints,* and *mappings* (Norman, 2002), which construct the basis for how visual information is perceived and processed by use in order to assist the user in using the product. Norman (2002) defines *affordances* as the actual properties of a thing that are perceived, particularly the essential properties that help determine for the user how this thing can actually be used. An *affordance* of a product provides strong clues about how it operates and how it should be operated. When *affordances* are strong enough, the user figures out how to use it just by looking and no label, picture or instruction is required. Norman (2002) gives example of the door to reveal how a door handle can *afford* users without push or pull signs, as in Figure 2.5. The image on the left in the figure shows a door with a horizontal handle, the one on the right shows a vertical door handle.

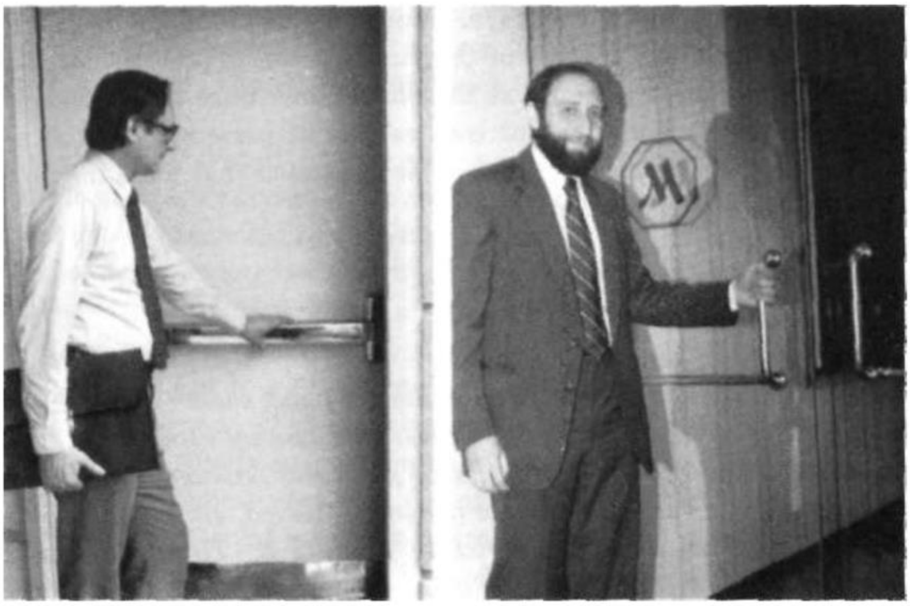


Figure 2.5 Left: The flat horizontal shape of the door handle affords users to push
Right: The vertical bar design affords to push the door (Norman, 2002, pp10).

Norman (2002) defines *constraints* as ways that make the usage of something easy and with few errors, by constraining the choices and thus preventing its usage in another way. He gives the battery and memory card examples for cameras, in which he says it is a good practice to design batteries and memory cards uniquely to fit only one way so that people do not make mistakes by inserting them in the wrong way. Despite the negative implication that comes to mind, constraints improve the interaction, just like affordances.

Mapping is defined by Norman (2002) as the relationship between controls and their consequent actions. In addition, as he states, natural mapping means taking advantage of physical analogies and cultural standards. He gives the example of the seat adjustment control of Mercedes-Benz as illustrated in Figure 2.6 for natural mapping. The shape of the control is analogous to the shape of seat. To adjust the front edge of the seat higher, the button lifted up from the front part. To adjust the back of the seat, use the button on the back is pushed backwards and forwards.

Figure 2.6 Mercedes-Benz Seat Adjustment Control (Norman, 2002, pp24)

2.3.2 Touch

Not only vision, but also touch has great importance in user-product interaction. As Sonneveld (2008) suggests that one learns the physicality of things through touching during which one assesses the weight, temperature, wetness, texture, elasticity, force and movements of these things. Touch also opens a channel for affections and emotions in human-product interaction. Sonneveld (2008) also proposes that people’s affective and emotional development and well-being may also be affected by the way they are touched by the objects. In addition, tactile modality enhances perception of other sensory modalities when combined with them (Karana, Pedgley, Rognoli & Ashby, 2013).

Furthermore, Sonneveld (2008) points out the distinction between active and passive touch. Active touch refers to the perception of the object being touched; whereas passive touch means being touched by the object, which creates internal sensation. In addition, she explains further with an example:

> "Imagine picking up a glass of wine, handling it in your hands, gently turning it to move the wine: You perceive its shape, its temperature, its fragility, and the movement of the liquid. On the other hand, imagine lying on the bench of a masseur who is putting hot stones on your back: You sense the pressure on your back, the warming of your skin, but you do not sense the shape and the size of the stone" (Sonneveld, 2008, pp45).

Figure 2.7 The Map of Tactual Properties of an Object (Sonneveld, 2008, pp49)

Moreover, Sonneveld (2008) also created a map which represents the perception of tactual properties (Figure 2.7). The study divides tactile attributes into four different properties as: the substance, the surface, the structure and th moving parts of the object. *The substance*, is related to the materials of the object and gives information on its hardness, elasticity, plasticity, temperature and weight. *The surface* is related to the texture and patterns. *The structure*, is about the geometry of the object and includes aspects such as its global shape, exact shape, volume and weight distribution (balance). Finally, t*he moving parts of the object* is about the way in which parts of this object move in relation to each other.

Furthermore, Sonneveld (2008) states that studies have shown that tactile sensory system is quite rapid and accurate in recognizing three-dimensional, familiar objects. The studies also shows that blindfolded users recognized 94% of common objects within 1-2 seconds (Klatzky, Lederman, & Metzger, 1985; cited in Sonneveld, 2008). The interesting point is that perception of specific tactual properties affect the way people explore the objects. It is also important to have experience in touching to explore objects efficiently and accurately. Figure 2.8 shows different exploratory movements for different objects.

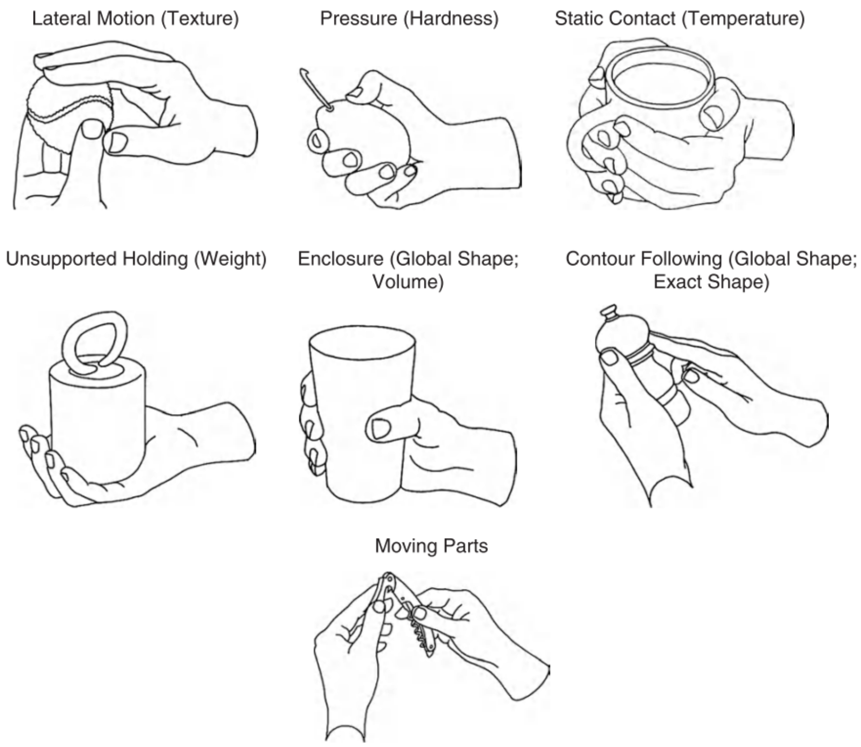


Figure 2.8 Exploratory procedures used for determining specific properties of objects (adapted from Klatzky et al., 1985; Sonneveld, 2008, pp47).

Sonneveld (2008) suggests that it is essential to understand why people interact with objects and why they interact in the way they do. Furthermore, she explains motivations for interaction. It is pointed out that the motivation is evidently reflected by the function of a product. The motivations to touch derived from various studies are summarized as follows (pp47):

- *Interaction for practical, functional use, as a tool*: This motivation relates highly to functional usages. For example, this motivation can be found when we want to use a pen for writing.
- *Interaction to play*: This motivation occurs for hedonic usage purposes. The action is sometimes referred to thoughtless playing with the object. To give an example, a pen can be stroked several times thoughtlessly for playing purposes. 3D surface textures could be used as one of the motivation properties for touching them thoughtlessly.
- *Interaction to care for and to be taken care of*: This motivation could be about either objects taking care of one, like toothbrush taking care of one's teeth, or humans who take care of their objects, like washing the toothbrush, repairing it, and storing it. This kind of motivation can be related to both functional and hedonic qualities.
- *Interaction to explore*: An object can be touched to explore it, regardless of its function. It may occur because it may be unknown and the user wants to discover it or the user may just want to perceive the feeling of touching the object. Again, this motivation can both refer to functional and hedonic qualities.
- *Interaction to carry*: As the name states, tactual interaction may occur from the motivation of carrying an object in one's pocket, in your hands or even on one's back. Both functional and qualities can evoke people to carry the object.
- *Interaction by accident, by coincidence*: Some interactions may not be purposeal but happen by accident. In this case, the tactual interaction occurs without motivation.

Stevens (1990) suggests that the perception of surface roughness is not equal for all body parts. The heel, the back, and the thigh are least sensitive while the lips and the fingers are most sensitive. This difference also relates to the topic of passive and active touch concepts.

For functional uses, the grip of the objects is very important (Sonneveld, 2008). The grip force can be defined as the degree of friction between hands and objects, which makes holding the object easier and more secure. However, it is highly influenced from the condition of skin, such as dry, sweaty or dirty. Textured surfaces offer the best grip for soapy hands whereas smooth surfaces *perform the best.*

Moreover, it is also worth mentioning about the dimensions used for textures. While Holliins, Faldowski, Rao, and Young (1993) refer to textures as rough/smooth, soft/hard, sticky/slippery and bumpy/flat, Picard, Dacremont, Valentin, and Giboreau (2003) suggest the four perceptual dimensions; (1) soft/harsh, (2) thin/thick, (3) relief/no relief, (4) hard/mellow.

2.3.3 Comparing Vision and Touch

To compare the two senses of vision and touch, Sekular and Blake (1994) mention about vision as a ‘distant sense’ because it does not require physical contact, whereas Sonneveld (2008) suggests that touching requires physical contact, which means the sense of touch is a strong basis for affection and intimacy. This distinction is very important for 3D surface textures, especially in hedonic qualities.

In contrast to Sonneveld's (2008) explanations, Jones and O’Neil (1985) suggest that we perceive objects more efficiently when we see them than when we explore them. It is also mentioned that visual information is more heavily weighted than haptic information in a partial judgment. However, texture perception is primarily suited for touch since vision cannot perceive all tactual details. For this reason, textures, which invite users to touch, bonds users with products more intimately.

Naturally, 3D surface textures provide great opportunities as design cues, to help improve the perception of how things operate. Along with that, 3D surface textures can add hedonic quality to an object. Some of the visual uses mentioned in the following section also apply to tactual uses and vice versa.

2.4 3D Surface Texture Examples

Functional and Hedonic Examples of 3D Surface Textures

Before diving deep into 3D surface textures, their meanings, and their relation with the senses, it is useful to give various examples to clarify the concept. The involvement of senses and feelings will be deeply discussed in the following sections.

One of the main uses of 3D surface textures is to guide the users' attention in a desired way or even provoking touch (MacLean, 2008). For instance, as Figure 2.9 shows, turn on/off switch of a hair dryer can be recognized in just a second with the help of surface texture used only in that region. Since the textured surface provides a non-slippery surface, users can understand that it is a sliding switch region. Apart from being non-slippery, it provides a delighting feeling when stroked it. As (Ashby, 2014) states, surface texturization gives tactile feedback of the location of important regions on the product.

In another example vertically arranged horizontal line shaped reliefs reveal the movement axis of the switch (Figure 2.9). Since the non-slipperiness is required for the switch, the user can make judgment about the movement direction by figuring out the non-slippery direction.

3D surface textures can also be used to prohibit touching the object/handle. This dimension was discussed as constraints. It makes the interaction easier and prevents any mistakes. In Figure 2.10, a sharp texture area is used grate the food, which is not intended for direct touch. The visual cue about sharpness gives clue that the surface should not be touch not to get any harm.

Figure 2.9 Left: Hair dryer switch with dotted texture. Right: Hair dryer switch with stripe texture (visuals are gathered from google images with keywords).

Figure 2.10 A grater with sharp texture (Wikipedia.org, 2014).

Surface textures also revamps the appearance of glass, as, the reflection, refraction and diffusion of the light can be manipulated. In the example in Figure 2.11, textured glass is used to hide what is behind it, however it still gets inside from the blurry glass. This 3D surface texture includes hedonic qualities as well since it provokes touch. The level and type of blurriness can also be counted as hedonic quality as it allows light to come inside in a visually appealing way.

Figure 2.11 Textured glasses for both hiding what is behind and creating a delightful view (visuals are gathered from google images with keywords).

Different types of products are grouped together by accommodating same design language used in surface textures. Products of the same series, or even a brand can be recognized by the type of these textures (MacLean, 2008). Figure 2.12 shows how textures are used to create 'association of industrial strength'.

As Karana et al. (2013) states, texture and texture combination can have a strong sensory impact and bring aesthetic appeal. Insights from nature, innovation in materials and processes, virtual reality, fantasy of mind, and daily and social life, etc. can be used to stimulate hedonic feelings. One of the other way of improving products by surface textures is to give a visually interesting surface not only by hiding but also by adding minor flaws, scratches and sink marks as Figure 2.13 states in the example (Ashby, 2014).

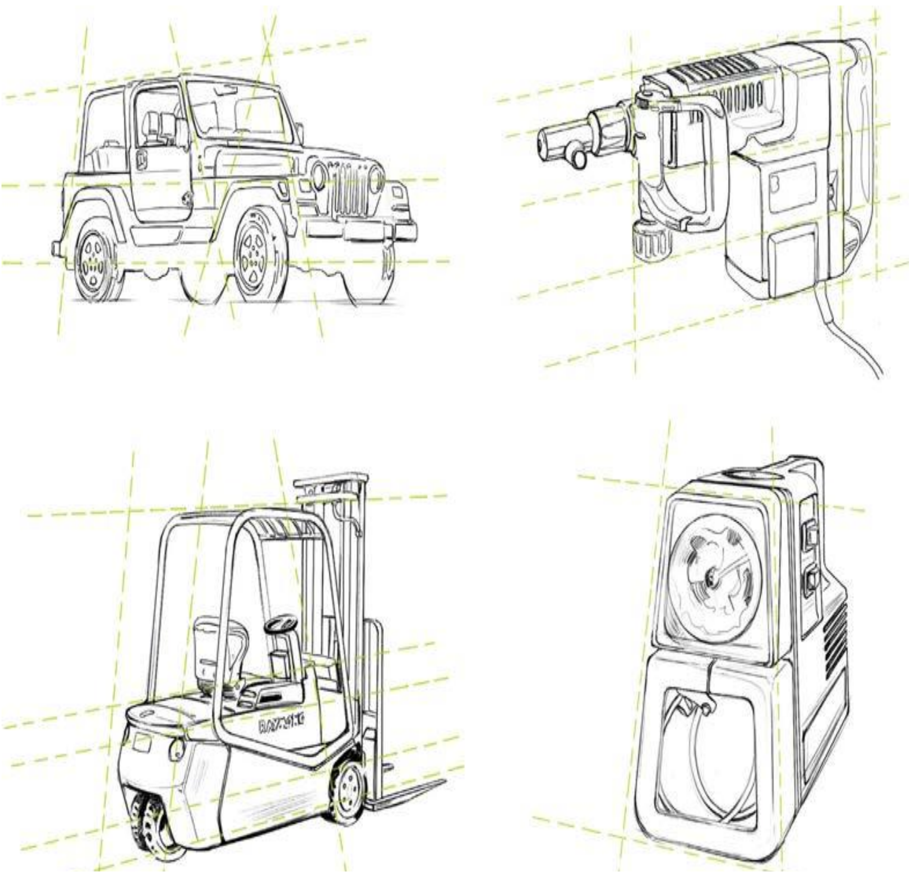


Figure 2.12 Different Products, same recognition of certain industrial strength (visuals are gathered from google images with keywords).

Figure 2.13 Different Products, same recognition of certain industrial strength (visuals are gathered from google images with keywords)

In the first picture minor flaws and scratches are added purposefully, whereas the car dashboard has 3D surface texture for hiding the minor flaws and sink marks. Both texturization is made for both functional (because it enhances grip, decreases slipperiness) and hedonic (because it feels strong, aged and it feels precisely machined) improvements.

Certain characteristics that can be perceived through the sense of vision can also be perceived through the sense of touch (e.g. shape, location, and surface texture). As a result, the sense of touch also plays an important role in functional user-product interactions (Karana et al., 2013).

One of the main uses of surface textures in consumer products is to enhance gripping force of a handle. Thanks to friction increased by textures on a handle (Figure 2.14), a product will require less force for holding and keeping it. Those custom textures also improve snap fits, which help use less material with more stability (Kruth, Leu, & Nakagawa, 1998).

Figure 2.14 Texturized bicycle grip (bikeforums.net, 2014.).

The other main use of surface textures is mass customization. Certain rules can be defined for creation surface textures to have unique properties for each product (Campbell, Hague, Sener, & Wormald, 2003). These customizations can also be used for visual manipulation.

Moreover, tactile toys, which have surface textures, help young children to develop the senses of apperception and differentiation. In that sense, these toys can be useful for educational, physiological, psychological and amusement purposes (Figure 2.15).

Figure 2.15 Tactile toys for babies (digit-eyes.com, 2014.).

2.5 Introduction to Additive Manufacturing

Additive manufacturing (AM) is a general term that also covers generative manufacturing, eManufacturing, direct digital manufacture, freeform fabrication, 3D printing and rapid manufacturing, which are all based on the dispersed-accumulated forming principle. According to American Society for Testing and Materials, AM is defined as “the process of joining materials to make objects from 3D model data, usually layer upon layer” (Cozmei & Caloian, 2012, pp458).

Industrial revolution brought products, which are affordable for everyone. Those products were manufactured by the methods of mass production. However, those technologies conceded some of the traditional techniques used by product makers, or so-called artificers before the industrial age. Industrially mass produced product has to let go some of its features including reliefs and fine handmade details. Products have to be designed conforming the limitations of conventional production technologies. However, emerging additive manufacturing techniques including FDM (Fused Deposit Modelling), SLA (Stereolithography) and LS (Laser Sintering) uses very different methodology to build the object. Obviously, these technologies are at the age of accomplishing baby steps, which means it requires more development to be main production method. However, additive manufacturing is becoming one of the common production methods of today thanks to cheaper and smaller 3D printers.

According to Cozmei and Caloian (2012), this manufacturing technology is capable of printing out solid end-use products and components such as aerospace, motorsport and automotive parts, communication devices, medical implants, hearing aids, lamps shades, dental crowns, surgical aids, fashion and jewelry to lighting, furniture, collectables and toys. Of course, AM technologies can produce any kind of products which can be made with conventional manufacturing technologies. As seen from the examples, this technology already started to replace the conventional manufacturing technologies for particular applications. Therefore, we can expect that AM will be complete reality at some point.

According to Royal College of Engineering (2013), new grounds will be opened up for innovation and a range of logistical, economic and technical advantages will be offered by AM’s unique processes, techniques and technologies. The benefits may be shown as following: low-volume production; lower-cost production; responsive production; shorter supply chains; democratization of production; and optimized design.

According to Jee and Sachs (2000), surface macro-texture (also referred as 3D surface texture) is a new type of product attribute thanks to AM techniques. Of course, there are some methods to create 3D surface textures with conventional methods. However, AM brings whole new grounds for creating impossible 3D surface textures for consumer products.

CHAPTER 3

ASSESSMENT OF THE CURRENT USES OF 3D SURFACE TEXTURES IN PRODUCTS

The literature review conducted in the previous chapter showed that 3D surface textures have potential for product improvements including instrumental ones that are basically functional for the users, and beyond instrumental ones that are hedonic.

In this chapter, the definition of 3D surface texture from the literature review is used as a key to create a framework for the analysis of sampled 3D surface textures. Although 3D surface textures are utilized for product improvement, it is observed that there is no adequate research conducted in this particular field. To fill this gap, a three-step research is planned.

Since the aim of the study is to explore 3D surface textures on products, a research plan must be constituted in order to understand the ways in which they are used, and their qualities that elicit a variety of attitudes in users.

The Study 3 poses the conclusions within the scope of the outputs of this thesis. However, to conclude with Study 3, it is required to have certain phases to prepare both samples and the theoretical framework for Study 3 that are conducted in Study 1 and Study 2.

As a result, the methodology of the research is composed of three studies:

(1) Study 1: A critical surveying, documentation, and classification of the current 3D surface textures available on products in the market. Then refinement and concentration process for the fabrication of 3D textures phase in Study 2.

(2) Study 2: Review of the current software for 3D surface texture generation capabilities, and the practice of fabricating generated 3D surface texture

samples found in the market via additive manufacturing. The samples that are manufactures in this phase are employed as 3D surface texture samples.

(3) Study 3: Evaluation of the qualities - specifically hedonic - of 3D surface textures based on the comparison via semantic differential regarding the subjectivity – elicited perception - of the observers. The data collection is made with repertory grid technique (RGT).

Figure 3.1 displays methodology of the research.

3.1 Introduction

In this chapter, the four stages of Study 1 are explained, in which 3D surface textures on current products are both sampled and analyzed. Study 1 is the first step of the field study, which encompasses the process of collecting samples of 3D surface textures that are available in the current market, analyzing them in a 3D surface texture evaluation table, and classifying them according to their visual resemblance relations.

3.2 Components of Study 1

There are four stages followed throughout Study 1 (Figure 3.2). The focus of Stage 1 is to create a basis for texture sampling. It is aimed to set parameters for the evaluation of obtained 3D surface textures. These parameters are sets of data types helping the characterization of 3D surface texture samples with certain determinants. The parameters are represented as the columns in the table where 3D surface texture samples are listed in relation to their host product. This table is called 3D surface texture evaluation table.

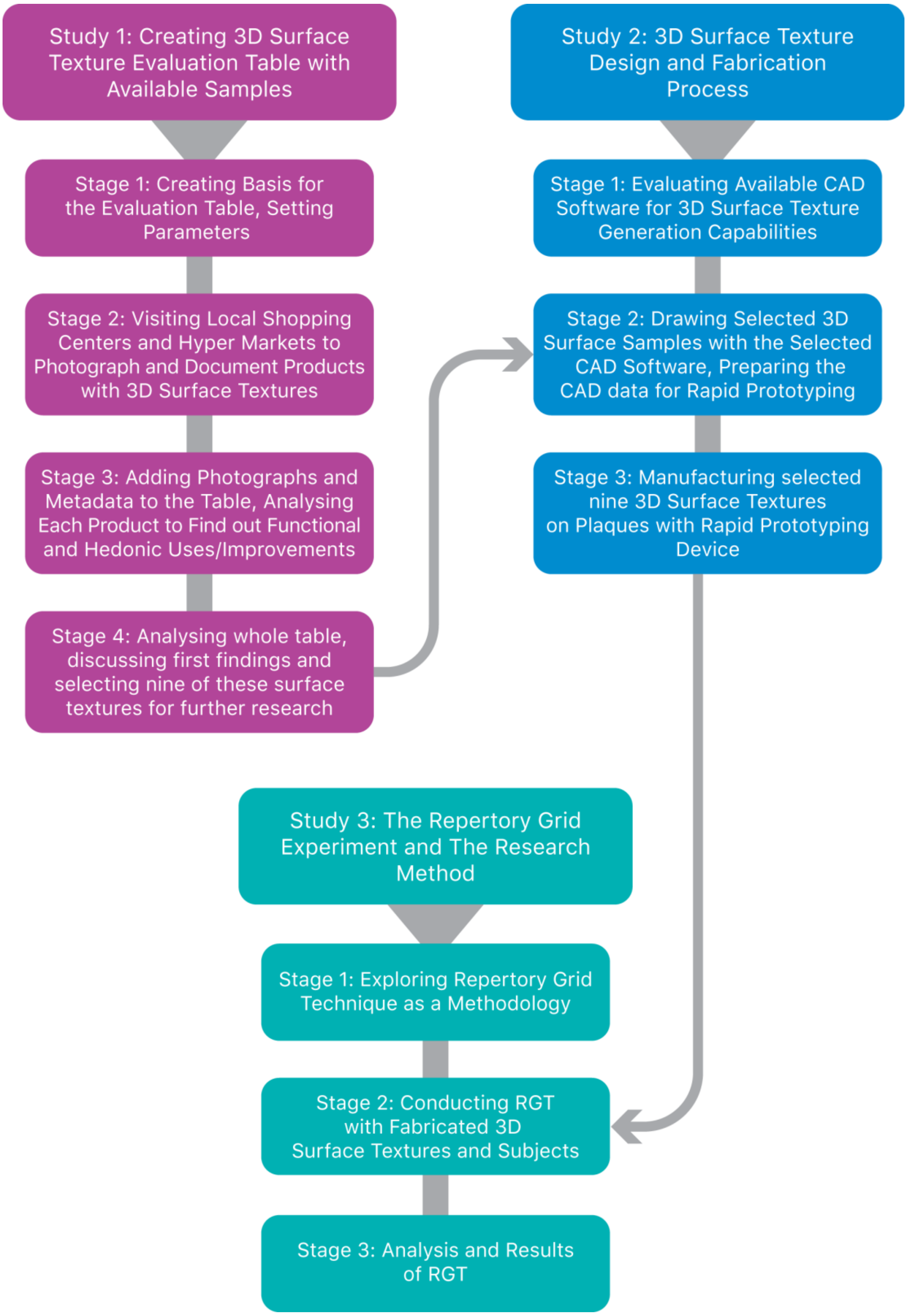


Figure 3.1 Methodology of the Research and the Stages of the Studies

Following this procedure, in Stage 2 it is aimed to survey the current products available in the market and determine the existing 3D surface textures. The procedure includes taking photographs of 3D surface textures in relation to their host products. The sampling process also includes relative measurement. The measurement is required for the necessity of generating and fabricating 3D surface textures.

As a following procedure, in Stage 3 of Study 1, the focus is to fill in the table for the predefined metadata defined in Stage 1. Along with the predefined property parameters that are required in the table, individual evaluations of functional and hedonic uses are also presented. As a final stage of Study 1, Stage 4 consists of the total analysis of the findings listed in the table. According to the parameters that are set in Stage 1, the commonality and the differentiation between the listed 3D surface textures have emerged. From this perspective, 31 3D surface textures are grouped according to their physical properties. As a result, these textures are resolved into nine different surface texture groups.

Figure 3.2 Components of Study 1

3.3 Stage I: Creating Basis for the 3D Surface Texture Evaluation Table

Before starting the product survey for collecting various texture samples, a table is formulated in which to fill with the samples for analysis. The table is constructed upon ten columns, which are based on the determination of the product, texture and their properties. Primarily, for each product, in the first column, individual item number is assigned. After setting an ID, product type and the product brand is mentioned for the product identification. At the fourth column, the product image is located to mention the texture-product relation. Right after the image, the surface texture image is placed. After the completion of product identification, the texture properties and several qualities of the texture such as; its location on product, the part of the user's body with which it contacts, and pattern type are mentioned. In the final two columns, the hedonic and functional improvements that the texture adds on to the product are determined. Figure 3 represents the columns of the table with a sample 3D surface texture[1].

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
1.	Shaver	Fakir			Fingers, fingertips	Top of the product, handle part, on/off switch	Repetition of rigidly defined stripes with clear contour of the stripe geometry. The transition between base surface and the surface texture feature has strong contrast. Height difference is more dramatic.	Increases friction to make it easier to hold, indicates place to hold	Looks premium, precisely crafted. Creates contrast with the surface on rest of the product

Figure 3.3 3D Surface Texture Evaluation Table: Columns and a Sample Evaluation

Following this, it was necessary to determine probable parameters for the study. Throughout the process of parameterizing, parameters are set regarding the two fundamental parts of this research: (1) the product and (2) the 3D surface texture. Accordingly, the 3D surface texture parameters are determined in correlation to the parameters that are set for the products. The utilization of these sampled 3D surface textures is evaluated in relation to the host product. For example, in personal care products, 3D surface textures are generally located on the place where the friction is

[1] The titles of the table columns are determined under the supervision of Assoc. Prof. Dr. Bahar Şener-Pedgley during the Researcher's involvement in the BAP-02-03-2014-001 coded scientific research project.

required for better gripping. The gripping is a functional improvement as a parameter, which can be understood through the 3D surface texture in relation to the product.

After defining the product visually and assigning the list number, two parameters are set for the product as: (1) type, and (2) brand and model. The details of the product catalyze the refinement process (Stage 4) of Study 1 that sets a basis for the evaluation of the texture.

For the 3D surface texture properties after defining the texture visually, five parameters are set as: (1) body contact, (2) location on product, (3) pattern type, (4) functional improvement, and (5) hedonic improvement. Body contact determines the part of the body that contacts the texture to perceive and to affect. Location on product, determines the place of the texture that is utilized and that may guide the designer to designate certain improvements for future product development. The pattern type defines the geometrical aspects of the texture, while functional and hedonic improvements reveal the operational and delectative contribution of the texture through the utilization of the product.

As a general overview to the process, both the product and the 3D surface texture properties are interrelated to each other. Accordingly, primarily the product that the texture is obtained from is described in detail, which constitutes a criterion for the evaluation of the texture. For instance, the type of the product and for what it is utilized, accordingly the location of the texture on the product, directly affect the evaluation of the functional and hedonic improvements and body contact parameters of the texture. As an illustration, the beverage bottle for the orange juice that has the repetitive dot shaped, bumpy pattern on gripping area that contacts the palm of the user, enhances the gripping quality via creating rough surface to prevent the slip of the bottle. This also enhances the hedonic qualities of the product while abstracting the ingredients of the beverage like reminding an orange peel.

3.4 Stage II: Visiting Local Stores for Collecting 3D Surface Texture Samples from Products

Stage 2 consists of two sub-stages that are a preliminary survey, followed by a refined survey. The surveys were conducted in order to collect various 3D surface textures used on consumer products. For the preliminary survey, that is based on the surveying and sampling of the current 3D surface textures on the market, at least one branch for each available brand of electronic markets, department stores, and hypermarkets in Ankara are visited and their current product ranges are examined. This preliminary survey was conducted within the scope of BAP-02-03-2014-001 coded scientific research project. The product range is wide enough to vary from home appliances to personal electronics, cosmetics to sanitary ware. However, due to the limitations of the product size that directly affects the availability of the 3D surface textures for the users' tactual experience, the product range is limited to manipulable objects which directly associate and increase the availability of the users' tactual experience via product surface.

3.4.1 Preliminary Survey

For the preliminary survey, in order to explore 3D surface textures, a wide range of different shopping centers and hypermarkets are visited in Ankara to have some understanding of the current uses of these textures. The exploration included four hyper markets, three consumer electronics stores, five personal care and cosmetics stores, four shoe stores, two kitchen tools stores and two DIY stores. Accordingly, 3D texture surveying process is conducted in seven stages throughout March 2015 to July 2015. Within the scope of the availability of the current products in markets, randomly available 258 3D surface textures were documented. 516 photographs, consisting of 258 pairs of textures and their host products were then processed for a better legibility. 96 of these photographs were eliminated because of the repetitions of the same product with a same 3D surface texture. 420 photographs were left which includes 210 products and 210 3D surface texture images. The scope of the products ranged from household appliances, shoes, cosmetic bottles, hand tools, heavy duty products to consumer electronics products.

The process of photographing included a measurement scale card designed by the researcher to have a sense of the physical properties of each 3D surface texture. Each of the 3D surface texture sample is photographed with this particular card. The measurement card is presented in Figure 3.4.

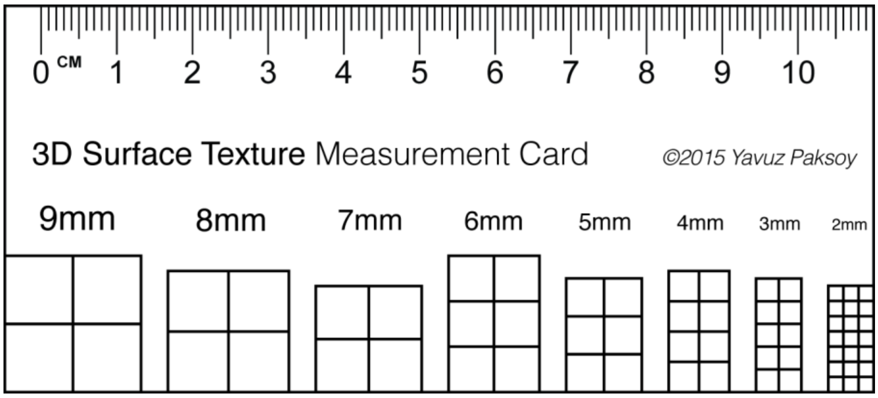


Figure 3.4 Measurement Card for 3D Surface Textures

The upper region of the measurement card includes a ruler based on measurement of cm unit. The lower part holds rectangular patterns created elements in different sizes. This measurement card becomes helpful when a 3D surface texture is being generated with CAD software. While photographs are utilized for the sampling of the geometrical properties of the texture, the measurement card ensures the proper scale of these sampled 3D surface textures. The samples collected for this survey were placed on the 3D surface texture evaluation table, and the completed table was submitted to the BAP project.

3.4.2 Refined Survey

Manipulability is a key factor within the scope of this research. The manipulability of the product enhances the tactual interaction of the user with the product. In order to carry out a renewed surface texture survey, certain criteria were followed. In this phase, textures from products that were mainly manipulable were chosen. From this perspective, the product range was limited to the three product categories of: (1) cameras and camera accessories, (2) personal care products, and (3) computer HIDs and storage devices. Accordingly, a new survey was conducted. New visits were carried out to various branches of MediaMarkt and Bimeks, two major consumer electronics stores in Ankara. These visits were conducted between October to November 2015. As a result, 31 pairs of images were collected, consisting of surface textures and the host products.

3.5 Stage III: Preparing Surface Texture Evaluation Table with Collected Samples

The collected 31 3D surface texture samples were placed onto the 3D surface texture evaluation table. The parameters were inherited from for the preliminary survey. For each product that is selected, after defining the product properties, the parameters are evaluated and filled for this final version of the table (Appendix A).

3.6 Stage IV: Analysis of the 3D Surface Texture Evaluation Table

Within the framework of this research, three main product groups reviewed are; (1) personal care products, (2) cameras and camera accessories, and (3) computer HIDs and storage devices.

3.6.1 Personal Care Products

Regarding the wide range of brands that manufacture shavers; the products of Fakir, Rowenta, Philips, Braun and Goldmaster are detected in the market. By means of commonality, it is noticed that the 3D textures are applied in parts of the product that interact with fingertips to ease and enhance the gripping. Since those products are manipulable, the placement of 3D surface textures is directly related with human contact. Accordingly, within the scope of these products, the utilization of 3D surface textures is concentrated mostly on palms and fingertips. So that, on handle and switch parts of the products, 3D surface textures are placed. The repetition of smooth hill topology is the most widely used 3D surface texture on the reviewed products. Besides hill topology, the texture by the repetition of rigid stripes, dots and nocthes are also seen. Alongside the shavers, same 3D surface textures are observed in hair straighteners in parts that have an interaction with the hand. Besides their functional qualities, these textures enhance the hedonic quality of the product. As an illustration, the hill topology looks prominent and precisely crafted, which improves the feeling obtained by the usage of the product that highlights the identity that is provided to the user.

3.6.2 Cameras and Camera Accessories

Following the personal care products, the 3D surface textures that are used on cameras and camera accessories are reviewed as the second product group including DSLR camera, DSLR camera lenses, compact camera, mirrorless camera, mirrorless camera lenses, selfie stick, and binoculars, covering the brands of Canon, Konus, Nikon, Samsung, Sony and Cellular Line. As it is observed in personal care products, in cameras and camera accessories, 3D surface textures are mostly placed on the gripping parts of the products, based on the tactual interaction via palms and fingertips. In DSLR camera lenses, around the lens ring mostly repetitive rectangular extrusions are used as a texture. In DSLR cameras, 3D textures are observed around the memory card slots using a repetition of dots, and the mode dial part of the camera using a repetition of pyramidal elements. In handle parts of the compact cameras and mirrorless cameras, repetition of dots with negative space is observed which enhances the gripping quality by increasing friction. Furthermore, in mirrorless cameras and their lenses the texture around the mode dial that is based on the dense repetition of notches increases the exactness with fine details which makes the product to easier to rotate. The precision in notch texture makes the product seen to be more professional and in lenses it makes it easier to adjust the lens angle precisely. In selfie sticks, around the handle, the repetitive rectangular extrusion creates the surface texture which makes easier to hold the camera and increases stabilization.

3.6.3 Computer HIDs and Storage Devices

As a third product group, computer HIDs and storage devices such as mice, portable HDDs and keyboards are examined. The products of Logitech, Seagate, Samsung and Microsoft are reviewed regarding the availability in the market. In mice, two kinds of textures are observed regarding the places where they are found; on scrolling wheels for the fingertips and on the side of the products for the thumb area. The texture on the scrolling wheel is based on the dense repetition of notches that increases the control and precision of scrolling. The texture located on the thumb area by the repetitive surface fraction that defines the surface modulation provides non slippery area for better handling. The modulated surfaces that are observed in mice, are also observed in portable HDDs. The reflective texture with surface modulation makes the product to be apprehended as elegant, precise, technical, unique and premium, which enhances its hedonic quality. In keyboards, the repetition of polygonal shaped hills located on the lower part of the product body for the palm, wrist and fingers of the user, increases the friction for hands and provides better typing experience.

As a general commentary that is obtained through the surveying of the product groups, it is observed that the repetition of linear elements such as notches and the hill topology are widely used to increase the gripping quality of the product. Beside its functional properties, these textures increase the feeling that the use obtains from the product, such as the premium feel and the identity.

3.6.4 Grouping of 3D Surface Textures

Based on the final version of the table, from the product range set for three different product groups, it is observed that there emerged several characteristics that may be perceived as common to the textures, based on their geometrical appearance and their locations on product. For instance, in selected shavers from personal care products, the dense repetition of linear surface topology is utilized in the handle parts of the product that has a contact with fingertips. These kinds of linearity on the surfaces in the handle parts improve the gripping quality. On this basis, an evaluation of the 31 3D surface textures is conducted and the clustering results are obtained. This evaluation is conducted with an academic peer[2] with experience in classification, in order to validate the decisions made for groupings of textures. There appeared nine different texture clusters according to their surface topology.

Group 1 (Figure 3.5): The dense repetition of pyramidal elements with sharp top end placed on base texture is observed. Negative and positive features of surface texture are equally distributed. The sharpness and precision of each pyramidal element is the feature for the difference.

Figure 3.5 Surface Texture Group 1

Group 2 (Figure 3.6): Smooth and repetitive hill topology is observed and the transition between the base surface and the hills are smoothly formed. The initiation and ending of the surface features cannot be identified by means of rigidity. The height difference is gradual.

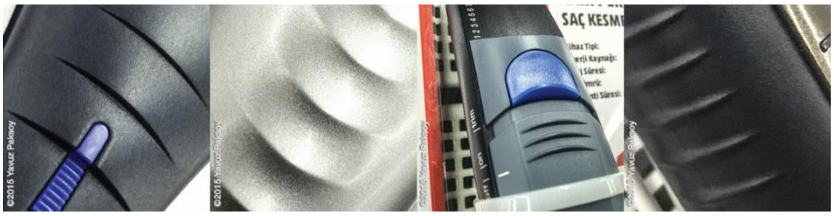


Figure 3.6 Surface Texture Group 2

Group 3 (Figure 3.7): The repetition of dots with negative space subtracted from base surface is observed as a surface geometry. The repetition fashion is constant in both

[2] Günsu Merin Abbas, MArch, PhD Student, Middle East Technical University, Department of Architecture.

X and Y direction of surface area. The 3D texture feature is differentiated by the property being indented.

Figure 3.7 Surface Texture Group 3

Group 4 (Figure 3.8): The repetitive rectangular stripy extrusion is observed. The transition between base surface and hills are rigidly created. The space between each rectangular extrusion is easy to distinguish.

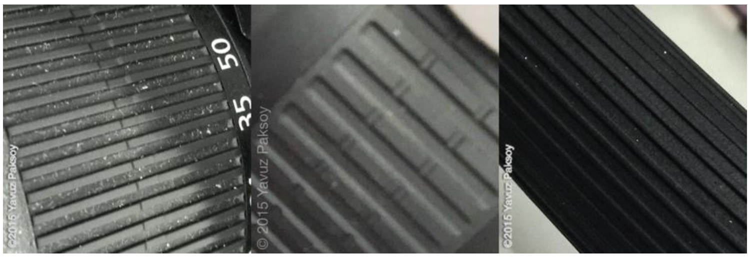


Figure 3.8 Surface Texture Group 4

Group 5 (Figure 3.9): The repetition of dot shaped hills added to base surface is observed. The repetition fashion is constant in both X and Y direction of surface area. The 3D texture feature is differentiated by the protrusion.

Figure 3.9 Surface Texture Group 5

Group 6 (Figure 3.10): The dense repetition of notch texture placed on certain regions of base surface is observed. Negative and positive features of surface texture are equally distributed. The slimness of the notch element is the feature for the difference.

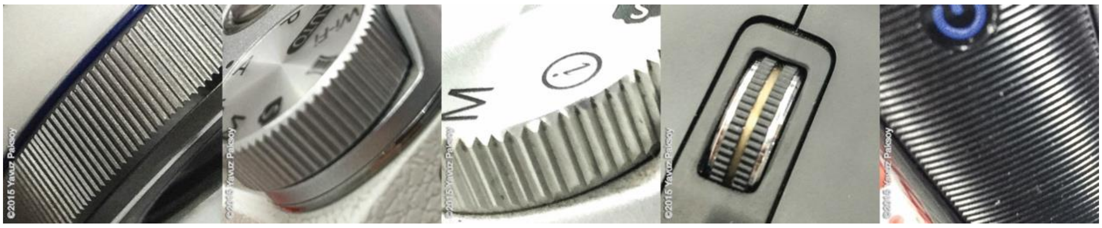


Figure 3.10 Surface Texture Group 6

Group 7 (Figure 3.11): The repetition of rigidly defined stripes with clear contour of the stripe geometry is observed. The transition between base surface and the surface texture feature has a strong contrast. The height difference is more dramatic.

Figure 3.11 Surface Texture Group 7

Group 8 (Figure 3.12): The repetitive surface fraction on base surface that defines the surface modulation is observed. The modulations on the base surface dramatically change in different directions.

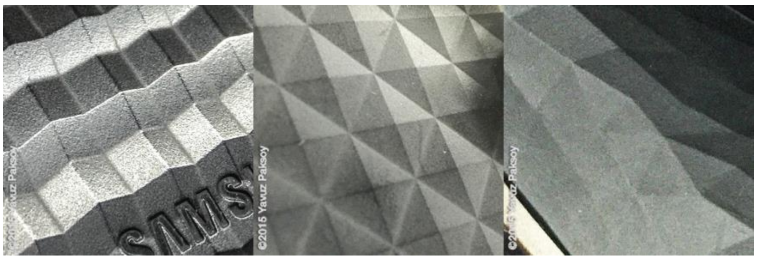


Figure 3.12 Surface Texture Group 8

Group 9 (Figure 3.13): The repetition of polygonal (triangular) shaped hills added to base surface is observed. The repetition fashion is relative to the shape of each individual element. There are also negative triangles in-between triangular hills.

Figure 3.13 Surface Texture Group 9

3.6.5 Classification Methodology

According to Arnheim (1969; cited in Abbas, 2014), human perception is based on the generic structures of the objects. Arnheim suggests that the generic structures are the first things that are perceived by the observer by means of human interpretation. Detection of the generic structure of the objects that are apprehended by the observer may lead the observer to create resemblance relations between the objects. This may be texture, color, forms and other product properties. At this stage, this research utilizes this approach to adjust the number of surface textures to evaluate shared properties. In Stage 4 of Study 1, 31 surface textures were identified on consumer electronics. Based on Arnheim's approach explained above, these 31 surface textures were grouped by means of resemblance relations. Within the scope of this research this resemblance relationship is constructed on geometric structures of the surface textures. The representations for each group of 3D surface textures classified in the previous section is required. Each group of the determined texture clusters were represented with a single type of representative surface texture type (Table 3.1).

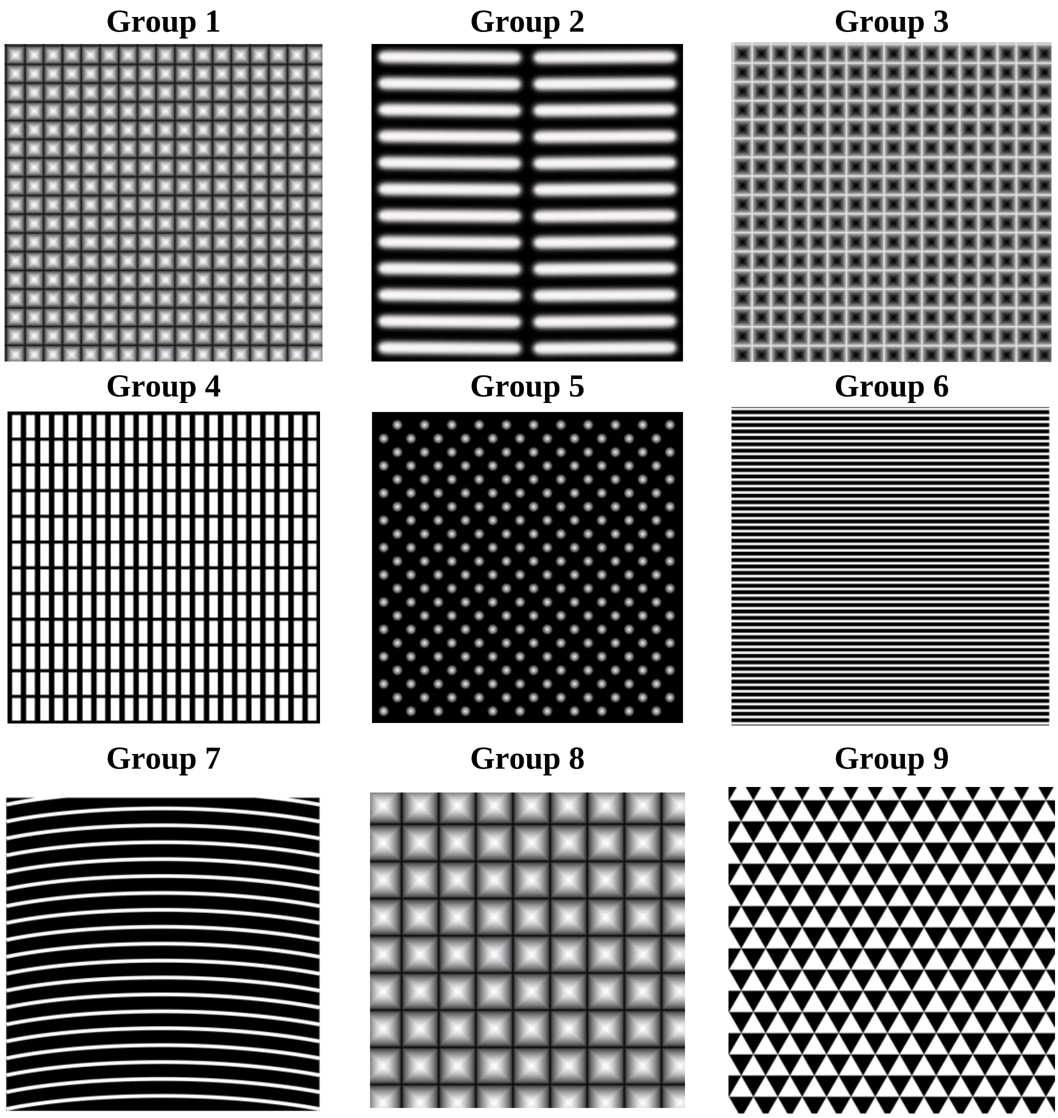


Table 3.1 Bitmap Resemblance Representations of 3D Surface Texture Groups

With these representations, Study 1 was concluded. The results of Study 1 are used in Study 2 as a reference for the production of 3D surface texture samples with rapid prototyping device.

3.7 Limitations of the Study

Wide range of product categories were sampled in the first stage of the Study 1. However, only consumer electronics products were evaluated in terms of their 3D surface textures. Further studies may include evaluation and comparison of 3D surface textures on different types of product categories which are not included in Study 1.

The limitation of the time led to the fact that the amount of sampled 3D surface textures was limited. More surface texture samples may be documented in a more systematic way to have a database which has wide range of 3D surface texture samples, that can be used by designers as a 3D surface texture catalog.

CHAPTER 4

3D SURFACE TEXTURE GENERATION AND FABRICATION PROCESS

4.1 Introduction

In this chapter, the field study of designing and fabricating 3D surface textures will be explained. This is the second study of the research, in which the design and manufacturing phases of the 3D surface introduced and explained. The textures fabricated in this study are utilized in Study 3, in which the Repertory Grid study is held and analyzed.

4.2 Components of Study 2

In the previous study, the purposes of using a particular surface texture on certain products are revealed in order to gain a deeper understanding of what both the instrumental and the beyond-instrumental improvements are. However, since the research about the topic is limited in the literature, the necessity of executing further and much more focused study is observed, which will also validate previously found results.

Since both visual and tactile stimuli are used in the experiments of *RGT* in the following chapter, the need for creating samples of 3D surface textures arose. The samples were chosen from the results of the previous 3D surface texture evaluation study as explained, and the textures are placed on 95 mm x 95 mm rounded rectangle plaques.

Study 2 process consists of three stages (Figure 4.1). In the first stage, CAD software for 3D surface texturization is explored. The second stage of the study is to create CAD models of chosen surface textures on plaques with the selected software and to prepare CAD models for rapid prototyping. The final stage of the study is to actually fabricate the plaques which have surface textures on them with an FDM based prototyping device.

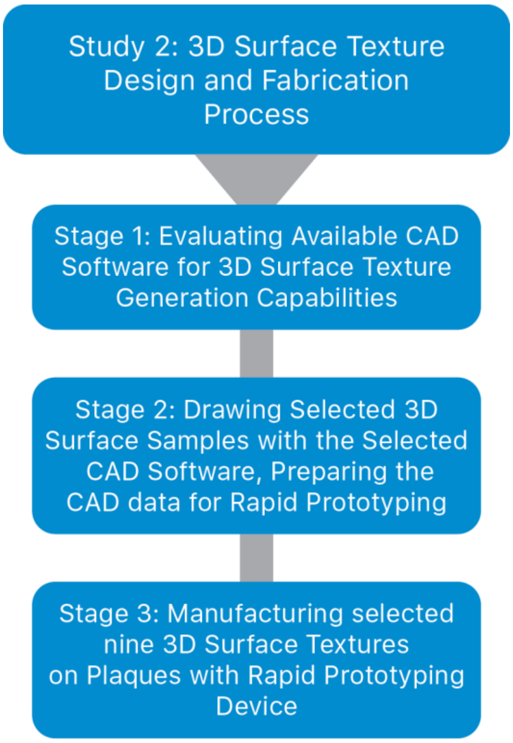


Figure 4.1 Components of Study 2

In the first stage of Study 2, the aim is to explore different CAD software, which are available to be used by the researcher. The available CAD programs include Rhinoceros, Grasshopper plugin for Rhinoceros, T-Splines plugin for Rhinoceros, 3-matic STL and Adobe Photoshop CC. These software programs are reviewed in terms of their 3D surface texture creation capabilities. Pixologic and Geomagic also have powerful tools to create surface textures; although they are unavailable to the researcher, they are reviewed. After the evaluation, a few of them are selected to be utilized in the second stage of Study 2.

In the second stage, the determined nine 3D surface textures are drawn in CAD software. The 3D surface textures are placed on 95 mm x 95 mm rectangle plaques with the most appropriate software available. Furthermore, the CAD files have had to be converted to print-ready STL files which also requires some effort for a frustration-free manufacturing experience in the final stage of Study 2.

Finally, in the third stage of Study 2, the STL files, which are the CAD files with the language of 3D printing machines, are manufactured with the employment of FDM based rapid prototyping device. The process of prototyping requires to go back and forth to have best results, which will be explained in detail.

4.3 Stage I: Evaluating Available CAD Software for 3D Surface Texturing Capabilities

In this stage, the available CAD software that have surface texture creation capabilities are evaluated.

4.3.1 Expected Properties from CAD Programs

The term CAD stands for Computer Aided Design, which is a name for a type of software that has ability to aid the design process, and creates digital CAD files as an output. The other useful term before starting to evaluate CAD software programs is CAM, which stands for Computer Aided Manufacturing. Rapid Prototyping process requires a CAM software, as well as a CAD software.

In this stage of research, several CAD programs are evaluated. The evaluation should have some standards, in other words, the evaluated software should meet some expectations for optimal surface texture creation. The expected features are listed as:

- Availability for the researcher;
- Ability to create 3D surface texture data from bitmap images;
- Support for parametric 3D surface texture creation;

- Ability to create surface textures with fine details, support for preparing models for CAM (Computer Aided Manufacturing) applications; and
- Eliminating the need for extra input devices (e.g. a haptic force-feedback device).

Naturally, the availability of the software is essential for the research to be conducted. All the available software offered by Middle East Technical University, Department of Industrial Design, were assessed for the expected features. There are other software programs which are also powerful at creating and editing surface textures, nevertheless these CAD programs are not available to be used by the researcher. A few of these unavailable software programs will also be reviewed through the data from the literature.

Several CAD programs support creating 3D surface textures from grey-scale bitmap images. In this technique, the bitmap image is mapped onto the desired surface on which 3D surface texture is added. The brightness/luminance level of each pixel defines the height of the topology at the corresponding mapped point of the surface. The white points have the maximum height and black points have no height at all. Grey points will have a height in-between maximum and minimum predefined height values according to their proximity to white or black points in terms of their tones. A standard image which has a standard color mode, supports 256 grades of grey-scale color with 0 being black, 255 being white and grey tones which are between 1-254. The more the luminance value of a pixel increases, the whiter the pixel will be, and more height the topology point will have. Grey tones on the bitmap images especially become helpful when surface texture requires gradual transitions from point to point. Figure 4.2 shows the gray scale bitmap image and the surface texture created with it side by side. The bitmap image of surface texture in the figure is created with Adobe Illustrator and the 3D surface texturing is made with 3-matic STL Texturing Module. These grey-scale surface texture maps can be created with bitmap based programs such as Adobe Photoshop, or a vector based program that has the ability to export bitmap images. Adobe Illustrator, which is a vector based software, can create seamless 2D gray-scale patterns and export them as a bitmap image.

Figure 4.2 Bitmap image is on the left, the 3D surface texture created with the bitmap image is on the right

The standards mentioned above also include support for the creation of parametric 3D surface textures. Parametric modelling is a technique in which parameters are used to define dimensions of certain entities, frequency of the desired elements and other numerical data which can be in relation with one another to define desired features of the CAD model. These parameters can be modified in a non-destructive fashion, which helps designers to modify their CAD models without drawing the models from scratch when alteration is required. This feature becomes useful in the process of creating 3D surface textures, especially for the ones which are based on mathematical formulas. For instance, with a simple modification of the height parameter of the surface texture, the desired maximum height can be altered without the need for redrawing the CAD model or scaling the height of surface texture manually. In addition, when repetitive elements are used in a 3D surface texture, formulas which are based on parametric values can be used to alter the amount of repetition, the distance between each element and other similar parameters without recreating the model from ground up. Figure 4.3 presents a variety of surface textures which have common parameters but different values for the desired modified features.

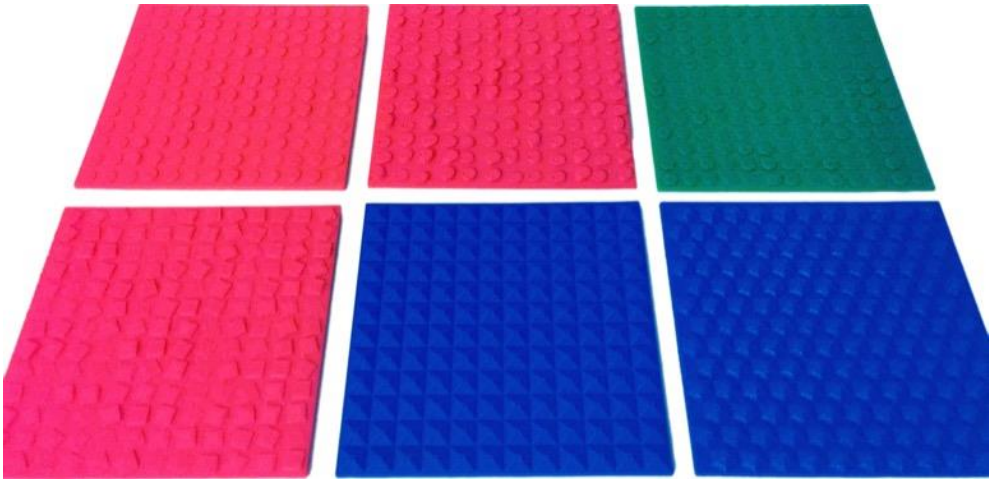


Figure 4.3 A variety of 3D surface textures made with common parameters in Grasshopper Plugin for Rhinoceros

Obviously, there are various CAD programs in the market. Some of these programs primarily focus on aiding the design process for CAM (e.g. designing for injection molding) and some focus on creating computer graphics for animations and games (e.g. character modelling for 3D animation) (Figure 4.4). CAM oriented CAD programs tend to have more precise controls for the 3D models, while the latter allow for more speed in modelling since the model is rather complex and it should be created in a very short period of time. Also, the latter does not require precise dimensions since there is no concern on how it is going to be produced or how it is going to fit another part. Clearly, this property differentiates CAM based software programs from others by giving more attention to precision, which is essential for creating 3D surface textures.

In addition, CAM based CAD programs generally have native support for AM, which has the file standard of stereolithography (STL). STL is the oldest type of AM, namely rapid prototyping or 3D Printing, in which 3D objects are created in a layer-by-layer fashion. STL is also used as a name for CAD data type, which has information about how each layer will be created by the RP device. Each machine movement is documented in STL files, which makes the CAD data ready for 3D printing. This feature of CAD programs becomes useful since the file output does not require extra treatment for Rapid Prototyping, which will be used as a method for fabricating the desired 3D surface textures.

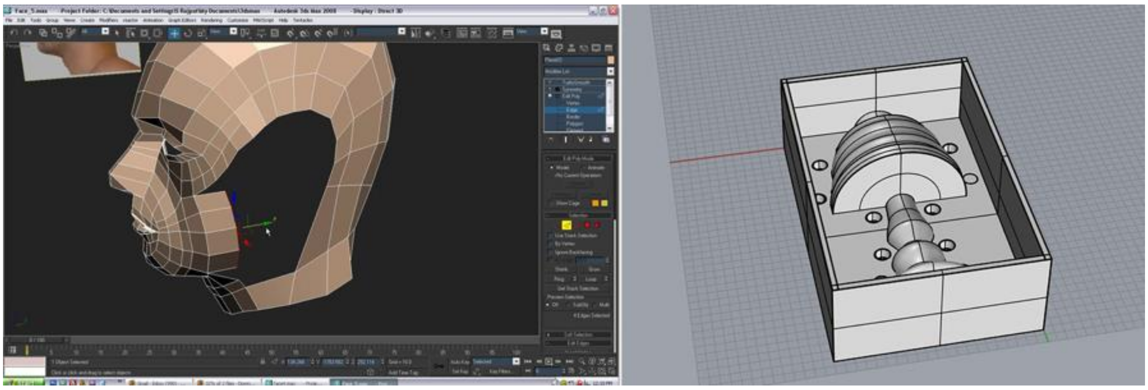


Figure 4.4 Left: Character modelling in 3Ds Max (“Human Face Modelling,” n.d.). Right: Mold modelling in Rhinoceros (Risseeuw, n.d.)

Finally, several CAD applications require an extra input device, which can be a haptic force-feedback device or a graphic tablet, which were not available to the researcher. A few of these programs were reviewed but they were excluded from the process of creating 3D surface texture CAD models.

4.3.2 Rhinoceros

Rhinoceros is a CAD modelling software, which is popular among industrial designers. The software is based on NURBS geometries, however Rhinoceros has the ability to import and edit mesh-based 3D model files. It is utilized in several fields, including industrial design, architecture and graphic design (“Rhinoceros 5 for Windows,” n.d.). It also has strong plugin support, which expands the features of the software. For instance, Grasshopper is a plugin for Rhino, which brings the ability to parametrically control dimensions and relations of entities in the drawing. The Grasshopper plugin will be explained in the following section. Rhinoceros also has great support for CAM applications, especially with the plugin called RhinoCAM, which makes it much easier to fabricate production-ready parts for Laser Cutting, CNC or RP applications.

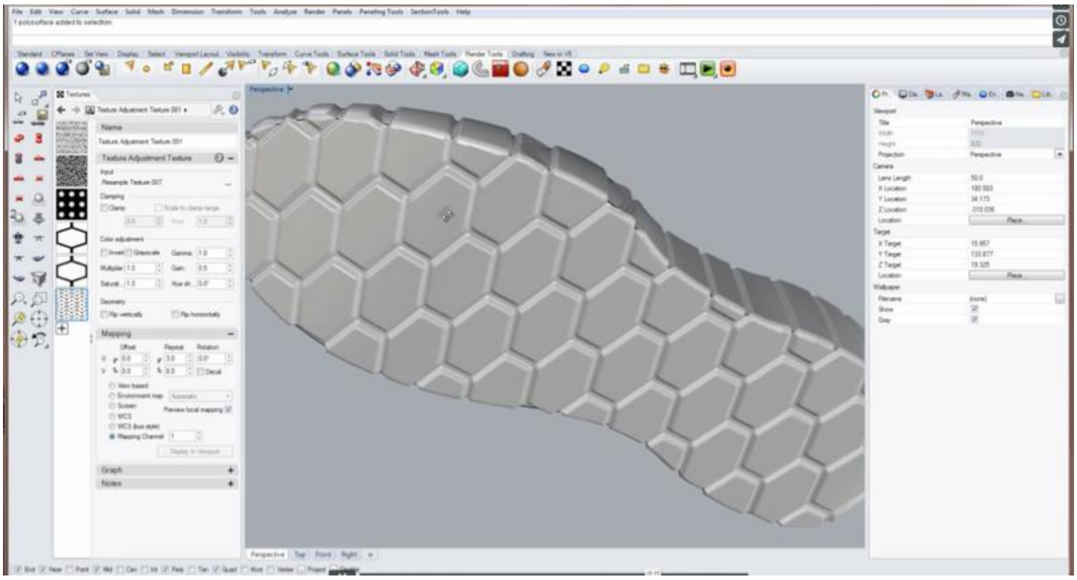


Figure 4.5 Displacement Map command in Rhinoceros 5 for texture creation (“Displacement in Rhino 5,” n.d.)

The software is available in the METU Faculty of Architecture Computer Lab and it is an essential tool for creating and editing 3D CAD files in the faculty. With the release of its latest version, which is Rhinoceros 5, it has the ability to create 3D surface textures from bitmap images with the command called ‘displacement map’ (Figure 4.5). The displacement feature allows adding 3D surface textures to different adjacent surfaces at the same time with pattern continuity.

Nevertheless, Rhinoceros does not support parametric 3D surface texture creation natively, but it has some plugins for parametric design applications. It has support for importing, editing and exporting STL files, which is the standard for CAM applications of RP. It also does not require extra input devices for precise surface modelling but there are several input devices to work with Rhinoceros.

Table 4.1 shows the properties that are supported by Rhinoceros natively. In the following two sections, software plugins of Rhinoceros, Grasshopper and T-Splines are reviewed.

Table 4.1 Evaluation of Rhinoceros 5 for 3D surface texturing

Expected Properties for 3D Surface Texture Creation	Rhinoceros 5
Availability for the Researcher	✓
Ability to create 3D surface textures from bitmap images	✓
Support for parametric 3D surface texture creation	✗
Native support for CAM, Ability to reproduce surface textures with fine details	✓
Eliminating the need for extra input devices for modelling	✓

4.3.3 Grasshopper Plugin for Rhinoceros

Grasshopper is a plugin for Rhinoceros, which adds additional features to Rhinoceros for parametric design process. It provides visual programming language in its canvas, which gives users the ability to create 3D models logically and parametrically (Tedeschi, n.d.). The parameters and logical relations can be modified in a non-destructive way. These features become very useful for creating 3D surface textures, since with a single operation, a 3D surface texture can be modified. The modifiable surface texture features include the height of the surface texture, the frequency of the elements in a surface texture, the flow of the elements in a given base surface, the shape of the elements, and many other parameters. Figure 4.6 shows how Rhinoceros and Grasshopper works side-by-side.

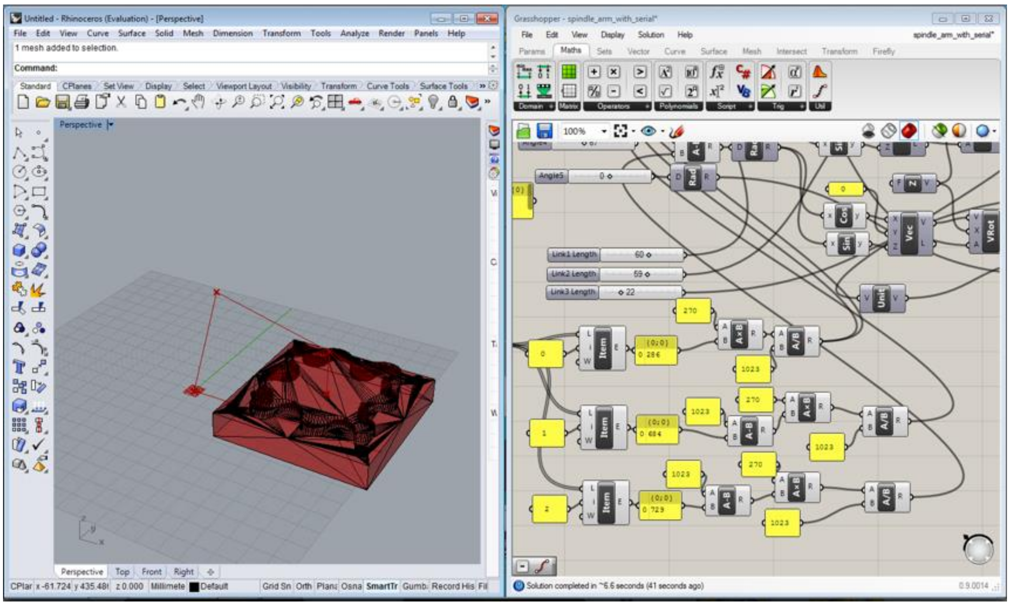


Figure 4.6 Rhinoceros Application is on the left, Grasshopper Plugin is on the right ("Grasshopper Code with Rhinoceros," n.d.)

Table 4.2 Evaluation of Grasshopper Plugin for 3D surface texturing

Expected Properties for 3D Surface Texture Creation	Grasshopper Plugin for Rhinoceros
Availability for the Researcher	✓
Ability to create 3D surface textures from bitmap images	✓
Support for parametric 3D surface texture creation	✓
Native support for CAM, Ability to reproduce surface textures with fine details	✓
Eliminating the need for extra input devices for modelling	✓

Since Grasshopper is a plugin, not a stand-alone program, it does not support all the required features on its own. Table 4.2 shows which properties are supported in Grasshopper. It is important to point out that Grasshopper gains some of its abilities from Rhinoceros.

In addition, as a Plugin, Grasshopper also supports Plugins. T-Splines Plugin for Rhinoceros, which is explained in the following section, also has Plugin for Grasshopper.

4.3.4 T-Splines Plugin for Rhinoceros

T-Splines is a Plugin for Rhino, which is developed by Autodesk, Inc. T-Splines improves Rhinoceros modelling environment with its special surface modelling properties. It gives designers the ability to add a detail on a necessary region of a CAD model without having to rebuild the whole model. To edit the CAD model without harming its solid structure, T-Splines allows users the ability to edit entities of models, which are vertices, edges and faces. Each entity can be modified on its own or as a group to create organic 3D surface textures ("What are T-Splines?," n.d.). It also maintains its NURBS compatibility for Rhinoceros, which helps designers to use Rhinoceros commands on T-Splines models. Figure 4.7 shows a 3D surface texture created with T-Splines plugin.

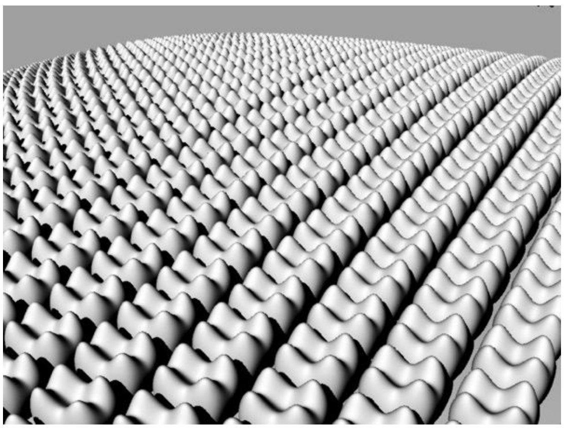


Figure 4.7 3D surface texture created with T-Splines: Detail of Textured Surface ("détail d'une surface plaquée," n.d.)

Interestingly, as a Plugin for Rhino, T-Splines has an additional Plugin for Grasshopper, which becomes also helpful when users need to use T-Splines entities in a parametric equation, since the T-Splines Plugin does not support parametric modelling on its own. Table 4.3 represents the evaluation of T-Splines Plugin for 3D surface texture creation capabilities. Several properties are only available with the employment of Rhinoceros software.

Table 4.3 Evaluation of T-Splines Plugin for 3D surface texturing

Expected Properties for 3D Surface Texture Creation	T-Splines Plugin for Rhinoceros
Availability for the Researcher	✓
Ability to create 3D surface textures from bitmap images	✗
Support for parametric 3D surface texture creation*	✓
Native support for CAM, Ability to reproduce surface textures with fine details	✓
Eliminating the need for extra input devices for modelling	✓

* The parametric surface texture creation support is only available with the utilization of T-Splines Plugin for Grasshopper

4.3.5 Adobe Photoshop CC

Photoshop is an image editing program developed by Adobe Systems. Interestingly, the bitmap editing software Photoshop also has 3D surface texture creation capabilities in its latest version, which is Adobe Photoshop CC. Since the main purpose of the software is raster graphic editing, 3D modelling capability of the software is limited. Photoshop CC can create basic extrusions, bevels and embosses in three dimensions, in addition, the software can convert bitmap images to 3D surface textures (Figure 4.8).

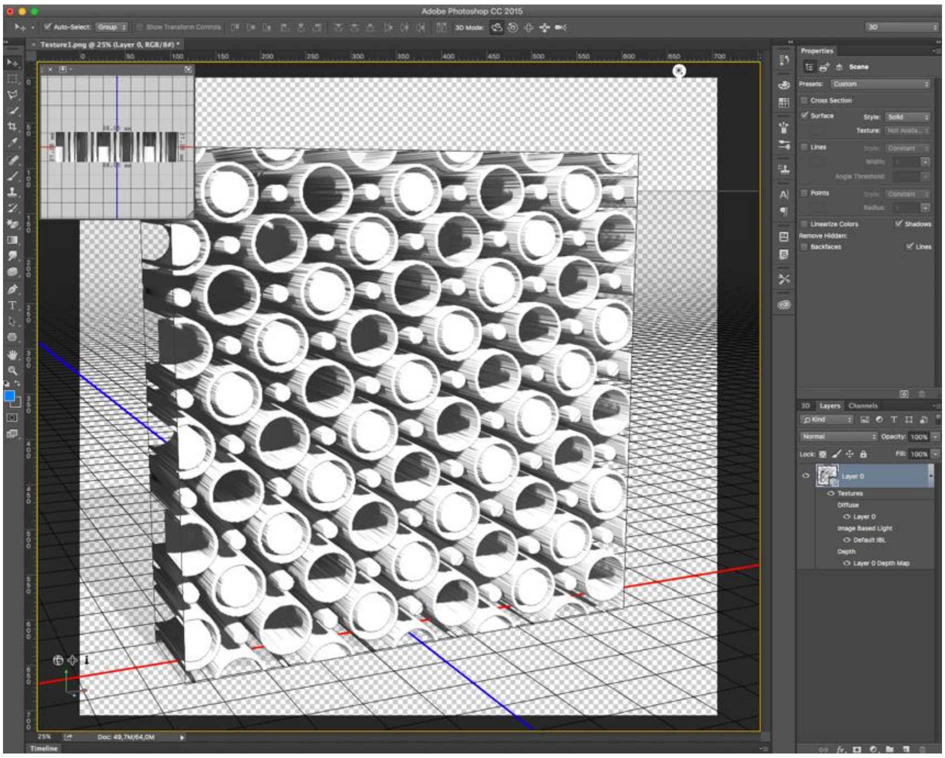


Figure 4.8 Adobe Photoshop CC has ability to convert bitmap images to 3D surface textures

The disadvantage of the software is that it has limited controls over the creation of 3D models, furthermore, the process of creating 3D models takes more time than expected, which makes the modelling experience inferior.

Nevertheless, Adobe Photoshop CC has support for several 3D printers, in other words, it supports some popular 3D printers including MakerBot Replicator and Ultimaker, which means the software does not require any third-party application to connect to these 3D printers. There is no additional CAM support for other fabrication processes in Adobe Photoshop CC. Yet, it supports exporting STL files for further treatment. Table 4.4 presents the expected features which are supported by Adobe Photoshop CC.

Table 4.4 Evaluation of Adobe Photoshop CC for 3D surface texturing

Expected Properties for 3D Surface Texture Creation	Adobe Photoshop CC
Availability for the Researcher	✓
Ability to create 3D surface textures from bitmap images	✓
Support for parametric 3D surface texture creation	✗
Native support for CAM, Ability to reproduce surface textures with fine details	✗
Eliminating the need for extra input devices for modelling	✓

Even though Adobe Photoshop CC has partial support for CAM, especially for RP application, the software is unable to reproduce 3D surface textures with fine details. As a result, the property for "Native support for CAM, Ability to reproduce surface textures with fine details" is not checked as valid in Table 4.4.

4.3.6 3D-matic STL

3-matic STL is a software which is developed by Materialise NV. The software company, Materialise creates different CAD programs for AM; 3-matic STL is one of them. The main purpose of the program is to modify STL files for simplification, 3D surface texturing, remeshing, and forward engineering ("3-matic STL | Software for Additive Manufacturing," n.d.) (Figure 4.9).

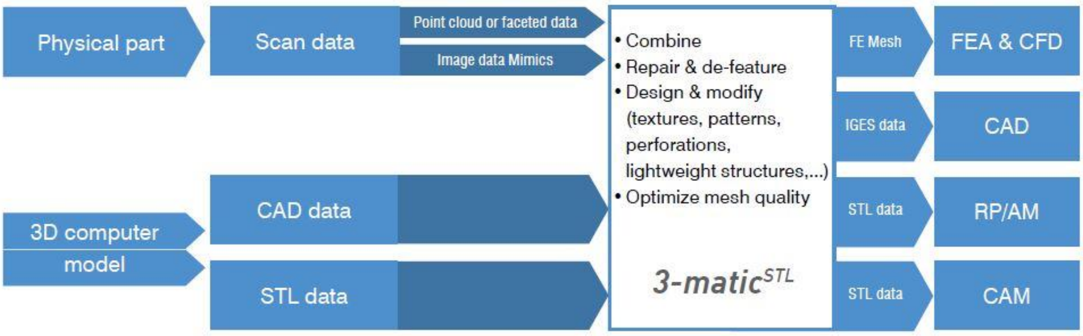


Figure 4.9 Workflow and Features of 3-matic STL (“3-matic STL | Software for Additive Manufacturing,” n.d.)

Even though the software has some tools to design CAD models from scratch, the main purpose of the software is to modify an existing CAD file and prepare it for AM. The STL optimization feature is very useful for 3D surface texture creation, as the software fixes several technical problems of the STL file, including naked edges and flipped normals with a single auto-fix command.

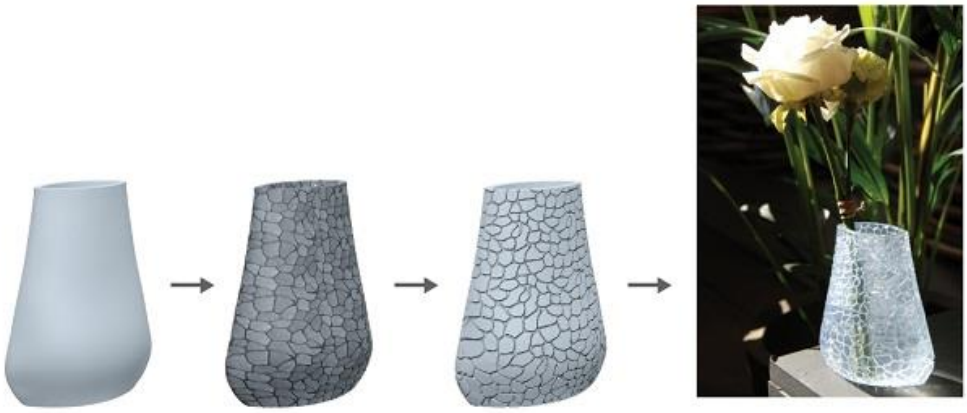


Figure 4.10 3D surface texturing method with the utilization of a bitmap image in 3-matic STL Texturing Module (“3-matic Texturing Module,” n.d.)

The software has a very powerful 3D texturing module, which allows designers to texturize desired surfaces with the utilization of bitmap images or 3D texture mesh. 3D texture mesh is a surface texture data composed of 3D model entities, in other words, instead of using a bitmap image to create 3D surface textures, a 3D model such as a chain structure can be used for texturing. Figure 4.10 represents the process of surface texturing with a bitmap image, while Figure 4.11 shows a product which is textured with 3D texture mesh.

Figure 4.11 3D surface texturing method with the utilization of a 3D texture mesh in 3-matic STL Texturing Module ("3-matic Texturing Module," n.d.)

Table 4.5 Evaluation of Materialise 3-matic STL for 3D surface texturing.

Expected Properties for 3D Surface Texture Creation	Materialise 3-matic STL
Availability for the Researcher	✓
Ability to create 3D surface textures from bitmap images	✓
Support for parametric 3D surface texture creation	✗
Native support for CAM, Ability to reproduce surface textures with fine details	✓
Eliminating the need for extra input devices for modelling	✓

The program has the ability to create very precise 3D surface textures, however, parametric modelling features, especially when designing for 3D surface textures, are limited. Other expectations are met for 3D surface texture creation as Table 4.5 represents.

4.3.7 Geomagic Sculpt

Geomagic Sculpt is a clay based modelling software, which enables to create virtual sculpts with either a standard mouse or a haptic force-feedback device that is also made by Geomagic. Unlike conventional CAD software, virtual voxel clay is used as a medium to create the desired 3D object, instead of standard geometric entities including curves and control points ("Geomagic Sculpt Overview," n.d.). Even though a standard mouse can be used as an input in the software, in a reasonable amount of time, precise details can only be created with the companion of a haptic force-feedback device. With the aid of haptic feedback, haptic sculpting is a technique used by designers to create detailed models (Olsson, Nysjö, Aneer, Seipel, & Carlbom, 2013). A haptic force-feedback device directs the virtual tool on the computer screen, in addition, the interaction between the tool and the object being shaped is reflected as a haptic sensation, such as a nudge or force, which feels like sculpting a clay in real life (Sener, Wormald, & Campbell, 2002). The software platform with the haptic force-feedback device becomes very useful for designers who want to create 3D surface textures on a product's surface, since it is analogous to sculpting 3D surface topologies in real life.

The Geomagic (formerly known as Phantom) haptic force-feedback device allows users to model objects in 3D, with a stylus attached to a moving arm that moves in 3D and gives haptic sensation in 3D whenever required, which necessitates high degrees of freedom (DOF) (Sener et al., 2002). Figure 4.12 shows the latest version of Geomagic Touch haptic force-feedback device in use.

Figure 4.12 Geomagic Touch haptic force-feedback device (“Touch(TM) 3D stylus,” n.d.)

The software is able to export STL files as output and has the ability to create 3D surfaces from bitmap images. Furthermore, the STL files exported with the software do not require significant treatment to be prepared for rapid prototyping. However, it does not support parametric modelling, since it is not feasible to document every touch made with the device and parameterize these modifications with several variables.

Nevertheless, neither the Geomagic Sculpt software nor the compatible haptic force-feedback device is available for the researcher. Hence, it was not possible to evaluate the software platform for creation of the sample 3D surface textures with hands-on experience of the researcher. Finally, Table 4.6 shows which expected properties for 3D surface texture creation are met by the software.

Table 4.6 Evaluation of Geomagic Sculpt for 3D surface texturing

Expected Properties for 3D Surface Texture Creation	Geomagic Sculpt
Availability for the Researcher	✗
Ability to create 3D surface textures from bitmap images	✓
Support for parametric 3D surface texture creation	✗
Native support for CAM, Ability to reproduce surface textures with fine details	✓
Eliminating the need for extra input devices for modelling	✗

4.3.8 Pixologic ZBrush

ZBrush is a digital sculpting software platform similar to Geomagic Sculpt. It is developed by Pixologic, however, it does not support haptic force-feedback devices as Geomagic Sculpt does. Alternatively, it supports graphic tablets as an input, which is another way of using stylus with sensitivity level ("ZBrush," n.d.), yet without the support of haptic feedback. A virtual clay can be shaped with push and pull commands in the software, without the limitations of using certain geometric entities used in conventional CAD software. 3D surface textures can be engraved on a desired surface with required precision level. Furthermore, with the employment of a pressure sensitive stylus, the force applied on the surface of the graphic tablet determines how much deformation is applied on the surface of the virtual clay. Latest versions of Wacom Intuos Graphic Tablets, supported by the latest version of ZBrush v4R6 software, can differentiate 2048 levels of pressure on the point applied. The graphic tablet also senses the tilting angle of the stylus, which can be parameterized as the direction of the virtual tool that applies force on the surface of virtual clay to modify it. The pressure of the stylus not only supports Z intensity of the modifications but also can be re-parameterized as color intensity, brush stroke size and other available customizations offered by ZBrush software. Figure 4.13 demonstrates the Wacom Cintiq Companion display tablet with ZBrush software.

Figure 4.13 Wacom Cintiq Companion Tablet with Pressure Sensitive Stylus for virtual clay modelling in ZBrush ("ZBrush," n.d.)

ZBrush has no support for parametric texture generation, nevertheless, it has the ability to create 3D surface textures from grey-scale bitmap images. It can also give STL files as output with no significant treatment and the software is available for the researcher. However, the software is not required for the samples of 3D surface texture to be modelled. In addition, the absence of a compatible graphic tablet and limitations of time made the review of this software unfeasible. Table 4.7 explains which features are supported according to the set of rules defined for the study.

Table 4.7 Evaluation of Pixologic ZBrush for 3D surface texturing

Expected Properties for 3D Surface Texture Creation	Pixologic ZBrush
Availability for the Researcher	✓
Ability to create 3D surface textures from bitmap images	✓
Support for parametric 3D surface texture creation	✗
Native support for CAM, Ability to reproduce surface textures with fine details	✓
Eliminating the need for extra input devices for modelling	✗

4.3.9 Comparison and Discussion of the Software Tools

Describing the first stage of Study 2, this section aims to collect convenient data about modelling software programs for creating 3D surface texture geometries in product design. For this end, a set of criteria is defined to evaluate these programs as mentioned earlier. Table 4.8 represents the comparison of all the reviewed modelling software in accordance with the criteria set.

The study revealed that 3D surface texture design and modelling features are made feasible only with the latest versions of the software programs reviewed. Rhinoceros version 5, is the latest version at the time the study is conducted, and it is the first version to support displacement maps, which is a very handy way of creating surface textures. In addition, the case is also valid for Adobe Photoshop CC, the latest version of Photoshop. The extensive graphic tablet support for ZBrush is only made possible with the latest release of the software, which is v4R6. The Materialise company which focuses on developing software for AM processes has a dedicated module for surface texturing, which emerged in the last versions of the 3-matic STL software. The review shows that tools for creating 3D surface topology is emerging, and the development is accelerating with additional releases. The reason behind these developments is also caused by the acceleration in developments of AM technologies, which are becoming readily available for both designers and manufacturers, and AM has much more potential for 3D surface textures.

Table 4.8 Evaluation of all the reviewed CAD Applications for 3D surface texturing

Expected Properties for 3D Surface Texture Creation	Rhinoceros 5	Grasshopper Plugin for Rhinoceros	T-Splines Plugin for Rhinoceros	Adobe Photoshop CC	Materialise 3-matic STL	Geomagic Sculpt	Pixologic ZBrush
Availability for the Researcher	✓	✓	✓	✓	✓	✗	✓
Ability to create 3D surface textures from bitmap images	✓	✓	✗	✓	✓	✓	✓
Support for parametric 3D surface texture creation	✗	✓	✓	✗	✗	✗	✗
Native support for CAM, Ability to reproduce surface textures with fine details	✓	✓	✓	✗	✓	✓	✓
Eliminating the need for extra input devices for modelling	✓	✓	✓	✓	✓	✗	✗

According to the set of criteria, as suggested in Table 4.8, throughout the 3D surface texture design process, Rhinoceros 5, with the aid of its plugins Grasshopper and T-Splines, were selected and utilized. The reason behind this decision is that Rhinoceros, which already is a flexible CAD software, becomes much more capable for 3D surface texture creation process, with the addition of plugins. Furthermore, Rhinoceros can create precise geometries, with precise dimensions without approximation of desired 3D surface texture. It has support for all the required expectations for the study, in addition, the researcher has deeper experience with Rhinoceros than the other software reviewed. The absence of availability of both software, which are ZBrush and Geomagic Sculpt, and companion devices which are a haptic force-feedback device and a graphic tablet, made these software less feasible to work with, which were then eliminated. Adobe Photoshop CC was also eliminated because of its poor 3D surface texture creation performance when it comes to speed and precision.

In addition, 3-matic STL software was also used for both creating 3D surface textures from bitmap images, where the software performed outstandingly in creating surface texture detail in the process, and fixing the STL files required by the models that need additional treatment for RP processes.

4.4 Stage II: Drawing Selected 3D Surface Texture Samples and Preparing Them for Rapid Prototyping

The first part of the field research, Study 1, resulted in identifying a set of 3D surface texture types, which were reserved for further research. Stage 2 of Study 2 covers the creation of the selected 3D surface CAD files with the software reviewed in the first stage of Study 2. The 3D surface textures were named *YD1, YD2, YD3, etc.*, where YD stands for *yüzey dokusu*, meaning surface texture in Turkish. It is also required to set a standard type of medium for evaluating different textures under equal conditions and to utilize this standard in the process of creating CAD files of 3D surface textures. These conditions are referred to as the standard, in addition, the differences applied for each 3D surface texture are referred to as parameters.

Each of the selected 3D surface textures are documented with detailed photographs and measurement information. The data collected via this documentation is used to define the creation process of 3D surface textures. 3D surface textures with repetitive elements are created with parametric 3D surface texture creation method, and the rest is created with non-parametric 3D surface texture creation method, which are explained in the following subsections.

4.4.1 The Predefined Standard Base for 3D Surface Textures

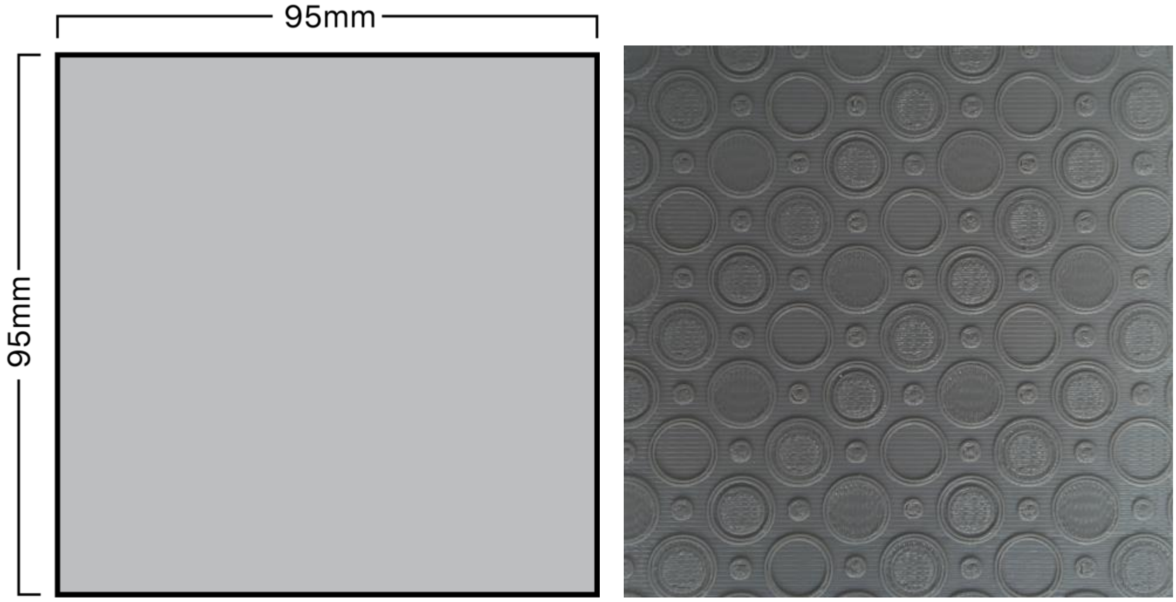


Figure 4.14 Left: Determined 3D surface texture base, which has 2 mm depth and neutral gray color. Right: Sample 3D surface texture output with determined standard base.

As explained earlier, the RGT experiment should be held under certain conditions for each 3D surface texture that is surveyed. The standard for the experimentation requires a certain type of surface base which should have 3D textures on it. The reason behind using plaques as a standard base is to separate 3D surface textures from their contexts which are the products that the textures are found on. The context of a product is related to its form and usage scenario, which may affect individuality of 3D surface textures while the evaluation process by the participants.

The 3D texture samples are standardized within the scope of this study. The 3D surface textures are standardized via sampling them as plaques rather than sampling them on actual products. This standardization leads 3D surface textures to be abstracted. Here, the abstraction of the textures gives the opportunity to research and evaluate the various potentials of them from different perspectives. As a result of such abstraction process, the evaluation of the surface textures by means of beyond-functional qualities reveals users' approach like the core ideas and feelings that are obtained from and expressed verbally by the attitudes rather than solely the evaluation of them by means of functional or formal qualities. Rather than solely analyzing the textures by means of concrete visibility, the emotional and hedonic outcomes are obtained and evaluated.

Considering the circumstances obtained from the particular RP machine the researcher had, which are explained in the following stage of the study, the standard base for 3D surface textures was defined as a 95 x 95 mm square plaque (Figure 4.14, left). The height of the base plaque was defined as 2 mm, which is adequate for holding 3D surface textures together. Since the aim is to define a standard base for each surface texture, the color of the material to be used in the RP process also had to be defined. The neutral grey-color was selected as appropriate for the research based on the reasoning that it would have least prejudice on subjects who are using visual stimuli while experimenting with different types of 3D surface textures. Certain vibrant colors could also affect the way of subjects' interpretations for visual stimuli. Therefore, the color gray was found to be the most suitable color, other than the nine vibrant RP filaments that the researcher had.

The predefined base with a random 3D surface texture is produced with the RP machine (Figure 4.14, right). The sample print showed that the predefined standard is adequate for experimenting with 3D surface textures in Study 3.

4.4.2 Parameters of 3D Surface Textures

Since the properties of particular surface base is defined, it is also required to set certain parameters for the structure of different surface textures. The characterization of surface roughness in three dimensions was parameterized for the 3D surface texture samples to be fabricated. Simple versions of 3D surface texture parameters were created, which were also suited to be employed in a parametric CAD software (e.g. Rhinoceros with Grasshopper Plugin). These 3D surface texture parameters are as follows:

- Height (Z dimension)
- Width and Length (X and Y dimension)
- Spacing between elements (X and Y spacing)

- Orientation on plane of XY axes (rotation angle around Z axis)/3D orientation
- Number of sides (for polygonal elements) of each repetitive element
- Type of Element (for non-polygonal elements)
- Grid Type (e.g. Rectangular Grid vs. Hexagonal Honeycomb Grid vs. Polar Grid)
- Particular Domain on the given surface for texturing

Before diving into the 3D surface texture parameters, it is reasonable to explain certain terminology. A *pattern* is made of a constant or variable set of *elements* that are sequenced according to a certain rule. *Element* is a certain type of 3D form that can be used as an instance to lay down on a particular surface with certain pattern. Each instance of element can be same or different according to a certain rule.

The height parameter can be defined as the altitude of peak point of an element when lowest point 3D surface texture is positioned/aligned on the reference/mean surface. Different elements can have different height values in a single, patterned 3D surface texture.

Width and length parameters are literally width and length of the element. If spacing is same for X and Y axis, width and length parameters also define aspect ratio of the whole pattern/3D surface texture.

Spacing between elements defines how far elements are to each other in both X and Y axis in a particular pattern. The X and Y are also referred to as U and V in order, in the field of CGI (computer generated imagery). The distinction is made to differentiate the scene and the surface of an object in CGI software, in which X, Y and Z axes are used to define the 3D scene of the model, while U, V and W (in order) axes are used to refer to imaginary points on a particular surface. However, this study refers to all analytical values as X, Y and Z. Interestingly, spacing values can be negative for creating overlapping elements in a patterned 3D surface texture.

Orientation refers to the angular transformation made to an element from its original position. An element could be rotated at a certain level in reference to X, Y or Z axis. This parameter also defines the direction that a certain element points at.

Polygonal shapes are composed of a certain number of sides (e.g. triangle, pentagon). This parameter defines the number of sides for the type of 3D surface texture element, which has polygonal base.

For non-polygonal elements (e.g. a heart shaped element or an ellipse), certain 3D data is provided to create the desired patterned 3D surface texture. A certain element cannot have both polygonal parameter and element-type parameter.

Grid type refers to arrangement rules of elements in a pattern. To simplify, each element may be located at the corner point of seamless rectangular pattern or hexagonal pattern to create rectangular or hexagonal grid of elements. In addition, the grid type may be polar, which means elements may be placed on a single circle or on interwoven circles or ellipses with a certain spacing setting.

Particular domain parameter refers to the particular area of a certain surface on which the 3D surface texture is applied. For instance, a square shaped surface may have 3D surface textures on all over its domain or on a particular area which is specified.

These parameters were utilized in the upcoming section on creating parametric 3D surface textures.

The parametric framework is only applicable for the 3D surface textures which are composed in a repetitive fashion, that is to say, the 3D surface texture is made of a certain pattern of elements. There are certain types of surface textures that are not repetitive in any type of composition setting. Naturally, these types of non-repetitive surface textures are not accepted as parametric surface textures.

4.4.3 Preparing 3D Surface Texture Samples for MakerBot Replicator 3D Printer

Until this section, the CAD files of selected 3D surface textures were prepared, with parametric or non-parametric methods. In this part, the prepared CAD files were converted to MakerBot Replicator compatible file format which has the extension of " .makerbot". The process requires two steps for a CAD file which was either created with Rhinoceros (Figure 4.16) or 3-matic software. In the first step, the CAD file was converted to STL format with desired tolerance level. Consecutively, the STL file was converted to MakerBot file via MakerBot Desktop application, which is also printing hub for MakerBot branded 3D printers.

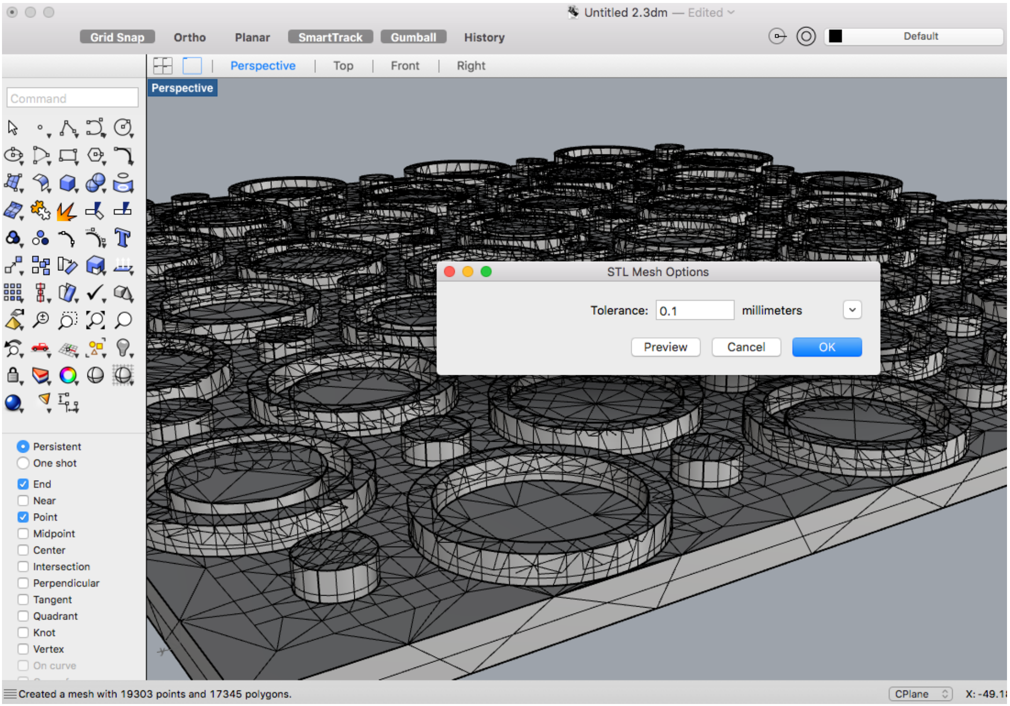


Figure 4.15 Rhinoceros STL Export Dialog box asking for tolerance value

Generally, STL is the standard file format for Additive Manufacturing processes. However, the latest generation of MakerBot Replicator printers requires a different proprietary file format which is only compatible with MakerBot 3D Printers. The MakerBot file format includes data similar to STL, which is sliced into multiple layers and converted to RP machine language.

In the first part of the preparation, the CAD file was exported as an STL file with certain tolerance value. Tolerance value determines the height of each layer sliced in the STL file, as the tolerance value decreases, precision value of the model increases. It is also reasonable that the tolerance value should be same with the layer precision setting which is defined by MakerBot Desktop software, since the corresponding data should match the 3D Printer's actual setting.

In the second part of the preparation, the STL file was imported to MakerBot Desktop software, which has the virtual build plate, similar to the one found on the actual 3D printer. The build plate of the RP device is a real estate area for models to be printed on. With the MakerBot software, certain models could be placed on the virtual build plate, with orientation and location information. Since FDM based RP devices generally have the best resolution through the Z axis, it is logical to orient the model according to the details on it. The most detail was required in the Z axis of the model in this study, which means that the 3D surface textures on predefined base plaques were laid in their original orientation on the build plate (Figure 4.17).

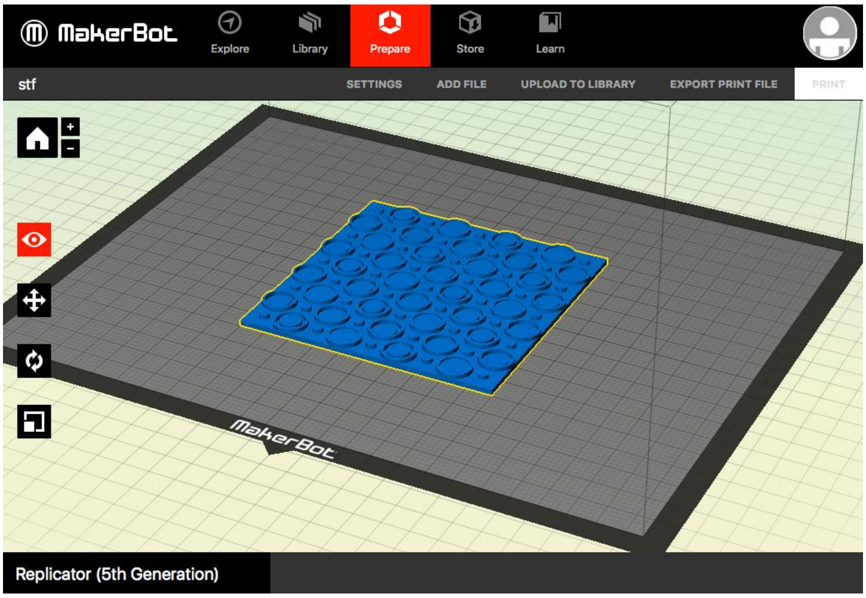


Figure 4.16 The MakerBot Desktop software with sample 3D surface texture data

Furthermore, the parameters of FDM based AM process could be modified through the settings windows of the MakerBot Desktop software. There were certain parameters in the setting panel which should be modified for increasing the reliability of the fabricated 3D surface texture models and stability of the 3D printer in the process of printing.

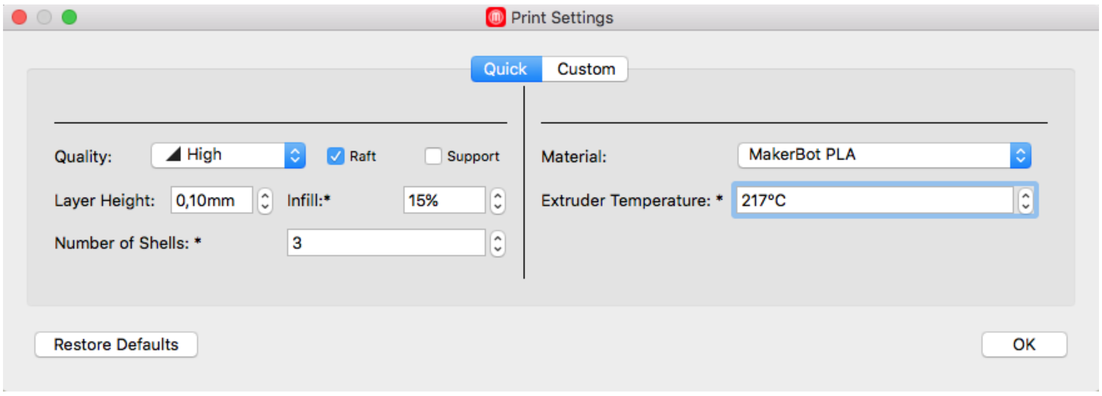


Figure 4.17 The optimal 3D printing parameters for 3D surface texture fabrication

After a long period of trial and testing, the optimal values for creating 3D surface texture plaques with PLA material can be seen in Figure 4.18. The quality section defines the height of each layer for the slicing and 3D printing process. As the layer height decreases, the model quality increases. However, since it requires more time to build more layers, the amount of print time increases dramatically with this option set to high. While ‘Normal’ setting has the layer height of 0,20 mm, the amount of elapsed time to print the model was about 2 hours and 13 minutes. However, when ‘High’ option is selected, the layer height becomes 0,10 mm, and the time required to print the model becomes 4 hours and 16 minutes, which is almost twice as more time to print. The high option of the parameter clearly increases build quality; hence the option is selected for the study. The infill value, number of shells and the temperature value was also altered to achieve best 3D surface texture detail on the printed plaques.

The following section explains the actual process of 3D printing. As mentioned earlier, the parts of Study 2 are overlapping with each other even though they have different titles.

4.5 Stage III: Manufacturing 3D Surface Texture Samples

Finally, in the last stage of Study 2, 3D surface textures are manufactured with the RP device available to the researcher, for the RGT experiment that is described in the next chapter. The RP device was MakerBot Replicator 5th Generation FDM based Rapid Prototyping machine (Figure 4.19). The printer was acquired through the BAP-02-03-2014-001 coded Scientific Research Project fund for another ongoing research project.

Figure 4.18 MakerBot Replicator 5th Generation Fused Deposit Modelling Rapid Prototyping Device (“MakerBot Replicator,” n.d.)

4.5.1 The Technical Properties of MakerBot Replicator (5th Generation)

The RP device was the latest generation of Replicator series of MakerBot Industries at the time the study was conducted. It has some unique features including the always-on cloud connected system.

The material supported by the device was PLA, which stands for polylactic acid. With its interchangeable Smart Extruder system, it supports different materials as a filament, however, at the time the research was conducted, there was no other version of Smart Extruder yet released.

The precision of the 3D printer is similar to the other FDM based RP devices. The layer height of the model created can be as low as 100 microns, which is equal to 0.1 mm. However, the nozzle which extrudes the filament, has the diameter of 400 microns, which is 0.4 mm. These measurements show that the RP device has 0.1 mm precision on Z axis, and 0.4 mm precision on X and Y axes.

The maximum build volume of the device is 25,2 cm in length, 19,9 cm in depth, 15 cm in height. The volume could also be mentioned as 7522 cm^3. In terms of volume and material, the RP device is adequate for the purpose of the research. However, it is also important to note that the produced 3D surface texture samples had unintended micro-textures because of the utilization of the particular AM technique, which is FDM (Fused Deposit Modelling), and which has the precision level of 0.4 mm in X and Y axes. In fact, the residual unwanted micro-textures can be removed with various finishing techniques including sanding, applying chemicals/solvents or curing with cooling chamber for the parts produced with FDM technique (“Smoothing FDM Parts | Finishing Processes,” n.d.). However, these procedures not only smoothen the unintended micro-texture derived from the FDM technique, but also the actual 3D surface textures purposeally put on a surface. Hence, the micro-texture residuals were ignored for the experiment. There are other AM techniques which results in much better surface quality, however, the FDM type of RP machine is the only machine that was available to the researcher.

4.5.2 The Manufacturing Process of 3D Surface Textures

The manufacturing process of 3D surface textures was handled in two stages. At the first stage, - preparation phase - preliminary research took place to find out the feasibility and precision capabilities of the rapid prototyping device. Arbitrary samples of 3D surface texture drawings were created with Rhinoceros Grasshopper software, which enables 3D surface textures to be controlled parametrically. The textures were applied to the predefined 95 cm x 95 cm plaques, consecutively these drawings were prepared for 3D printing process and manufactured correspondingly as presented in Figure 4.20.

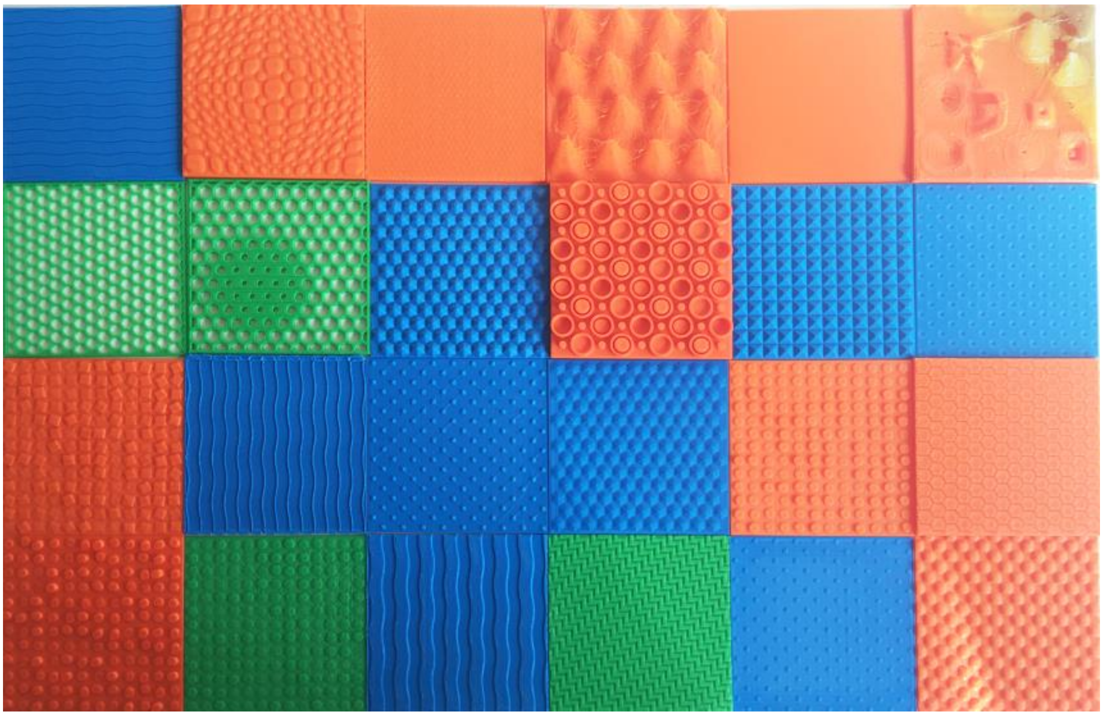


Figure 4.19 Preliminary Research with MakerBot Replicator 5th Generation FDM based 3D Printer

Through the preparation process and 3D printing stage, different parameters were applied to reach the ideal setting of 3D surface texture manufacturing workflow. The diversity of arbitrarily generated samples allowed the researcher to accommodate the optimal settings, even for the extreme cases that required special attention due to the limitations of the rapid prototyping device. The parameters of rapid prototyping device to be considered through the manufacturing of 3D surface texture samples include, but are not limited to; layer height, extruder temperature, presence of rafts – raft which is the additional bottommost base surface in 3D printed models-, extruder speed in X and Y directions, infill amount, and shell count.

Thanks to the preliminary study, the selected 3D surface texture samples were manufactured as precise as it can be obtained from the available rapid prototyping device. Figure 4.21 presents the final samples for the RGT survey, which took place in Study 3.

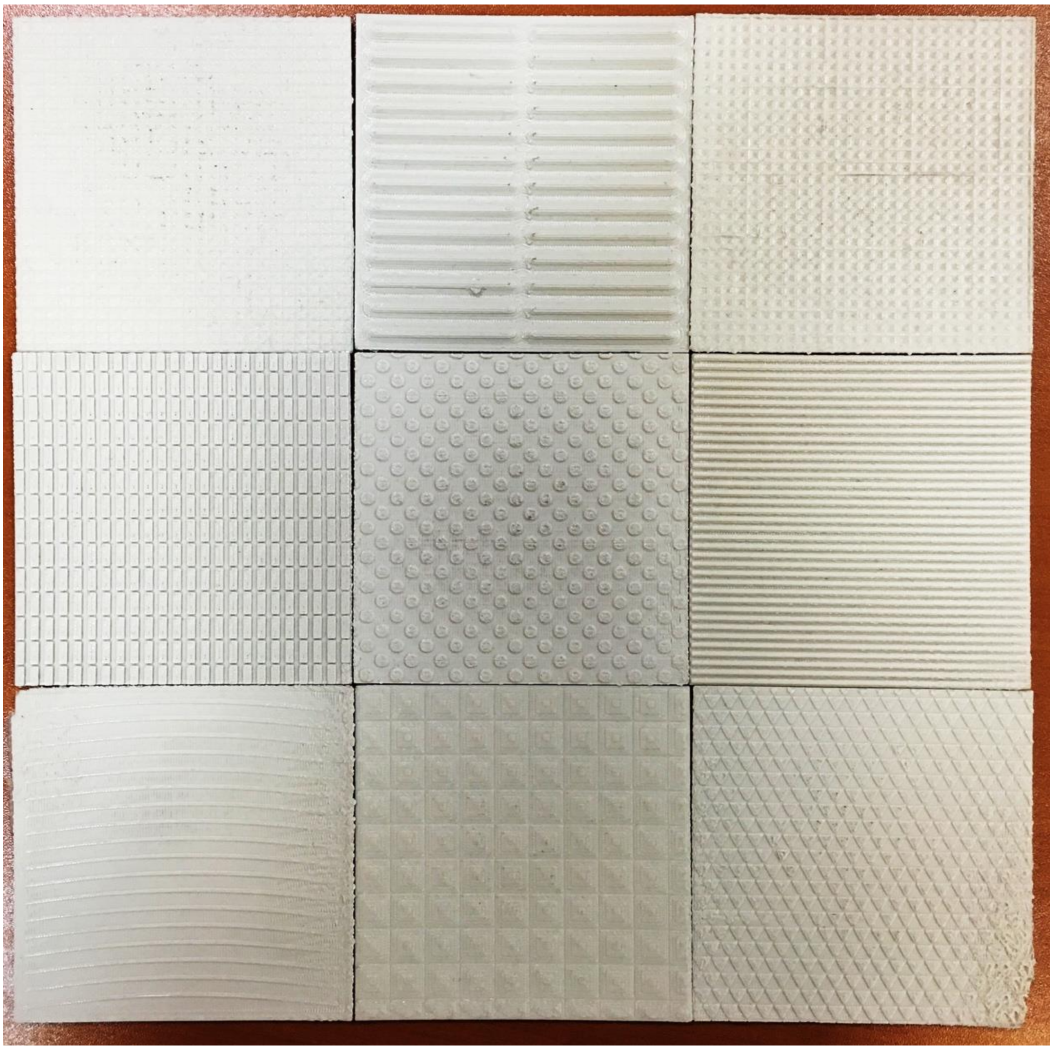


Figure 4.20 Manufactured 3D Surface Textures for RGT Survey

Table 4.9 Bitmap Resemblance of Manufactured 3D Surface Texture Samples

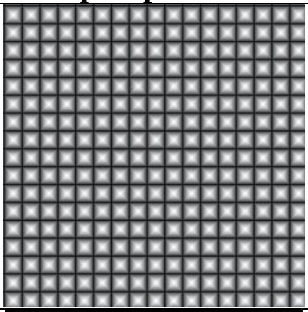
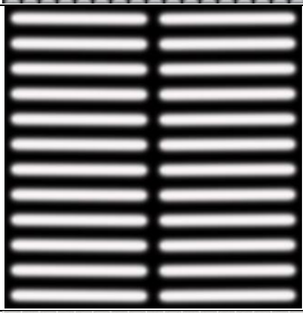
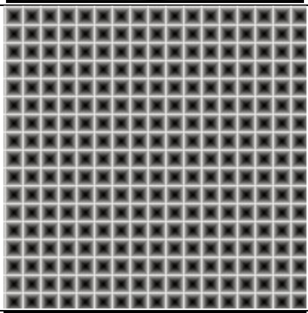
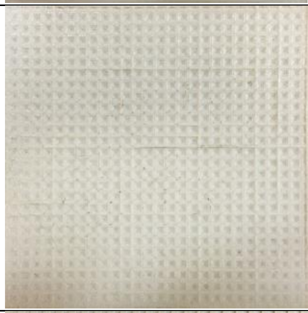
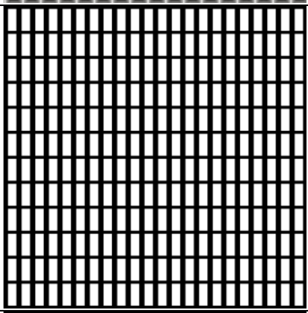
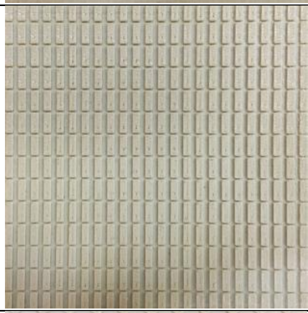
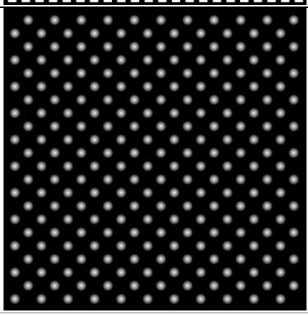
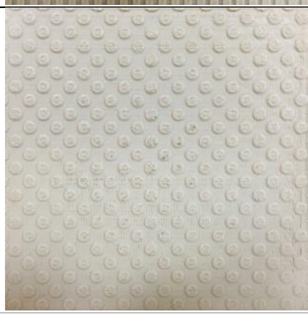
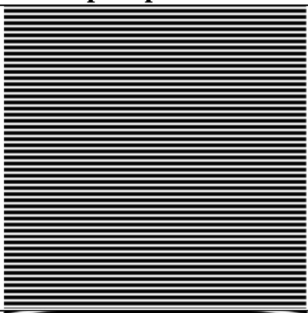
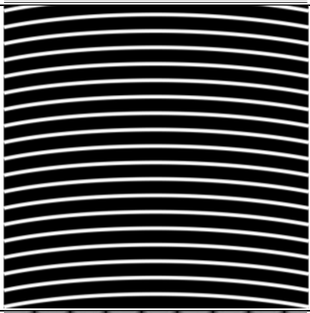
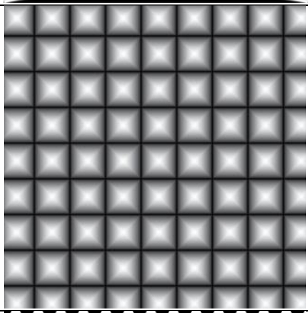
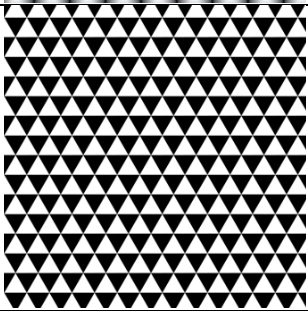
Texture ID	Bitmap Representation	Manufactured Sample
YD-01		
YD-02		
YD-03		
YD-04		
YD-05		

Table 4.9 Continued

Texture ID	Bitmap Representation	Manufactured Sample
YD-06		
YD-07		
YD-08		
YD-09		

4.6 Discussion

This chapter provided the overview of the methodology followed for the 3D surface texture creation process with the utilization of a rapid prototyping device. 3D surface texture generation process with available tools, which are both 3D modelling software programs and a rapid prototyping device, are explored to have a sense of the workflow of adding 3D surface textures to the desired products.

In the first stage, the standard – a set of criteria – is introduced for evaluating 3D modelling programs for 3D surface texture generation capabilities. With this set of criteria, different 3D surface programs were evaluated and suitable ones were chosen to be utilized on texture sample generation process. Rhinoceros with Grasshopper Plugin and 3matic STL were used to produce 3D surface texture samples.

Digital modelling of 3D surface textures is included in the second stage of this study. Rhino Grasshopper and 3-matic STL are used as the 3D surface texture creation tools. While Rhino Grasshopper is used to create parametric 3D surface textures, 3-matic STL is used to create 3D surface textures from bitmap images.

In the last stage of Study 2, 3D surface texture drawings were manufactured using the available rapid prototyping device. First part of this stage included the parameter setting of both printable STL file and rapid prototyping device. The second part of the stage included the process of manufacturing nine 3D surface texture samples on predefined plaque settings.

This chapter included basic workflow of using both 3D surface texture generation programs and manufacturing process with a rapid prototyping device. It is understood that there are still requirements for an advancement on 3D surface texture creation programs to fully utilize the power of rapid prototyping device.

4.7 Limitations of Study 2

The software research is not thorough because of time limitations and lack of having software within the availability of the researcher. Further studies would cover more CAD software to unleash the full potential of using digital tools including the digital voxel clay based software programs.

The surface textures are only tested on a predefined planar surface. The perception and usage of 3D surface textures on non-planar forms could enhance the results of further studies in this topic. 3D surface textures on actual products would enhance its usage scenario, and could also bring new ways of interactions.

The only material used in this study is PLA since it is restricted with the limitations of the rapid prototyping device. ABS is another kind of material that could be used in FDM based rapid prototyping devices. ABS has better compatibility with post-treatments like acetone bath to improve the surface finish of textures. There are also other materials on other type of rapid prototyping devices which could also alter the course of this study.

The number of surface textures could be increased since it is limited with the textures sampled from the stores in Ankara. There are thousands of different texture types, which could contribute to the newly developing 3D surface topic in the field of industrial design This is only an attempt to start a new research area since this study is the start of a new era in the field.

CHAPTER 5

THE REPERTORY GRID EXPERIMENT AND METHODOLOGY

In this chapter, the process and the procedures of Study 3 is explained. Within the scope of this chapter, the Repertory Grid Technique (RGT) is used as a method to elicit the attitudinal approach for the manufactured 3D textures in Study 2. Primarily, the RGT method is introduced and reviewed. Then, the data collection procedures are explained and the obtained results are analyzed and discussed.

5.1 Aim of the Study

The aim of the study is to find out the elicited attitudinal approaches perceived from sampled 3D surface textures; both apprehended from visual and tactual stimuli. It is intended to understand and evaluate the user experience through the interaction with those textures and anticipate the potential improvements in product design via surface textures. As mentioned, RGT is utilized to obtain the experimental data. The main reason of choosing RGT as a methodology is to have an opportunity to gather unbiased data from the participants. Since each stimulus is subjective and depends on the individuals, the surface texture samples should be evaluated via unbiased methodology.

By choosing RGT as a method, it is aimed to determine and coin the terms that are generated by the observers personally out of this field study – the constructs, as they are termed in RGT – that are directly related to the individual's way of perceiving the surface textures and mentioning them verbally. Such verbalization phase of this study poses both a challenge and an opportunity to detect the similarity and difference relations between the sampled textures. Accordingly, the experimental set-up is organized by placing the verbalization phase in prior. To optimize this study, nine 3D surface textures were chosen as they are sampled from Study 1 and produced with explored manufacturing technique mentioned in Study 2.

5.2 Components of Study 3

Earlier studies of this thesis covered both the purposes of using a particular surface texture in certain products and the methods to manufacture sampled 3D surface textures with the utilization of CAD programs and rapid prototyping device. Now that the sampled 3D surface textures are produced, this last study of this thesis introduces the RGT experiment of the sampled and produced 3D surface textures. Figure 5.1 represents the structure of Study 3.

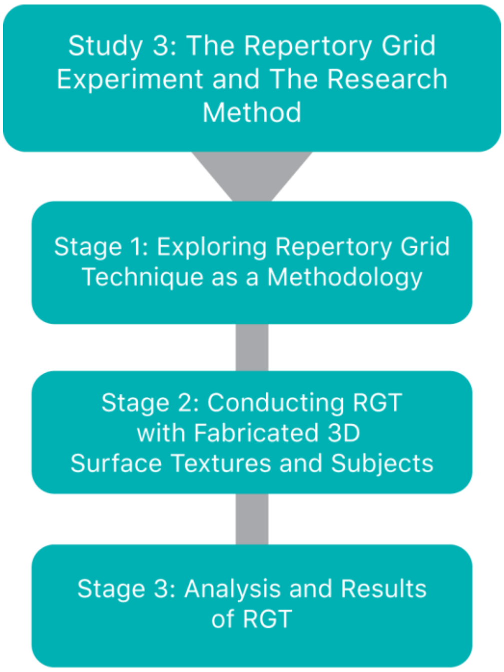


Figure 5.1 Components of Study 3

The first stage of Study 3 covers Repertory Grid Technique as a methodology to utilize the technique as a surveying tool to reveal elicited attitudes of participants towards sampled and produced 3D surface textures.

Following the first stage, the second stage of Study 3 accommodates the preparation phase of materials for the Repertory Grid technique. Thanks to the pilot research conducted prior to the actual experiment, all the required elements, including the Repertory Grid Response Sheet, are prepared. Necessary circumstances for the survey is also set up. Stage 2 also presents the information about the actual surveying of participants with 3D surface textures, to give brief instructions of the RGT methodology applied. Data collection of elicited attitudes towards 3D surface textures is explained with the actual set up of the surveying field.

The final stage of the Study 3, which is Stage 3, presents the analysis methodology and results of the experiment.

5.3 Stage 1: What is RGT?

Repertory Grid Technique (abbr. RGT) is a methodology that is based on George Kelly's seminal work (1955; cited in Akbay, 2013) on personality and cognition, known as Personal Construct Theory. Kelly's Personal Construct Theory consists of two major points about personal states and the cognition of minds as; (1) an individual's process of making sense by means of their interaction with their environments, and (2) the feelings and the experiences that individuals obtain from those interactions.

RGT is utilized both for qualitative and quantitative practical exercise of the Personal Construct Theory that focuses on the constructs of a person about his/her experience. This method promotes the definition of a set of elements based on the person's individual constructs that are anticipated from his/her experience, which sorts out and examines the relationships between the elements and personal constructs (Bell, 2003; cited in Akbay, 2013).

The method proposes a grid as a two-dimensional matrix that is constructed by means of data that is provided by a single observer. There are two principal components of the matrix as; (1) elements, and (2) personal constructs. As two-dimensional matrix is generated by the columns that includes parameters which are the elements while rows signify the personal constructs that are provided by the observer. By using columns and rows, this data matrix reveals the interrelations between the elements and the personal constructs (Leach, 1980; Osbourn, 1988).

To define these two principal components; **elements** are the events or things that are abstracted and evaluated as a construct by the observer. It can be obtained that the elements are the things that are subjected to the evaluation which converges as constructs (Kelly, 1963; Osbourn, 1988). **Constructs** are the concepts that are obtained through the evaluation of the elements, which are based on the process of persons' strategies of evaluating the similarities and differences between the elements that are subjected to judgment (Osbourn, 1988). According to Kelly (1955; cited in Akbay, 2013), constructs are mostly dichotomous which highlights the bipolarity of the constructs which are expected to be provided by the observer.

There are six different strategies that Kelly proposes while generating constructs, however within the scope of this research dyadic and triadic elicitation procedures are found necessary to review (Caputi & Reddy, 1999).

Dyadic Elicitation Procedure is the most common procedure that is used for the complex elicitation (Easterby-Smith, 1980) processes by means of being easier to apply and revealing consistent framework regarding Personal Construct Theory (Osbourn, 1988). This procedure is based on the comparative analysis of **two elements** that are selected from a set of elements and presented to the observers and from the observer it is expected to obtain the evaluation of similarity and difference. It is also expected to obtain the facts behind the differences and similarities (Easterby-Smith, 1980). As a result of each dyad there emerges bipolar constructs based on conceptual dichotomies.

Triadic Elicitation Procedure is known as the standard procedure to obtain constructs by means of evaluating three elements selected from a full set of elements. The order of the elements to be selected directly effects the grid structure, so the elements are required to be chosen randomly (Easterby-Smith, 1980; cited in Akbay). The chosen three elements are presented to the observer and it is expected to obtain the ideas behind what makes two elements alike and how they differ from the third one and in what ways the third element differs from the other two elements from the observer.

By iterating the same procedure ends up with the observer’s unwillingness to reveal new triadic constructs.

Akbay (2013) has conducted a research on elicited attributes of 11 basic colours in her PhD thesis. For this she has used 11 colour cards in A6 size (148x105 mm). In her pilot study, she has tried out both the triadic and the dyadic elicitation procedures, but has come to the conclusion that dyadic elicitation procedure was more suitable to the nature of her study. The reasons were (Akbay, 2013):

- The probability of dyads of different surface textures to appear during the study to be presented to observers were higher than the probability of triads to appear.
- More explicit constructs poles were elicited using dyads. This means the participants founded easier to compare two samples rather than the use of three samples. On the other hand, using the triadic elicitation procedure, observers had to produce implicit poles which required excessive effort to indicate opposites.
- Using dyads made it possible to collect more interpersonal data that could be generalizable for this research.

As this research follows a parallel approach using sample cards of textures, the dyadic elicitation procedure was preferred to utilize in this research.

5.4 Stage 2: RGT and the Methodology of Study 3

5.4.1 Methodology of Data Collection

The data collection procedure is based on the Dyadic Elicitation Procedure that is conducted as an individual interview by the researcher and concerted by 30 participants. The participants are design students with ages ranging from 20 to 25; 17 of them are female and 13 of them are male. For data collection, a pre-formatted data sheet is used and the procedure is followed separately for each participant. For this, Akbay’s (2013) data collection sheet is used as a reference. The data sheet is termed as response sheet within the scope of this research (Figure 5.2).

Yüzey Dokusunun Ayırt Edici Özellikleri **Tarih:**

Katılımcı No: **Yaşı:** **Cinsiyeti:** ☐ **K** ☐ **E** **Bölümü:** **Görüşme Süresi:**

Lütfen aşağıda kodları yer alan 9 yüzey dokusunu (YD-01, YD-02, YD-03, YD-04, YD-05, YD-06, YD-07, YD-08, YD-09), sizin tarafınızdan tanımlanan karşıt özelliklerini birbirinden bağımsız olarak ne kadar taşıdığına dair **1’den 5’e** (düşükten yükseğe) kadar değerlendiriniz.

1 2 3 4 5

[IP] TUTUM SOL	YD-01	YD-02	YD-03	YD-04	YD-05	YD-06	YD-07	YD-08	YD-09	[EP] TUTUM SAĞ

Figure 5.2 RGT Response Sheet

The response sheet is mainly based on the verbal mapping of the arbitrary dyadic comparison of presented 3D textures via bipolar semantic chart. As a chart geometry, the sheet is split up into two poles based on implicit pole, abbreviated as IP, and emergent pole, abbreviated as EP. In-between those IP-EP cells, the surface texture code numbers are listed side by side to ease their visibility during the process of scoring, using a scale between 1 and 5.

Akbay (2013) used a 1-to-7 scale in her research. In a pilot study made for this research, this 1-to-7 scale was used for three participants. As a result, it was observed that the scale was found to be confusing during the scoring phase. Therefore, for this study, a 1-to-5 scale was preferred.

As it is mentioned, the procedure is based on the dyadic comparison process and it is requested from participants to compare the presented 3D surface textures by means of similarity and difference and jot their constructs down on IP-EP cells. The sheet contained 10 rows. Following this phase, it was requested from participants to evaluate all the textures within the scope of elicited constructs by using a 1-to-5 scoring scale. As it is illustrated in the response sheet, the scale represents the IP as it gets closer to 1 and EP as it gets closer to 5.

5.4.2 The Participants

The procedure was conducted in a semi-private archive room affiliated to the Department of Industrial Design (Room no. 14). The study for all 30 participants was carried out between the dates 15 December 2015 and 2 January 2016, distributed to weekdays and weekends, depending on the availability of the participants. The participants were 29 undergraduates from the Department of Industrial Design and one graduate student from the Department of Architecture, volunteering upon invitation. The group of participants are preferred specifically from design students due to their basis on academic background which enhances their visual literacy and knowledge. The age range was between 20 and 25. Table 5.1 represents the demographic information of the participants.

Table 5.1 Demographic Information of the Participants

Male	Female	3rd Year	4th Year	Graduate Level
13	17	27	2	1

5.4.3 Data Collection Procedure

The procedure of data collection followed for each participant was as follows. Firstly, the participant was invited into the experiment room. The participant was introduced to the topic of the research, the methodology of the RGT, and shown the response sheet. The nine texture samples were available for viewing during this explanation but were not given to the participants for exploration. At the end of the explanation, the procedure began with the introduction of the first set of dyads. The dyads were randomly distributed to cover all the possible combinations of pairs

(Appendix C). Therefore, prior to the study, the pairs were determined beforehand and presented to the participants in a random order.

The participants were asked evaluate each predefined dyad to come up with an elicited attribute, - an adjective – to be written on the emergent pole of the response sheet. Once the participants were no longer able to produce adjectives for the particular dyad, next dyad was presented. The elicitation procedure included both visual and tactile stimuli for each dyad. In the meantime, for each dyad, the participants were asked to produce an opposite pole for their elicited attributes. For this it was explained to the participants that this opposite pole did not have to indicate the antonym of the emergent attributes and could represent other types of opposition which could have a meaning to the way participants perceived the texture.

The response sheet contained 10 rows. In the procedure it was aimed to complete all ten rows, in order to be able to obtain rich data. Once this was completed, the participants were asked to evaluate all the nine texture samples with their elicited attributes on a scale ranging from 1 to 5. The score of 1 being the closest to the left hand side of the response sheet (implicit pole, the opposite adjective of the primarily elicited adjective), and 5 being closest the right (emergent pole, the adjective that was primarily elicited as a response to the texture).

Yüzey Dokusunun Ayırt Edici Özellikleri

Tarih: 25/12/2015

Katılımcı No: P07 Yaşı: 21 Cinsiyeti: [X] K [ ] E Bölümü: ID Görüşme Süresi: 32 dk

Lütfen aşağıda kodları yer alan 9 yüzey dokusunu (YD-01, YD-02, YD-03, YD-04, YD-05, YD-06, YD-07, YD-08, YD-09), sizin tarafınızdan tanımlanan karşıt özelliklerini birbirinden bağımsız olarak ne kadar taşıdığına dair **1'den 5'e** (düşükten yükseğe) kadar değerlendiriniz.

1 — 2 — 3 — 4 — 5

[IP] TUTUM SOL	YD-01	YD-02	YD-03	YD-04	YD-05	YD-06	YD-07	YD-08	YD-09	[EP] TUTUM SAĞ
rahatsız edici	1	5	1	1	3	5	3	3	3	zevk verici
lineeelik	2	1	1	1	3	1	2	2	3	diagonal
akışkan	5	2	3	3	5	1	1	2	3	engebeli
daha seyrek	5	2	5	3	1	3	1	4	4	kalabalık
pürüzlü	1	3	1	2	1	3	5	5	2	kaygan
ritmik	2	1	3	1	1	1	1	4	2	sıkıcı
basamaklı	2	1	3	2	1	1	1	5	2	akışkan
güven verici	1	3	2	2	2	3	2	3	2	elinden kayıp gidicek gibi
desen gibi tekrar eden	1	2	1	1	1	3	2	1	1	rastgele
kaygan his	5	3	4	4	4	2	2	4	4	tutması daha kolay

Figure 5.3 Response Sheet Filled by P07

Overall the number of dyads presented to the participants ranged from three to seven. While ten participants carried out the experiment with three dyads, eight participants carried out the experiment with four, four participants carried out the experiment with five, five participants carried out the experiments with six and three participants carried out the experiment with seven dyads. The duration of the sessions ranged from 23 minutes to 69 minutes.

As a consequence, from 30 participants a total number of 300 elicited attributes (bipolar personal attitudes) were obtained. Figure X represents a filled example of the response sheet of P07.

5.5 Stage 3: Analysis Procedure

In order to evaluate the collective data, both qualitative and quantitative analysis procedures were adapted from Akbay's PhD Study (2013).

5.5.1 Content Analysis

Within the frame of this research, content analysis is used as a scientific procedure to evaluate data systematically that is obtained from RGT.

Content analysis as a scientific analysis procedure, is used mainly for verbal and textual data which are obtained through surveying, interviewing and observing and conducted through examining the contextual meaning to get veridic inferences from data (Hsieh & Shannon, 2005). Content analysis poses both qualitative and quantitative status; it is qualitative due to the process of inductive reasoning that reveals the subjective descriptions of how individuals apprehend the context/case; and it is quantitative due to the process of deductive reasoning that provides numerical data by means of statistics. Within the scope of this research, both qualitative and quantitative state of content analysis availed during the analysis of elicited attitudes and hence constructs (Zhang & Wildemuth, 2005).

Here, the major aim of content analysis is to sort the elicited attitudes in RGT into consistent content classes, called constructs. Qualitative content analysis is used to examine the contextual meaning of the elicited attitude of the participants in RGT, then within those elicited attitudes, the common attitudes are searched to form a construct. Quantitative content analysis is performed through the frequency counts – **C Count** - among elicited attitudes to evaluate the commonness and iteration in constructs.

5.5.2 Processing Derived Attitudes into Constructs

The processing stage of the elicited attitudes is based on the elimination procedure that covers the process of generating constructs from elicited attitudes of participants towards nine 3D surface texture samples.

With the content analysis, the elicited attitudes that have same or similar meaning are grouped and formed into a single construct. By evaluating each individual elicited attitude, the 300 elicited attitudes gathered in the experiment are reduced to 41. Through this reduction process, even in a response sheet of single particular participant, the attitudes with similar meaning or context is searched and in such cases, the iterated (by means of context and meaning) attitudes were grouped into a single attitude. It can be said that, the elimination phase is both conducted interpersonally and person-specific. The reduction process is verified and cross-checked with the values through CID process. As CID signifies the ***construct identity***, CID process is mainly based on assigning each elicited attitude a unique identity number to both determine the number of constructs and the frequency in the iteration of the attitude for further phases of the study.

Through this study, all elicited attitudes as they are derived in Turkish (Table 5.2), the native language of the participants due to the location of the experiment, are translated into English (Table 5.3). Each attitude is translated by considering all their usages in both languages and implied meanings of the attitudes are verified via participants through interview process.

Continuing from the last stage, attitudes were condensed which has similar meanings and values in the results section and 41 attitudes are reduced to 33. Table 5.4 represents a pair of different elicited attitudes which are condensed into a single construct. Up to this stage, by considering semantic aspects of the constructs, qualitative elimination is conducted.

CID	C Count	IP	YD-01	YD-02	YD-03	YD-04	YD-05	YD-06	YD-07	YD-08	YD-09	EP	Difference
1	4	*Ciddi*	2,25	2,25	2,25	2,00	4,00	3,50	2,75	2,25	3,00	*Gündelik*	2,00
2	19	*Rahatsız Edici*	1,53	2,37	3,42	3,32	3,26	4,05	3,68	2,79	3,05	*Rahatlatıcı*	2,53
3	24	*Pürüzlü*	2,00	3,17	2,46	2,63	2,79	3,50	2,92	2,92	2,46	*Pürüzsüz*	1,50
4	8	*Çekici*	2,38	2,13	3,25	2,25	3,13	2,13	3,38	2,50	3,63	*İtici*	1,50
5	1	*Zamansız*	4,00	3,00	3,00	1,00	1,00	1,00	4,00	3,00	2,00	*Geçici*	3,00
6	14	*Alışıldık*	3,64	3,57	3,36	2,64	3,29	2,50	2,79	3,21	3,50	*Sıradışı*	1,14
7	11	*Dinamik*	3,64	2,82	3,55	3,27	3,18	3,18	2,27	3,91	2,55	*Durgun*	1,64
8	10	*Akışkan*	4,60	2,40	3,60	2,60	4,20	1,80	2,00	2,40	3,20	*Durağan*	2,80
9	10	*Sert*	1,30	2,60	2,60	3,40	3,30	4,10	3,60	4,00	3,10	*Yumuşak*	2,80
10	6	*Keyifli*	3,00	3,17	3,17	3,00	2,00	2,33	1,83	4,00	2,33	*Sıkıcı*	2,17
11	11	*Göz Alıcı*	3,36	2,36	3,27	2,36	2,27	2,73	3,55	3,55	3,27	*Vasat*	1,27
12	4	*Yenecek*	2,25	3,75	1,00	3,75	2,75	3,50	4,50	3,75	2,25	*Yenimeyecek*	3,50
13	1	*Heryere Uygun*	3,00	3,00	4,00	3,00	1,00	1,00	4,00	4,00	4,00	*Kısıtlı*	3,00
14	6	*Dişi*	2,67	1,00	3,00	3,00	1,67	2,67	3,00	2,67	3,00	*Erkek*	2,00
15	15	*Karmaşık*	4,20	3,20	4,00	4,07	3,20	4,53	3,80	3,73	3,27	*Basit*	1,33
16	10	*Yönlü*	3,40	2,40	3,20	1,70	4,00	1,60	1,80	3,40	2,90	*Yönsüz*	2,40
17	2	*Forma yakın*	3,00	1,00	4,00	2,00	3,00	2,00	4,00	4,00	4,00	*Formdan uzak*	3,00
18	5	*Doğal*	2,60	2,60	4,40	3,20	3,20	2,60	2,60	2,60	2,20	*Endüstriyel*	2,20
19	10	*Tekrar Eden*	2,20	2,40	2,00	1,50	2,40	1,80	2,70	1,80	1,60	*Süreksiz*	1,20
20	2	*İlüzyon yaratan*	3,00	5,00	2,00	5,00	5,00	2,00	5,00	5,00	1,00	*Gözü yanıltmayan*	4,00
21	6	*Gıdıklayıcı*	2,67	2,33	3,00	2,33	2,33	1,67	4,00	3,00	2,33	*His uyandırmayan*	2,33
22	11	*İfadeli*	2,64	1,91	2,64	3,55	3,45	3,27	3,36	4,55	3,18	*İfadesiz*	2,64
23	1	*Uyumlu*	2,00	3,00	1,00	4,00	3,00	4,00	5,00	4,00	5,00	*Uyumsuz*	4,00
24	4	*İşlevli*	4,00	2,25	4,50	1,25	2,75	1,75	2,00	3,25	3,50	*İşlevsiz*	3,25
25	17	*Güvenli*	3,59	1,94	4,24	2,18	2,71	2,06	2,65	3,65	2,88	*Güvensiz*	2,29
26	4	*Modern*	2,50	1,50	2,00	1,00	2,00	2,00	2,00	4,50	2,50	*Antik*	3,50
27	4	*Ucuz*	2,00	4,00	1,00	3,50	3,00	2,50	3,50	4,00	2,50	*Pahalı*	3,00
28	2	*İleri teknoloji*	3,00	1,00	3,00	1,00	5,00	3,00	4,00	3,00	5,00	*Sıcak*	4,00
29	12	*Sık*	1,50	4,00	1,92	2,58	3,75	2,50	4,50	3,00	2,83	*Seyrek*	3,00
30	4	*Yuvarlak*	5,00	3,50	4,50	5,00	2,00	3,50	2,50	4,50	4,50	*Köşeli*	3,00
31	5	*Temiz*	3,20	3,00	3,20	3,00	2,40	2,60	1,40	2,20	4,00	*Kirli*	2,60
32	12	*Lineer*	2,50	3,00	2,33	3,17	3,17	3,00	3,17	2,83	3,00	*Diagonal*	0,83
33	7	*Derin*	4,14	2,14	3,43	4,14	2,43	4,00	2,43	3,57	3,57	*Sığ*	2,00
34	4	*İyi*	3,00	3,50	3,00	1,50	3,50	1,50	1,50	3,00	2,50	*Kötü*	2,00
35	3	*Üstüste*	4,33	2,33	2,00	2,33	1,00	2,00	5,00	3,33	3,33	*Entegre Olmayacak*	4,00
36	8	*Aşınır*	3,38	3,75	2,63	3,50	3,00	3,13	3,75	3,25	3,38	*Uzun Ömürlü*	1,13
37	9	*Gevrek*	4,00	2,67	3,22	3,44	2,89	3,78	3,89	3,56	3,00	*Esnek*	1,33
38	3	*Yükselen*	3,33	1,00	5,00	3,00	2,33	1,33	2,00	3,00	3,00	*Alçalan*	4,00
39	2	*Kararlı*	3,00	1,00	4,00	2,00	3,00	2,00	5,00	5,00	3,00	*Kararsız*	4,00
40	8	*Dağınık*	4,25	4,13	3,50	4,50	3,50	4,25	4,00	3,75	3,25	*Düzenli*	1,25
41	1	*Tam*	5,00	1,00	3,00	4,00	3,00	4,00	1,00	5,00	3,00	*Eksik*	4,00

Table 5.2 List of Elicited Attitudes in Turkish in Relation to the Average Ratings of 3D Surface Texture Samples

CID	C Count	IP	YD-01	YD-02	YD-03	YD-04	YD-05	YD-06	YD-07	YD-08	YD-09	EP	Difference
1	4	*Serious*	2,25	2,25	2,25	2,00	4,00	3,50	2,75	2,25	3,00	*Leisure*	2,00
2	19	*Disturbing*	1,53	2,37	3,42	3,32	3,26	4,05	3,68	2,79	3,05	*Relaxing*	2,53
3	24	*Rough*	2,00	3,17	2,46	2,63	2,79	3,50	2,92	2,92	2,46	*Smooth*	1,50
4	8	*Appealing*	2,38	2,13	3,25	2,25	3,13	2,13	3,38	2,50	3,63	*Repellent*	1,50
5	1	*Timeless*	4,00	3,00	3,00	1,00	1,00	1,00	4,00	3,00	2,00	*Ephemeral*	3,00
6	14	*Usual*	3,64	3,57	3,36	2,64	3,29	2,50	2,79	3,21	3,50	*Extra-ordinary*	1,14
7	11	*Dynamic*	3,64	2,82	3,55	3,27	3,18	3,18	2,27	3,91	2,55	*Stagnant*	1,64
8	10	*Fluid*	4,60	2,40	3,60	2,60	4,20	1,80	2,00	2,40	3,20	*Constant*	2,80
9	10	*Firm*	1,30	2,60	2,60	3,40	3,30	4,10	3,60	4,00	3,10	*Soft*	2,80
10	6	*Delighful*	3,00	3,17	3,17	3,00	2,00	2,33	1,83	4,00	2,33	*Boring*	2,17
11	11	*Spectacular*	3,36	2,36	3,27	2,36	2,27	2,73	3,55	3,55	3,27	*Mean*	1,27
12	4	*Foody*	2,25	3,75	1,00	3,75	2,75	3,50	4,50	3,75	2,25	*Uneatable*	3,50
13	1	*Regular*	3,00	3,00	4,00	3,00	1,00	1,00	4,00	4,00	4,00	*Limited*	3,00
14	6	*Female*	2,67	1,00	3,00	3,00	1,67	2,67	3,00	2,67	3,00	*Male*	2,00
15	15	*Complicated*	4,20	3,20	4,00	4,07	3,20	4,53	3,80	3,73	3,27	*Plain*	1,33
16	10	*Directional*	3,40	2,40	3,20	1,70	4,00	1,60	1,80	3,40	2,90	*Non-directional*	2,40
17	2	*Close to Form*	3,00	1,00	4,00	2,00	3,00	2,00	4,00	4,00	4,00	*Far from form*	3,00
18	5	*Natural*	2,60	2,60	4,40	3,20	3,20	2,60	2,60	2,60	2,20	*Industrial*	2,20
19	10	*Iterative*	2,20	2,40	2,00	1,50	2,40	1,80	2,70	1,80	1,60	*Discontinuous*	1,20
20	2	*Illusive*	3,00	5,00	2,00	5,00	5,00	2,00	5,00	5,00	1,00	*Non-illusive*	4,00
21	6	*Tittlating*	2,67	2,33	3,00	2,33	2,33	1,67	4,00	3,00	2,33	*Sensless*	2,33
22	11	*Expressive*	2,64	1,91	2,64	3,55	3,45	3,27	3,36	4,55	3,18	*Unexpressive*	2,64
23	1	*Harmonious*	2,00	3,00	1,00	4,00	3,00	4,00	5,00	4,00	5,00	*Disharmonious*	4,00
24	4	*Functional*	4,00	2,25	4,50	1,25	2,75	1,75	2,00	3,25	3,50	*Functionless*	3,25
25	17	*Secure*	3,59	1,94	4,24	2,18	2,71	2,06	2,65	3,65	2,88	*Insecure*	2,29
26	4	*Modern*	2,50	1,50	2,00	1,00	2,00	2,00	2,00	4,50	2,50	*Antique*	3,50
27	4	*Cheap*	2,00	4,00	1,00	3,50	3,00	2,50	3,50	4,00	2,50	*Expensive*	3,00
28	2	*Hi-tech*	3,00	1,00	3,00	1,00	5,00	3,00	4,00	3,00	5,00	*Hot*	4,00
29	12	*Closely*	1,50	4,00	1,92	2,58	3,75	2,50	4,50	3,00	2,83	*Sparse*	3,00
30	4	*Aspheric*	5,00	3,50	4,50	5,00	2,00	3,50	2,50	4,50	4,50	*Angular*	3,00
31	5	*Clean*	3,20	3,00	3,20	3,00	2,40	2,60	1,40	2,20	4,00	*Dirty*	2,60
32	12	*Linear*	2,50	3,00	2,33	3,17	3,17	3,00	3,17	2,83	3,00	*Diagonal*	0,83
33	7	*Deep*	4,14	2,14	3,43	4,14	2,43	4,00	2,43	3,57	3,57	*Shallow*	2,00
34	4	*Good*	3,00	3,50	3,00	1,50	3,50	1,50	1,50	3,00	2,50	*Bad*	2,00
35	3	*Integrated*	4,33	2,33	2,00	2,33	1,00	2,00	5,00	3,33	3,33	*Non-integrated*	4,00
36	8	*Corrdible*	3,38	3,75	2,63	3,50	3,00	3,13	3,75	3,25	3,38	*Non-Corrodible*	1,13
37	9	*Brittle*	4,00	2,67	3,22	3,44	2,89	3,78	3,89	3,56	3,00	*Flexible*	1,33
38	3	*Rising*	3,33	1,00	5,00	3,00	2,33	1,33	2,00	3,00	3,00	*Descending*	4,00
39	2	*Stable*	3,00	1,00	4,00	2,00	3,00	2,00	5,00	5,00	3,00	*Unstable*	4,00
40	8	*Dispersed*	4,25	4,13	3,50	4,50	3,50	4,25	4,00	3,75	3,25	*Orderly*	1,25
41	1	*Complete*	5,00	1,00	3,00	4,00	3,00	4,00	1,00	5,00	3,00	*Lacking*	4,00

Table 5.3 List of Elicited Attitudes in English in Relation to the Average Ratings of 3D Surface Texture Samples

Rahatsız Edici	1.53	2.37	3.42	3.32	3.26	4.05	3.68	2.79	3.05	*Rahatlatıcı*
Pürüzlü	2.00	3.17	2.46	2.63	2.79	3.50	2.92	2.92	2.46	*Pürüzsüz*

Table 5.4 Elicited Attitudes with Similar Meanings and Values

At this stage of the elimination process, quantitative analysis is conducted via frequency count – C Count - that determines the density in the iteration of the attitudes. Out of 33 elicited attitudes, the ones which are observed less than 5 times are eliminated because of the reliability of data cannot be verified by being dependent on subjectivity of an individual (Akbay, 2013) (Figure 5.4). The dashed orange line is placed perpendicular to represent the minimum required number of observations at the rating value of 5.

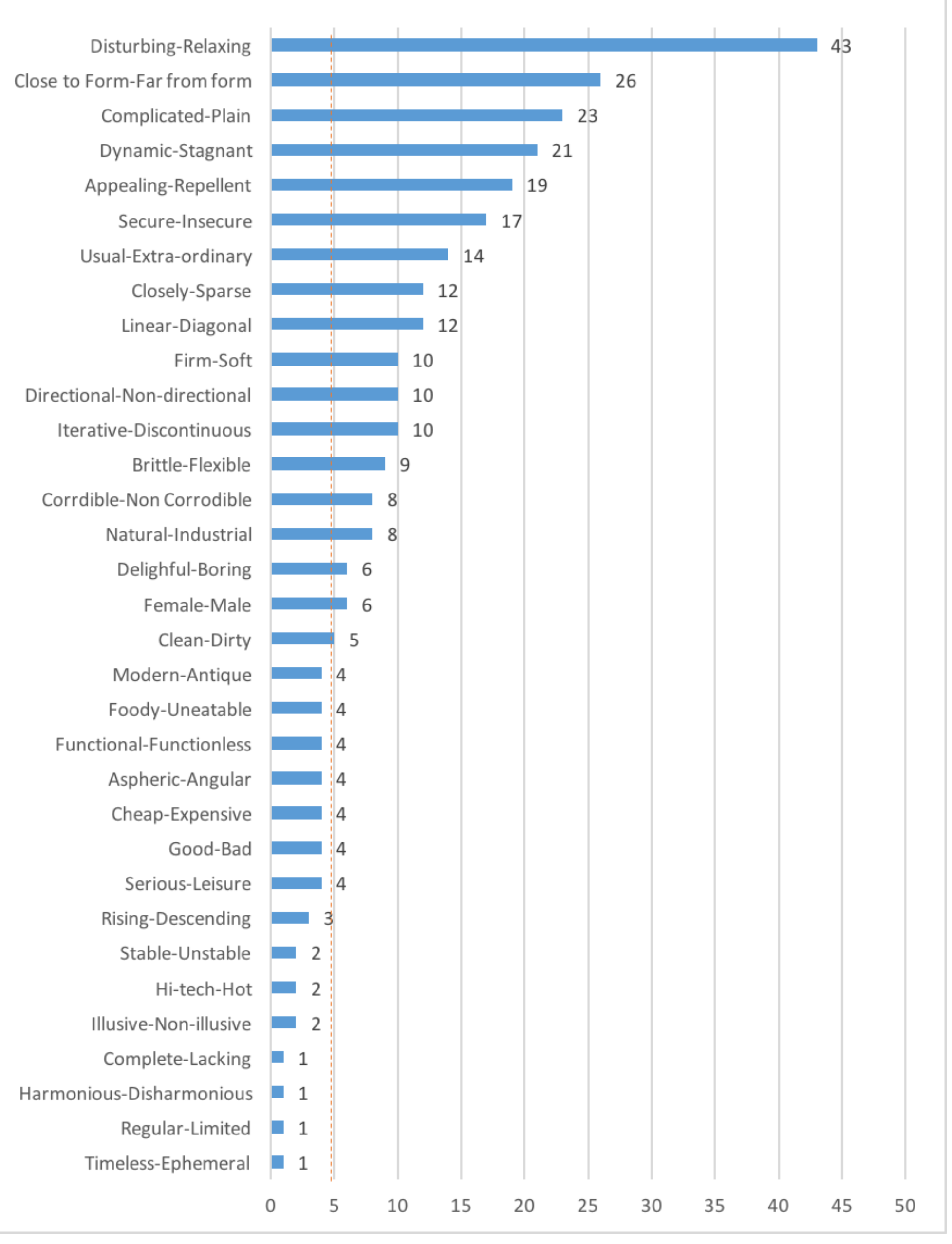


Figure 5.4 Number of Observations (C Count) of Elicited Attitudes

Furthermore, quantitative analysis is once more conducted via the determination of a breaking point as 1.33 and 1.88. Accordingly, 10 constructs are obtained (Figure 5.5).

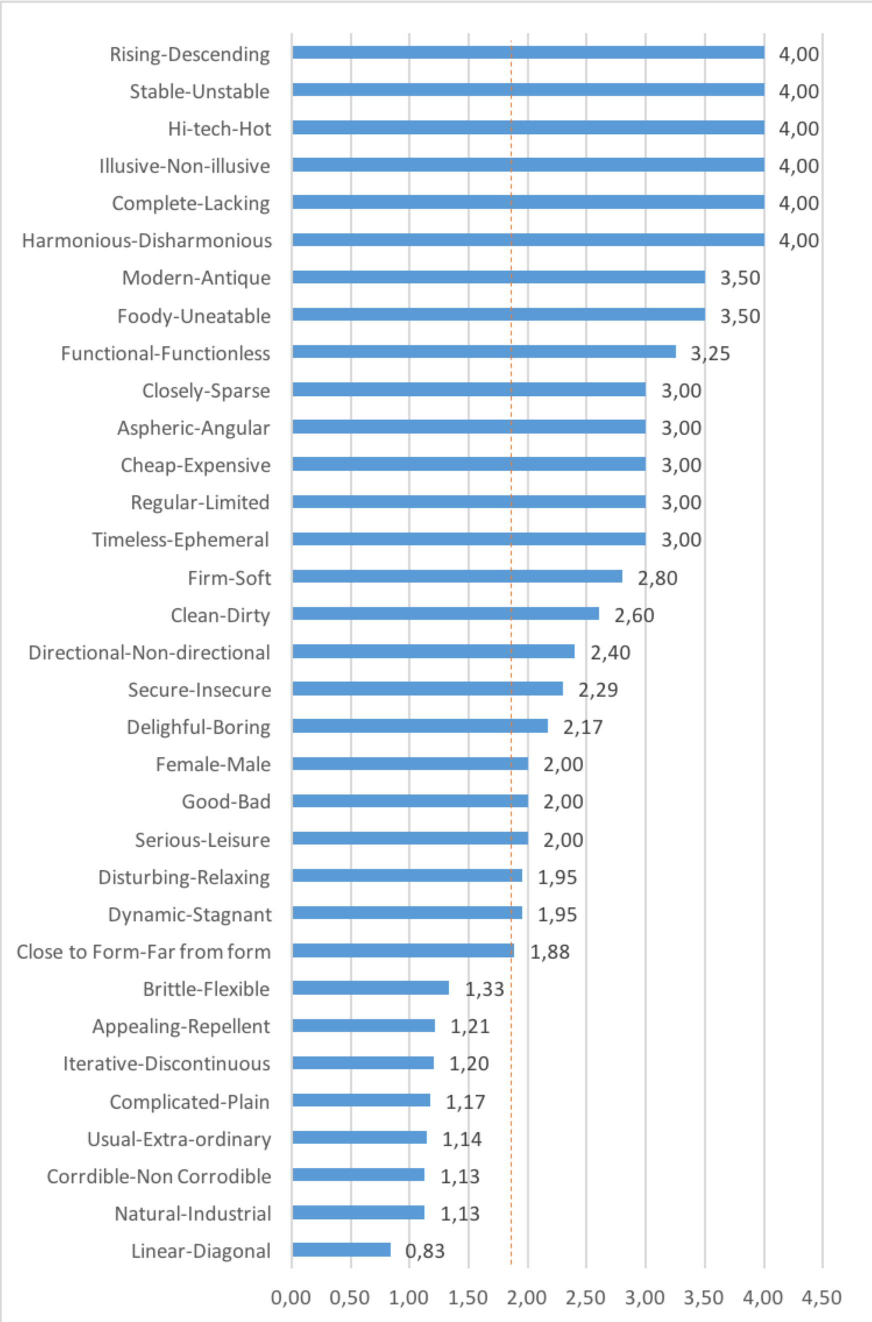


Figure 5.5 The Difference between Minimum and Maximum Rating of Each Elicited Attitude in Relation to All Sampled 3D Surface Textures

Within those 10 constructs and 3D surface textures, two active correlation analyses are conducted to map the similarity relation between the constructs and between the 3D surface textures.

The values revealed for each construct in this matrix can be interpreted in terms of their closeness. The more the value approaches 1, which is the maximum value, the more two constructs are similar. The closer the value is to -1, the more dissimilar are the constructs. Accordingly, in the first correlation chart it can be seen that, the similarity between *disturbing-relaxing* and *firm – soft*, as well as the similarity among *dynamic – stagnant* and *directional – non-directional* have been mapped. Although these constructs as couples of similarity signifies similar meanings, in order not to over-simplify the outcomes of the research, they remain separate. Table 5.5 represents correlation matrix of constructs.

Table 5.5 Correlation Matrix of Constructs

		1	2	3	4	5	6	7	8	9	10
1	Disturbing-Relaxing	1	0,025	-0,706	-0,480	0,445	0,864	-0,549	-0,367	0,032	-0,448
2	Close to Form-Far from form	0,025	1	0,095	0,462	-0,233	0,396	0,081	0,196	0,763	-0,276
3	Dynamic-Stagnant	-0,706	0,095	1	0,648	-0,640	-0,628	0,802	0,327	-0,028	0,364
4	Secure-Insecure	-0,480	0,462	0,648	1	-0,521	-0,361	0,646	0,416	0,415	0,128
5	Closely-Sparse	0,445	-0,233	-0,640	-0,521	1	0,448	-0,195	-0,403	-0,456	-0,593
6	Firm-Soft	0,864	0,396	-0,628	-0,361	0,448	1	-0,387	-0,146	0,153	-0,488
7	Directional-Non-directional	-0,549	0,081	0,802	0,646	-0,195	-0,387	1	0,231	-0,240	0,195
8	Delighful-Boring	-0,367	0,196	0,327	0,416	-0,403	-0,146	0,231	1	-0,040	0,202
9	Female-Male	0,032	0,763	-0,028	0,415	-0,456	0,153	-0,240	-0,040	1	0,041
10	Clean-Dirty	-0,448	-0,276	0,364	0,128	-0,593	-0,488	0,195	0,202	0,041	1

Furthermore, the second correlation chart is based on the mapping of the similarity between the 3D surface textures. Accordingly, regarding the data that is obtained and illustrated below, it is observed that YD-01 and YD-03 poses resemblance (Table 5.6).

Table 5.6 Correlation Matrix of 3D Surface Texture Samples

	YD-01	YD-02	YD-03	YD-04	YD-05	YD-06	YD-07	YD-08	YD-09
YD-01	**1,00**	-0,35	0,81	-0,34	-0,08	-0,69	-0,75	-0,02	0,09
YD-02	-0,35	**1,00**	-0,50	-0,02	0,44	0,04	0,14	-0,03	-0,09
YD-03	0,81	-0,50	**1,00**	-0,30	-0,23	-0,41	-0,65	0,13	0,02
YD-04	-0,34	-0,02	-0,30	**1,00**	-0,40	0,76	0,24	0,06	0,19
YD-05	-0,08	0,44	-0,23	-0,40	**1,00**	-0,06	0,24	0,15	-0,08
YD-06	-0,69	0,04	-0,41	0,76	-0,06	**1,00**	0,50	0,08	0,10
YD-07	-0,75	0,14	-0,65	0,24	0,24	0,50	**1,00**	0,15	-0,22
YD-08	-0,02	-0,03	0,13	0,06	0,15	0,08	0,15	**1,00**	-0,55
YD-09	0,09	-0,09	0,02	0,19	-0,08	0,10	-0,22	-0,55	**1,00**

5.5.3 Discussions of the Constructs in Terms of the Texture Samples

After concluding the content analysis by obtaining 10 constructs via processing a set of elicited attitudes, there appeared a need for the discussion of the relation between those constructs and sampled 9 3D surface textures (Table 5.7).

Table 5.7 Ratings of 3D Surface Texture Samples in Relation to the Constructs Derived from Elicited Attitudes

C Count	*IP*	YD-01	YD-02	YD-03	YD-04	YD-05	YD-06	YD-07	YD-08	YD-09	*EP*	Difference
43	*Disturbing*	1,79	2,81	2,88	2,93	3,00	3,74	3,26	2,86	2,72	*Relaxing*	1,95
21	*Dynamic*	4,10	2,62	3,57	2,95	3,67	2,52	2,14	3,19	2,86	*Stagnant*	1,95
10	*Firm*	1,30	2,60	2,60	3,40	3,30	4,10	3,60	4,00	3,10	*Soft*	2,80
6	*Delighful*	3,00	3,17	3,17	3,00	2,00	2,33	1,83	4,00	2,33	*Boring*	2,17
6	*Female*	2,67	1,00	3,00	3,00	1,67	2,67	3,00	2,67	3,00	*Male*	2,00
10	*Directional*	3,40	2,40	3,20	1,70	4,00	1,60	1,80	3,40	2,90	*Non-directional*	2,40
26	*Close to Form*	3,08	2,00	3,04	3,31	2,88	3,00	3,31	3,88	3,15	*Far from form*	1,88
17	*Secure*	3,59	1,94	4,24	2,18	2,71	2,06	2,65	3,65	2,88	*Insecure*	2,29
12	*Closely*	1,50	4,00	1,92	2,58	3,75	2,50	4,50	3,00	2,83	*Sparse*	3,00
5	*Clean*	3,20	3,00	3,20	3,00	2,40	2,60	1,40	2,20	4,00	*Dirty*	2,60

Among those 10, ***disturbing-relaxing*** is the most observed construct by counted 43 times while ***clean-dirty*** is the least observed construct by counted 5 times. Disturbing – relaxing is translated into English from *rahatsız edici – rahatlatıcı* in Turkish, while clean – dirty is translated from *temiz – kirli*. With disturbing – relaxing, the participants qualify the textures regarding their tactility and the physical apprehension that they get from the tactual relation with the texture. While the participants define textures as clean – dirty, they mostly consider the visual qualities that they observe and anticipate, if the surface is less rough, they tend to qualify those textures as clean while the rough textures are qualified as dirty by keeping the dirt on the surface. Within sampled 9 3D surface textures, by scoring 3.74, YD-06 is the closest texture to elicit *relaxing* attitude, while by scoring 1.79, YD-01 is the closest texture to elicit *disturbing* attitude. For *clean-dirty*, by scoring 4.00, YD-09 is the closest texture to provoke *dirty* attitude, while by scoring 1.40, YD-07 is the closest texture to provoke *clean* attitude.

In between disturbing-relaxing and clean-dirty, there are 8 more constructs determined. Following disturbing - relaxing, ***formed – unformed*** is the second most observed construct by being counted as 26 times. Formed – unformed is a construct translated from *forma yakın* - *formdan uzak* that signifies the clarity of the surface texture to be apprehend geometrically formed, or obscurity in the apprehension of the surface geometry. By scoring 3.88, YD-08 is the closest texture to be apprehended as unformed, while by scoring 2.00, YD-02 is the closest texture to be apprehended as formed.

After formed – unformed, ***dynamic – stagnant*** is the third most observed construct and counted 21 times. Dynamic – stagnant is translated from *dinamik – durgun* in Turkish. By qualifying a texture dynamic is mostly based on the roughness and dramatic changes in the roughness of the surface, while qualifying a texture as a stagnant is mostly observed through the surface with minimum roughness and constant stability on the surface. By scoring 4.10, YD-01 is the closest texture to stagnant, while by scoring 2.14, YD-07 is the closest texture to dynamic.

Secure – insecure is the fourth most observed construct by being counted 17 times. Secure – insecure is translated from *güvenli – güvensiz* and the textures to be qualified as secure is mostly observed for rough surfaces and for smooth kind of surfaces are observed to be named as insecure. Here the roughness and smoothness of the surface gives a clue for gripping qualities while rough surfaces are apprehended as secure for good gripping quality unlike smooth surfaces for their poor gripping quality. With 4.24, YD-03 is the closest texture to insecure, while with 1.94 YD-02 is the closest texture to secure.

Closely – sparse is the fifth most observed construct by being counted 12 times. It is translated from *sık – seyrek* in Turkish. Closely-sparse signifies the density of the repetition on the surface. If the repeated surface element is located by each other closely, participants defined such textures as closely and if the repeated surface element is located each other distantly, the participants defined those textures as sparse. With 4.5, YD-07 is the closest texture to be elicited as sparse, while with 1.5, YD-01 is the closest texture to be elicited as closely.

Firm – soft and ***directional – non-directional*** are the sixth most observed constructs by being counted 10 times. Firm – soft is *sert – yumuşak* which signifies both the tactual and visual apprehension of participants. By scoring 4.10, YD-06 is the closest texture to soft, while by scoring 1.30, YD-01 is the closest texture to firm. Due to the gradient hill topology of the repetitive notches, participants might feel the texture as smooth while, sharp-pointed repetitive rectangular surface might be apprehended as firm. Directional – non-directional is translated from *yönlü – yönsüz* which highlights the clarity or obscurity of the apprehension of the surface texture. By scoring 4.00, YD-05 is the closest texture to non-directional, while by scoring 1.60, YD-06 is the closest texture to directional.

Delightful – boring and ***female - male*** are the seventh most observed constructs by being counted 6 times. Delightful – boring is translated from *keyifli – sıkıcı.* By scoring 4.00, YD-08 is the closest texture to qualified as boring, while by scoring 1.83, YD-07 is the closest texture to delightful. Participants might apprehend precise and dynamic textures more adventurous, whereas the rigidly regular and densely repetitive textures are found as boring. *Female – male* is translated from *dişi – erkek*, which signifies the negativity and the positivity that is apprehended on the surface. By scoring 3.00, YD-03, YD-04, YD-07, YD-09 remain average without signifying any poles, accordingly there is no value recorded for the closest texture to male, while by scoring 1.00, YD-02 is the closest texture to female.

5.5.4 Discussions of the Texture Samples in Reference to the Constructs

The discussion of constructs in the previous section created the requirement to discuss the elements of the table.

5.5.4.1 Surface Texture Sample 1 (YD-01)

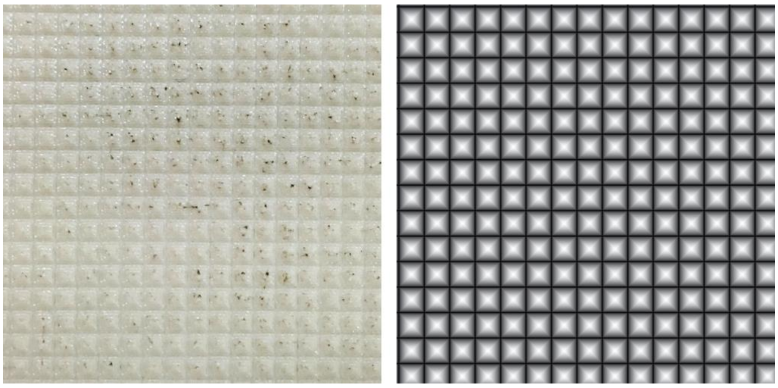


Figure 5.6 Left: Manufactured Surface Texture of YD-01, Right: Bitmap Representation of YD-01.

YD-01 (Figure 5.6), which is a texture type composed of the dense repetition of pyramidal elements with sharp top end, was found to be significantly *disturbing* among the others. Since this type of 3D surface texture is used on components which required precise control for the use of fingertips, a 95mm x 95mm plaque base was found to be intense to touch with hand. Along with being the most *disturbing*, the surface texture also found to be most *stagnant*, *firm* and *closely* with precisely located dense small elements.

5.5.4.2 Surface Texture Sample 2 (YD-02)

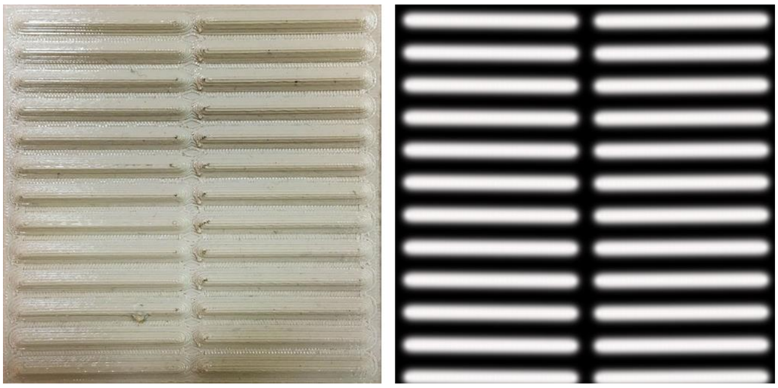


Figure 5.7 Left: Manufactured Surface Texture of YD-02, Right: Bitmap Representation of YD-02.

YD-02 (Figure 5.7) has smooth and repetitive ribbon shaped hill topology in which transition between the base surface and the hills are smoothly formed. This surface texture is observed as the most *secure* among others. Its visual structure would be associated with the products which are associated with security. The security may also be related to the easiness of holding when the surface texture is placed on a handle. It is also declared as the most *female* one among others. Being the one of most the *sparse* one throughout all the sampled textures, it is also the sample which is observed as the *closest to form*.

5.5.4.3 Surface Texture Sample 3 (YD-03)

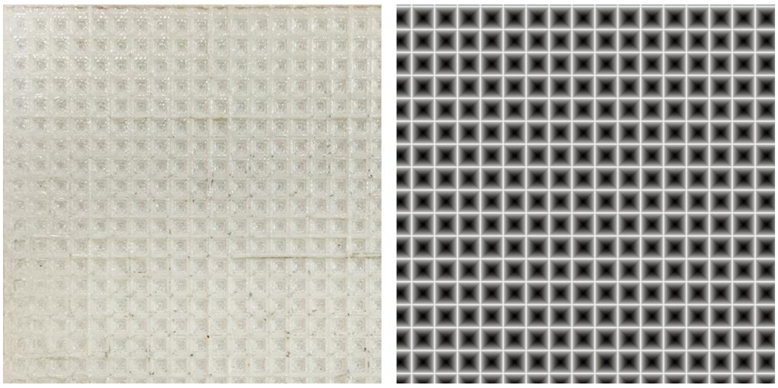


Figure 5.8 Left: Manufactured Surface Texture of YD-03, Right: Bitmap Representation of YD-03.

YD-03 (Figure 5.8) is found to be the most *insecure* surface texture among others, which is composed of repetition of dots with negative space subtracted from the base surface. The insecurity of the sample may be related to lack of having male protrusion as a surface feature. The 3D surface texture sample also found to be *closely* because of its small elements which are adjacent to each other.

5.5.4.4 Surface Texture Sample 4 (YD-04)

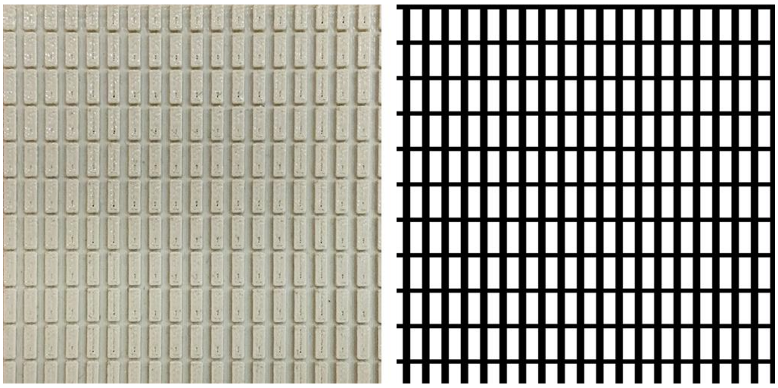


Figure 5.9 Left: Manufactured Surface Texture of YD-04, Right: Bitmap Representation of YD-04.

YD-04 (Figure 5.9) is composed of rectangular stripy extrusion with a rigid surface transition with base surface. The texture sample found to be the most *directional* one among others. This property may be related to the existence of the surface texture type on a camera lens rings, which requires a directional clue for both visual and tactile purposes. It is also found to be *soft* when compared to other 3D surface texture samples.

5.5.4.5 Surface Texture Sample 5 (YD-05)

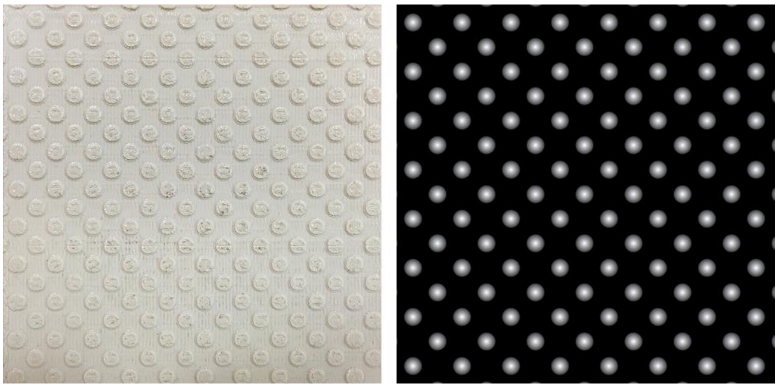


Figure 5.10 Left: Manufactured Surface Texture of YD-05, Right: Bitmap Representation of YD-05.

YD-05 (Figure 5.10) is made of the dense repetition of notch. The protrusion which is on both X and Y direction, is spot shaped. The surface texture is found to be the most *non-directional* one among other samples. This comment of participants may be related the fact that the elements of texture is equally distributed in all directions. It is also qualified as one of the most *female* among others, which may be linked to the fact that the pattern of elements is similar to textile products with spotted pattern.

5.5.4.6 Surface Texture Sample 6 (YD-06)

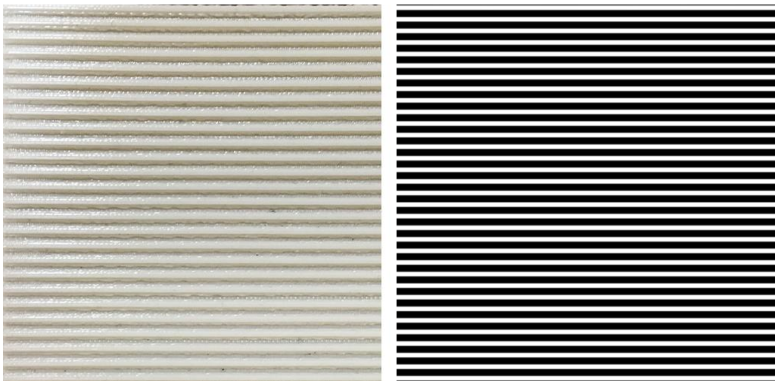


Figure 5.11 Left: Manufactured Surface Texture of YD-06, Right: Bitmap Representation of YD-06.

YD-06 (Figure 5.11) is defined by the repetition of rigidly placed stripes with clear contour of the stripe geometry. The texture sample is evaluated as the *softest* and most *relaxing* among others. The precision of the elements and predictability of each adjacent element could be the reason behind the most relaxing and the softest. Interestingly, it is also qualified as the most *directional* throughout all texture samples.

5.5.4.7 Surface Texture Sample 7 (YD-07)

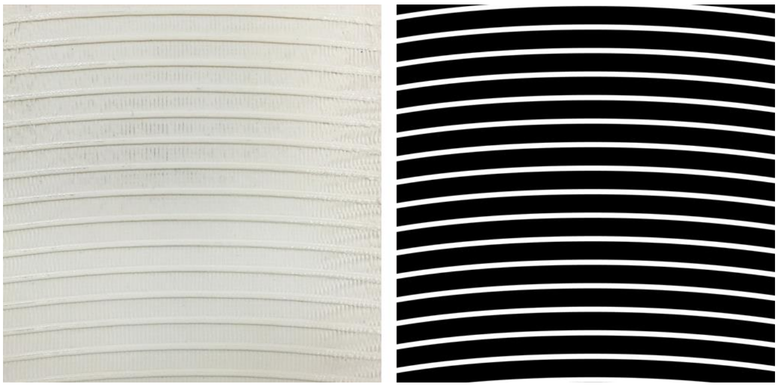


Figure 5.12 Left: Manufactured Surface Texture of YD-07, Right: Bitmap Representation of YD-07.

YD-07 (Figure 5.12), which is composed of the repetition of rigidly defined stripes with clear contour of the geometry, is qualified as the *sparsest* and the *cleanest*. Interestingly, it is also found to be the most *delightful*, which can also be related to the spacing between elements. It also seen that YD-07 is the most *dynamic* among others, which could be inherited from the arch shaped elements.

5.5.4.8 Surface Texture Sample 8 (YD-08)

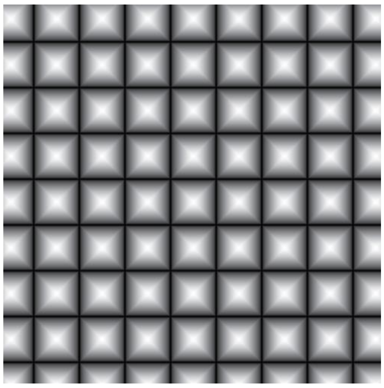



Figure 5.13 Left: Manufactured Surface Texture of YD-08, Right: Bitmap Representation of YD-08.

YD-08 (Figure 5.13) can be defined as the repetitive surface fraction on base surface that defines the surface modulation. It is qualified as most *distant (far) from a form.* The sample is also declared as one of the *softest*, and the most *boring*. Predictability of the elements may cause the *boring* construct strong on this particular 3D surface texture among others. The reason behind being the most boring may be linked to the fact that each element in the texture is easily identifiable, bigger in size in reference to its plaque dimensions, therefore a lesser number of elements is used on the plaque.

5.5.4.9 Surface Texture Sample 9 (YD-09)

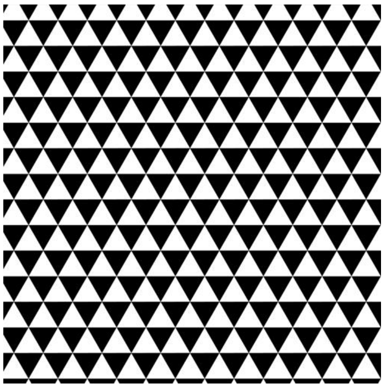



Figure 5.14 Left: Manufactured Surface Texture of YD-09, Right: Bitmap Representation of YD-09.

YD-09 (Figure 5.14) is made of the repetition of polygonal (triangular) shaped hills which are added to base surface. It is evaluated as the *dirtiest* among other 3D surface texture samples, interestingly, which could be related to the fact that the actual 3D printed texture sample got dirty over time of usage. This evaluation may also be based on the shape triangle, which forms a pattern of acute internal angles. It is also qualified as one of the most *distant from form* among others. This may be due to the size of the triangle elements. With these explanations, discussions of the texture samples in reference to the constructs, is completed.

5.5.5 Hierarchical Cluster Analysis – Dendrograms: The Relationships Among 3D Surface Textures

Within the scope of content analysis and the evaluation of the outputs, hierarchical cluster analysis is used to map the proximity relationships among presented 3D surface textures. Hierarchical cluster analysis is an analysis method that aims to structure the clusters or a set of elements regarding their resembling characteristics by building a hierarchical order (Hubert, 2006). In the basis, it is a data segmentation and compression procedure that organizes a set of objects by defining common characteristics by generating sub-clusters among them (Mucha, Bartel, & Dolata, 2005). The idea is to merge similar elements that is defined by an inclusive cluster. For mapping those resemblance relationships, ***Dendrograms*** are used as a visualization method. Dendrograms, in the basis, are tree-like graphs that are generally utilized in biological systematics, especially in comparative biology and cladistics (Luther, 2012). Those tree-like graphs illustrate the resemblance relationships by mapping out the distance between clusters; with a criterion of high resemblance among the elements are placed nearer to each other, and with a criterion of low resemblance are placed apart. Primarily, all objects are defined as they are separate clusters. In each phase of resemblance comparison, two clusters that share the most common characteristics form into a new cluster. By following this process, dendrograms are generated.

Dendrograms have 2 axes; (1) horizontal, and (2) vertical. On the horizontal axis, the distance which means the dissimilarity among the clusters are mapped. On the vertical axis, the clusters and objects that form those clusters are represented. Each cluster has its own edge that is connected to another sub-cluster or, its upper-cluster by a node as dendrograms are rooted to graph theory (Mucha et al., 2005).

Although it is quite useful to utilize dendrograms to map proximity relations in one-dimensional cases, the applications for high-dimensional cases are limited.

Within the framework of this research, dendrograms are generated regarding the 10 constructs that are obtained and shortened from RGT phase of the study based on the difference and similarity co-factor obtained from the analysis. The dendrogram out of those 9 sampled textures against 10 constructs is structured upon the values that are evaluated in analysis chart. The values of the constructs of the samples that converge to each other form a cluster while the values that diverge from each other form separate clusters and are located distant from each other.

As mentioned above, multi-dimensionality poses a challenge for dendrograms, therefore within the depth of this research, the dendrogram based on similarity analysis for 9 sampled surface texture is illustrated (Figure 5.15).

By reading this dendrogram, it is observed that there are mainly three major branches. Those three branches are analyzed in order from top to bottom and from right to left. Primarily, the first branch holds two sub-branches that hold YD-03 and YD-01 in the same sub-cluster as well as YD-09 in another sub-cluster. To be located in the same sub-cluster signifies that, YD-03 and YD-01 are resembling each other more than YD-09. The second main branch splits up into two branches that hold YD-05 and YD-02. The first and the second main branches are linked to each other by the same node, which make them to be located under the same main cluster and highlights that the textures located under the first and the second branches are much more resembling to each other in comparison to the third main branch. When it is come to the third branch, under the main node, there are two edges linked to each other. The first sub-branch of the third main branch splits up into two branches that hold two more splits. Therefore, there are three sub-clusters under the third branch as YD-06 and YD-04 as one sub-cluster while, YD-07 forms another individual sub-cluster as well as YD-08. On this basis, those four surface textures are resembling each other more than, YD-03, YD-01, YD-05 and YD-02. However, by being located under the same sub-cluster, YD-06 and YD-04 are resembling each other more than YD-07 and YD-08.

As an overall comparison, by being the most short-edged sub-cluster, YD-01 and YD-03 are the most resembling surface textures, while by being second short-edged sub-cluster, YD-06 and YD-04 are the second most resembling surface textures among others. Also, in reference to the shortness of the edges, YD-06, YD-04 and YD-07 are much more resembling to each other in comparison to YD-05 and YD-02. The most distant resembling relation is observed between YD 08 and YD-01-YD-03.

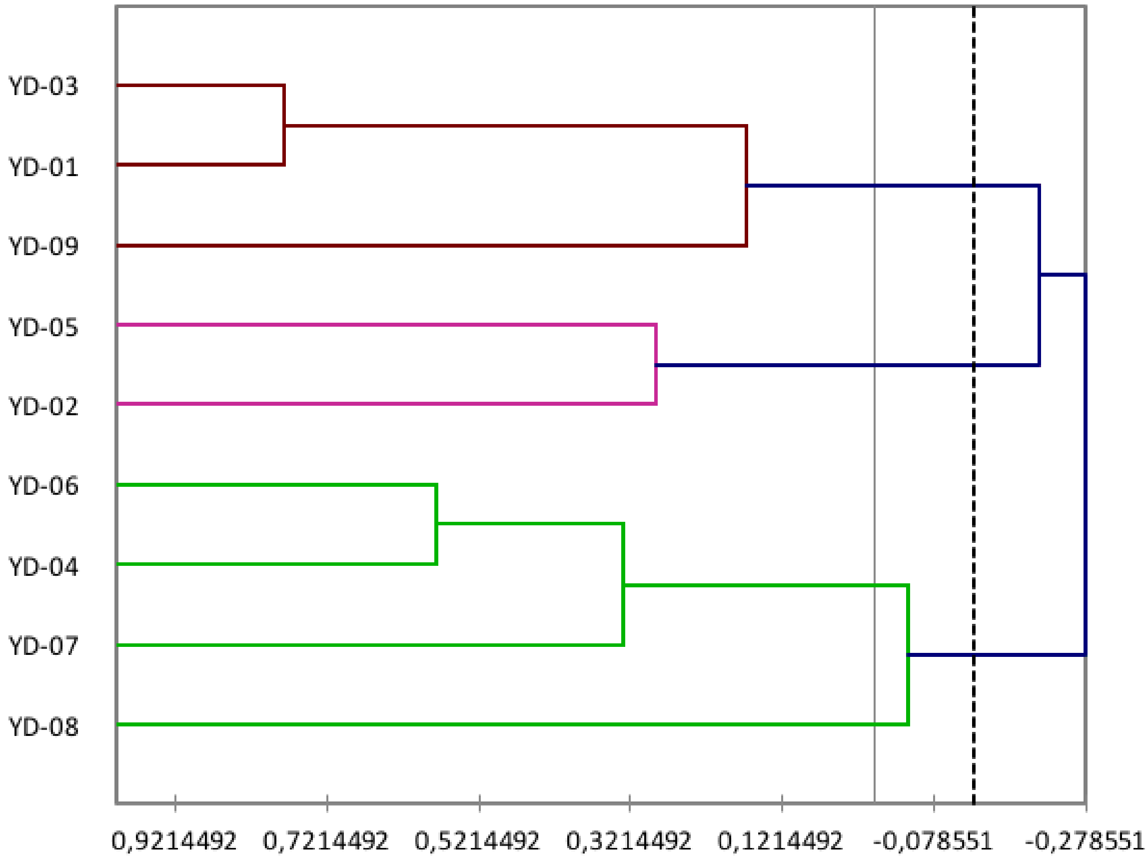


Figure 5.15 Dendrogram Taxonometry of Sampled 3D Surface Textures

To compare the elicited attitudes obtained from RGT, the semantic differential analysis is conducted between several constructs based on the values generated. The analysis is based on the evaluation and the comparison among the constructs. 3D surface texture samples with common edge which are located at the lowest segment of the cluster are grouped together to be evaluated on semantic differential chart. The grouped samples are; *YD-01 – YD-03, YD-02 – YD-05, and YD-04 – YD-06,* which are inferred from the dendrogram graph of the taxonomy of sampled 3D surface textures.

Figure 5.16 shows the semantic differential chart of YD-01 and YD-03, which are evaluated within 10 refined constructs with a 5-point rating scale rating. The vertical dotted line represents the midpoint of the 1-5 scale, which has the value of 3. The comparison shows that YD-01 is closer to the left poles when it is contrasted with YD-03. YD-03 seems to be more relaxing and softer when it is checked against YD-01.

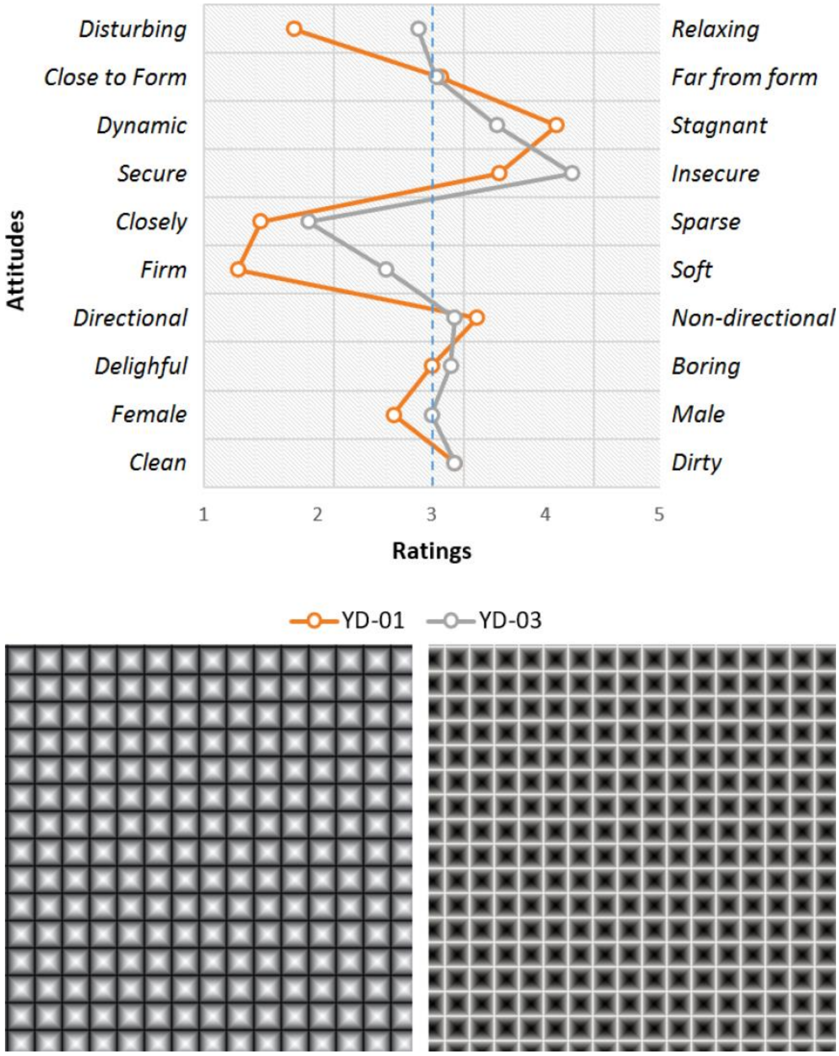


Figure 5.16 The Semantic Differential Chart in Relation to the Ratings of YD-01 and YD-03

Figure 5.17 shows the semantic differential chart of YD-02 and YD-05, which are evaluated within 10 refined constructs with a 5-point rating scale rating. The vertical dotted line represents the midpoint of the 1-5 scale, which has the value of 3. The comparison shows that YD-02 is closer to the left poles when it is contrasted with YD-05. YD-05 also seems to be less directional, softer and more stagnant. YD-02 is much more close to the form.

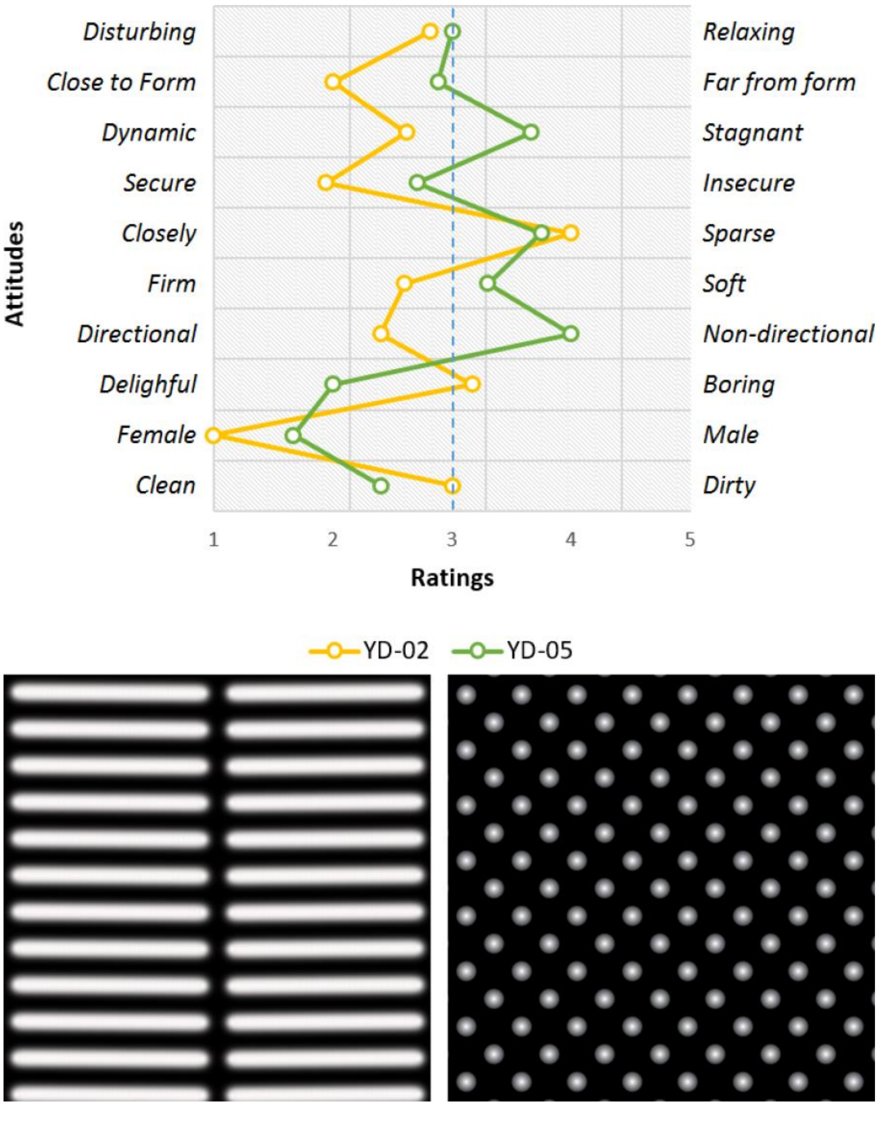


Figure 5.17 The Semantic Differential Chart in Relation to the Ratings of YD-02 and YD-05

Figure 5.18 shows the semantic differential chart of YD-04 and YD-06, which are evaluated within 10 refined constructs with a 5-point rating scale rating. The vertical dotted line represents the midpoint of the 1-5 scale, which has the value of 3. While YD-04 could be interpreted as more disturbing, YD-06 can be qualified as softer when compared. Ratings of the rest of the constructs seem to be similar. With these representations, Study 3 was concluded.

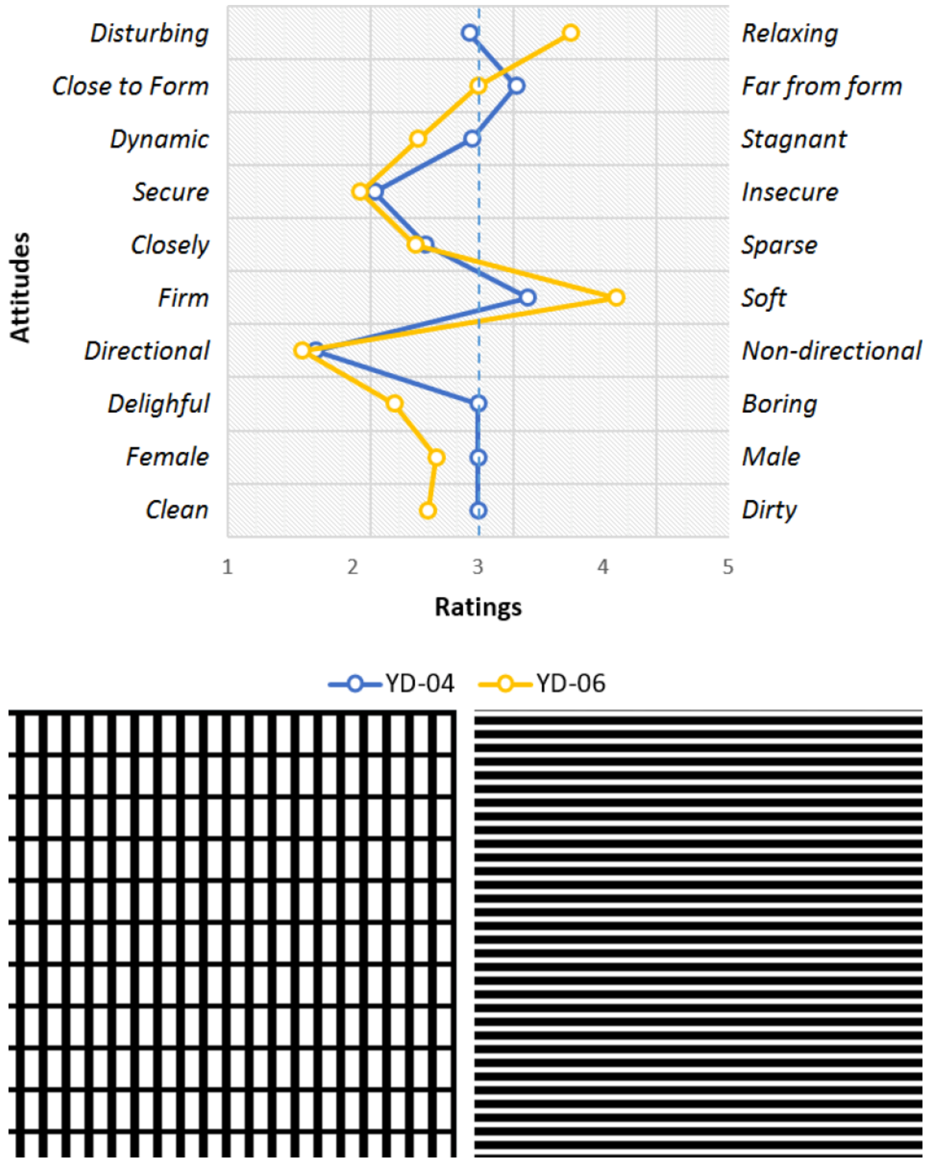


Figure 5.18 The Semantic Differential Chart in Relation to the Ratings of YD-04 and YD-06

5.6 Limitations of Study 3

As a limitation of this study, for RGT phase, it is decided by the to set and limit the number of attitudes to 10 rows. Participants were asked to fill their attitudes and evaluation of each surface texture samples to all 10 rows. However, according to the standard RGT procedures, the number of attitudes should not have been limited. For further studies, RGT research must follow this rule and must be conducted accordingly, without limiting the number of attitudes.

As expressed earlier in this thesis, planar surfaces were employed for participants to evaluate 3D surface textures. The exploration of 3D surface textures on actual products would enhance the contribute more to the topic. The improvement of usage scenario and new ways of interactions can be provided with such study.

CHAPTER 6

CONCLUSION

This study aims to explore 3D surface textures on products, particularly consumer electronics, in order to understand the ways in which they are used, and their qualities that elicit a variety of attitudes in users. It is seen that, 3-D surface textures are used on such products for both their functional (e.g. better gripping, indicating contact region on the product) and their hedonic (e.g. visual or tactile pleasure) qualities. These qualities contribute to the user experience of the products.

It was also aimed to use textures derived from a survey to reveal the resemblance relations and parameterization of these sampled 3D surface textures. Furthermore, the study also covered the elicited attitudes of participants towards certain types of 3D surface textures.

In the literature review, the definition of 3D surface texture is set to address the deficiency of the topic in the literature. Furthermore, certain perceptual dimension of these features are covered in terms of visual and tactual modality. Several examples are also covered to have a sense of potential functional and hedonic improvements, which can be provided by 3D surface textures.

In addition, Study 1 covered the analysis of 3D surface textures on consumer electronic products. Several parameters are defined and used as a analysis methodology. The groupings of 3D surface textures in terms of their generic structures also covered in this chapter, which provided nine different surface texture samples.

Apart from this, Study 2 explored methods and tools to create 3D surface textures. Software tools are evaluated according to their 3D surface texture creation capabilities. Thanks to certain types of software tools, 3D surface texture samples were manufactured with the utilization of a rapid prototyping device. The capabilities of FDM based AM technique is also covered during the manufacturing process of nine 3D surface texture samples.

The Repertory Grid Technique (RGT) is covered as a methodology in Study 3, and utilized to reveal elicited attitudes of users towards 3D surface textures. The nine 3D surface texture samples were used in the RGT experiment to reveal participants' attitudes to the certain types of textures. The results of the experiment are discussed deeply in the final phase of three step field study.

6.1 Revisiting Research Questions

While concluding the research, there appears a necessity to revisit the research questions to overview what have been done throughout the research and study period.

6.1.1 3D Surface Textures

Within the scope of the literature review, there appeared various definitions from various disciplines for the concept of texture. However, within the framework of design discipline, there is no definition that is set for 3D surface textures. Accordingly, throughout this research, it is aimed to set a definition for 3D surface textures. Based on the literature review, the definition for 3D surface textures is set as; the geometrical features located on the object, which have three dimensionalities that create height differences, which are not obtained through coating process or material attribute, also which are perceivable by multimodal sensory receptors and designed to be functional or beyond-functional. After setting a definition for 3D surface textures, for the rest of the research, the studies are conducting in reference to this definition.

6.1.1.1 Consumer Electronics Products with 3D Surface Textures

Within the scope of surveying 3D surface products that are currently being used in consumer electronics products, electronic markets, department stores and hypermarkets are visited. According to the availability of the products and the textures, the range of the products that are surveyed and documents changes from household appliances, shoes, cosmetic bottles, hand tools, heavy duty products to consumer electronics products. The amount of textures that are documented is reduced to eliminate the repetition of the same texture for several times. Furthermore, manipulability is another factor that limits the range of the products due to the enhancement in the tactual interaction. Another thing that limits the product range is the textures that were related to the form of the products, so they were also eliminated from the scope.

Accordingly, the product range is set to be concentrated on three main categories as; (1) cameras and camera accessories, (2) personal care products, and (3) computer HIDs and storage devices. Therefore, from 210 products that are documented, 31 products that provide potential for 3D surface textures are examined.

6.1.1.2 Categorization of Textures in Consumer Electronic Products

When those 31 products are examined, it is observed that from several aspects some of the textures might be perceived as they have some common characteristics, such as geometrical appearance of the repetitive elements on the surface. Here, Arnheim’s ideas on generic structures, which are to be the very first things detected by the human perception, are overviewed. According to Arnheim, detection of such common features may lead observer to have resemblance relations between the objects. The common features might be texture, color, form or another property. Based on the apprehension of generic structures, the 31 3D surface textures are evaluated accordingly. As a result, based on resemblance relations on textures which refers the way of utilization of the texture, 31 is reduced to nine 3D surface texture to be sampled.

6.1.2 3D Surface Texture Generation and Manufacturing Tools

Texture generation and manufacturing tools are covered in Study 2. Software programs including Rhinoceros, T-Splines, Grasshopper, 3-matic STL and Adobe

Photoshop are evaluated to have a sense of the capabilities of these tools to create 3D surface textures. As a result of the evaluation, Rhinoceros, Grasshopper and 3-matic STL are found to be the most useful ones for the purpose of this study. Along with software programs, a FDM based 3D printer is also evaluated for producing 3D surface texture samples. The process required several iterations to obtain the most useful parameters for the manufacturing of 3D surface texture with the employment of a Rapid Prototyping device. It can be inferred from the manufacturing process of the study that a more precise Additive Manufacturing tools are required for 3D surface textures to be placed on a surface of a product on the shelves. Still, there is a lot potential for 3D surface textures in terms of their improvements.

6.1.3 User Evaluation of 3D Surface Textures

For user evaluation stage of this research, Study 3 is conducted. Study 3 is structured upon the utilization of RGT as a surveying tool to apprehend the user perception and the evaluation about 3D surface textures. Dyadic elicitation procedure that is based on the similarity comparison of two 3D surface textures is applied for RGT. As mentioned in the related chapter, RGT is a method that focuses on the relation of the individual with its environment, therefore the process of Study 3 puts subjectivity of the individual in the focus. Therefore, due to the dyadic elicitation procedure and the subjectivity of the participants, there emerged 300 elicited bipolar attitudes. Due to the plentitude of the attitudes, there appeared a need to qualitative and quantitative elimination. Accordingly, semantic duplicates were eliminated by means of qualitative analysis, and by means of quantitative analysis, two breaking points which are determined through the RGT, is set as lower limit. Accordingly, 300 attitudes were processed and eliminated for several times. After the content analysis, 10 constructs remained. In related chapter, those constructs were analyzed and discussed in relation to surface textures both semantically and statistically.

This study led the way to apprehend the potentials of 3D surface textures from the user point of view, which may be beneficial to be utilized in current product ranges. Moreover, this study reveals the potentials of those textures both from functional and beyond-functional aspects. For instance, some textures are found sufficient to be utilized in gripping parts of the products, while some of them feel slippery to handle. While focusing on functional aspects, participants evaluate those textures from sensorial aspects which proposes the improvement in hedonic qualities for products.

6.2 Recommendations for Further Research

The availability of limited number of software programs is another obstacle to explore and assess all the tools for 3D surface texture creation capabilities. Only the ones which are available for the use of the Department of Industrial Design at Middle East Technical University are covered. Further studies would cover more software programs to gather a more useful data.

Furthermore, MakerBot Replicator 5^{th} generation 3D printer is the only rapid prototyping device available to the researcher. The capabilities of the device are limited because of its technique to manufacture products. Precision of the device is limited to 100 microns, which makes each layer of the manufactured object traceable and perceivable. Apart from this, the only available material type was PLA, which requires more attention for the post treatment of the surface of a produced object. SLA and SLS based AM devices have much more precision with a wide range of material options.

Finally, the quantity of participants is limited because of the time limitation. Majority of the participants were students who are in the Department of Industrial Design, Middle East Technical University. The range of the participants' age could be extended to have a sense of elicited attitudes of people with different age groups and different demographic properties. Furthermore, during the RGT experiment, seven of the participants were aware of the procedure before coming into the session most likely because their peers were shared their experience related to the sessions beforehand, even though the participants were reminded to keep the methodology and the elements of the study secret. Overcoming this limitation may increase reliability rate of the results.

Within the scope of this research field, this thesis draws conclusion by proposing several suggestions for the further research. Primarily, the studies are conducted by means of current 3D surface textures. For further studies, those studies are suggested to be conducted by means of the manufacturing of new 3D surface textures to evaluate the potentials and the limits of CAD software and AM techniques. Additionally, new 3D surface textures may have the potentials to reveal new instrumental and beyond-instrumental (hedonic) experiences for the users.

Another suggestion is the utilization of those textures on actual products. This holds the potential for the accurate evaluation of the user experiences about surface textures such as hedonic and functional improvements that are spotted by the user.

For the RGT part of the study, there are several methods that can be suggested to conduct a study based on the user-evaluation of 3D surface textures as; (1) follow-up interview and, (2) survey which both may be useful to provide accurate user feedback.

For further analysis and follow up study, designers can make use of the results as constructs that are obtained through such procedures. These constructs can be used in a scale measurement system to employ participants to evaluate and to test the existence of certain characteristics of 3D surface textures. By conducting such kind of analysis through surface textures holds the potential to enhance the product quality and the user feedback. For instance, new textures can be designed or the current textures can be enhanced regarding the current feedbacks of the RGT participants. By enhancing texture qualities, the use of such textures on actual products can be realized in a more efficient manner.

REFERENCES

3-matic STL | Software for Additive Manufacturing. (n.d.). Retrieved August 18, 2015, from http://software.materialise.com/3-maticSTL

Additive manufacturing : opportunities and constraints. (2013). London: Royal Academy of Engineering.

AKBAY, S. (2013). *MULTI-ATTITUDINAL APPROACHES OF COLOUR PERCEPTION: CONSTRUING ELEVEN BASIC COLOURS BY REPERTORY GRID TECHNIQUE*. Middle East Technical University.

Ashby, M. (2014). *Materials and Design*. Butterworth-Heinemann.

Balaji, M. S., Raghavan, S., & Jha, S. (2011). Role of tactile and visual inputs in product evaluation: a multisensory perspective. *Asia Pacific Journal of Marketing and Logistics*. http://doi.org/10.1108/13555851111165066

Batra, R., & Ahtola, O. T. (1991). Measuring the hedonic and utilitarian sources of consumer attitudes. *Marketing Letters*, *2*(2), 159–170. http://doi.org/10.1007/BF00436035

Bicycle Grip. (n.d.). Retrieved October 16, 2014, from http://www.bikeforums.net/general-cycling-discussion/112150-what-your-favorite-handlebar-shape.html

Bourne, M. (2003). *Food Texture and Viscosity: Concept and Measurement*. *International Journal of Food Science and Technology* (2nd ed., Vol. 38). San Diego: Academic Press. http://doi.org/10.1046/j.1365-2621.2003.00667.x

Campbell, R. I., Hague, R. J., Sener, B., & Wormald, P. W. (2003). The Potential for the Bespoke Industrial Designer. *The Design Journal*, *6*(3), 24–34. http://doi.org/10.2752/146069203789355273

Caputi, P., & Reddy, P. (1999). A comparison of triadic and dyadic methods of personal construct elicitation. *Journal of Constructivist Pyschology*, *12*, 253–264.

Chitturi, R., Raghunathan, R., & Mahajan, V. (2008). Delight by Design: The Role of Hedonic Versus Utilitarian Benefits. *Journal of Marketing*, *72*(3), 48–63. http://doi.org/10.1509/jmkg.72.3.48

Coskun, M. (2014). *Sensorial experiences during instrumental interaction: a study on tea makers and vacuum cleaners*. Middle East Technical University.

Cozmei, C., & Caloian, F. (2012). Additive Manufacturing Flickering at the Beginning of Existence. *Procedia Economics and Finance*, *3*(march 2009), 457–462. http://doi.org/10.1016/S2212-5671(12)00180-3

Crowley, A. E., Spangenberg, E. R., & Hughes, K. R. (1992). Measuring the hedonic and utilitarian dimensions of attitudes toward product categories. *Marketing Letters*, *3*(3), 239–249. http://doi.org/10.1007/BF00994132

Dana, K. J., & Nayar, S. K. (1999). Correlation model for 3D texture. In *Proceedings of the Seventh IEEE International Conference on Computer Vision* (pp. 1061–1066 vol.2). IEEE. http://doi.org/10.1109/ICCV.1999.790389

Demirbilek, O., & Sener, B. (2003). Product design, semantics and emotional response. *Ergonomics*, *46*(13-14), 1346–60. http://doi.org/10.1080/00140130310001610874

Desmet, P., & Hekkert, P. (2007). Framework of Product Experience. *International Journal of Design*, *1*(1), 57–66. Retrieved from http://www.ijdesign.org/ojs/index.php/ijdesign/article/view/66/15

Diefenbach, S., & Hassenzahl, M. (2011). The dilemma of the hedonic – Appreciated, but hard to justify. *Interacting with Computers*, *23*(5), 461–472. http://doi.org/10.1016/j.intcom.2011.07.002

Easterby-Smith, M. (1980). The design, analysis and interpretation of repertory grids. *International Journal of Man-Machine Studies*, *13*(1), 3–24. http://doi.org/10.1016/S0020-7373(80)80032-0

Eng, J. W. B. (2003). *Rotation Invariant Classification of 3D Surface Texture Using Photometric Stereo*. Edinburgh Heriot-Watt University University.

Evans, M. A. (2005). Rapid prototyping and industrial design practice: can haptic feedback modelling provide the missing tactile link? *Rapid Prototyping Journal*, *11*(3), 153–159. http://doi.org/10.1108/13552540510601273

Geomagic Sculpt Overview. (n.d.). Retrieved August 18, 2015, from http://www.geomagic.com/en/products/sculpt/overview

Grater. (n.d.). Retrieved April 13, 2014, from https://en.wikipedia.org/wiki/Grater#/media/File:Zest_Grater.jpg

Hassenzahl, M. (2001). The Effect of Perceived Hedonic Quality on Product Appealingness. *International Journal of Human-Computer Interaction*, *13*(4), 481–499. http://doi.org/10.1207/S15327590IJHC1304_07

Hekkert, P. (2006). Design aesthetics : principles of pleasure in design Design aesthetics : principles of pleasure in design. *Psychology Science*, *48*(2), 157 – 172. Retrieved from http://www.pabst-publishers.de/psychology-science/2-

2006/06_Hekkert.pdf

Hekkert, P. Schifferstein, H. N. J. (2008). Product Aesthetics. In *Product Experience*. San Diego: Elsevier.

Holliins, M., Faldowski, R., Rao, S., & Young, F. (1993). Perceptual dimensions of tactile surface texture: A multidimensional scaling analysis. *Perception & Psychophysics*, *54*(6), 697–705. http://doi.org/10.3758/BF03211795

Hoogs, a., Collins, R., & Kaucic, R. (2002). Classification of 3D macro texture using perceptual observables. In *Object recognition supported by user interaction for service robots* (Vol. 4, pp. 113–117). IEEE Comput. Soc. http://doi.org/10.1109/ICPR.2002.1047412

Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277–1288.

Hubert, L. J. (2006). Hierarchical Cluster Analysis. In *Encyclopedia of Statistical Sciences*. Hoboken, NJ, USA: John Wiley & Sons, Inc. http://doi.org/10.1002/0471667196.ess0947.pub2

Jee, H., & Sachs, E. (2000). Surface macro-texture design for rapid prototyping. *Rapid Prototyping Journal*, *6*(1), 50–60. http://doi.org/10.1108/13552540010309877

Jones, B., & O'Neil, S. (1985). Combining vision and touch in texture perception. *Perception & Psychophysics*, *37*(1), 66–72. http://doi.org/10.3758/BF03207140

Karana, E., Pedgley, O., & Rognoli, V. (2013). *Materials Experience: fundamentals of materials and design*. Oxford: Elsevier. Retrieved from http://www.amazon.com/Materials-Experience-fundamentals-materials-design/dp/0080993591

Karana, E., Pedgley, O., Rognoli, V., & Ashby, M. (2014). Foreword: Materials Experience—Fundamentals of Materials and Design. In *Materials Experience* (pp. xvii–xxii). Retrieved from http://www.sciencedirect.com/science/article/pii/B978008099359106001X

Kelly, G. A. (1963). *A Theory of Personality: The Psychology of Personal Constructs*. *Norton library N152* (Vol. 1). Retrieved from http://www.amazon.com/Theory-Personality-Psychology-Personal-Constructs/dp/0393001520

Klatzky, R. L., Lederman, S. J., & Metzger, V. a. (1985). Identifying objects by touch: An "expert system." *Perception & Psychophysics*, *37*(4), 299–302. http://doi.org/10.3758/BF03211351

Kruth, J.-P., Leu, M. C., & Nakagawa, T. (1998). Progress in Additive

Manufacturing and Rapid Prototyping. *CIRP Annals - Manufacturing Technology*, *47*(2), 525–540. http://doi.org/10.1016/S0007-8506(07)63240-5

Leach, C. (1980). Direct analysis of a repertory grid. *International Journal of Man-Machine Studies*, *13*(1), 151–166. http://doi.org/10.1016/S0020-7373(80)80041-1

Luther, M. (2012). Christian University, *2506489*, 2506489.

MacLean, K. E. (2008). Haptic Interaction Design for Everyday Interfaces. *Reviews of Human Factors and Ergonomics*, *4*(1), 149–194. http://doi.org/10.1518/155723408X342826

MakerBot Replicator. (n.d.). Retrieved July 16, 2015, from http://store.makerbot.com/replicator

Mucha, H., Bartel, H., & Dolata, J. (2005). Techniques of Rearrangements in Binary Trees (Dendro- grams) and Applications, *54*, 561–582.

Nefs, H. T. (2008). On the Visual Appearance of Objects. In *Product Experience*. San Diego: Elsevier.

Norman, D. A. (2002). *The Design of Everyday Things* (Vol. 18). Basic Books.

Olsson, P., Nysjö, F., Aneer, B., Seipel, S., & Carlbom, I. B. (2013). SplineGrip. In *ACM SIGGRAPH 2013 Posters on - SIGGRAPH '13* (p. 1). New York, New York, USA: ACM Press. http://doi.org/10.1145/2503385.2503440

Osbourn, R. J. (1988). *The aesthetic response : An application of personal construct theory to the perception and appraisal of visual art*. University of Exeter.

Picard, D., Dacremont, C., Valentin, D., & Giboreau, A. (2003). Perceptual dimensions of tactile textures. *Acta Psychologica*, *114*(2), 165–184. http://doi.org/10.1016/j.actpsy.2003.08.001

Rhinoceros 5 for Windows. (n.d.). Retrieved August 18, 2015, from http://www.novedge.com/products/2217

Sekular, R., & Blake, R. (1994). Perception (3rd edn). New York: McGraw-Hill.

Sener, B., Wormald, P., & Campbell, I. (2002). Towards "virtual clay"modelling-challenges and recommendations: A brief summary of the literature. *Proceedings of the DESIGN*, (Figure 1), 545–550. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:TOWARDS+?+VIRTUAL+CLAY+?+MODELLING+-+CHALLENGES+AND+RECOMMENDATIONS+:+A+BRIEF+SUMMARY+OF+THE+LITERATURE#0

Sonneveld, M. H. . S. H. N. J. (2008). Product Experience. In *Product Experience* (pp. 41–67). Elsevier. http://doi.org/10.1016/B978-008045089-6.50005-8

Stevens, J. C. (1990). Perceived roughness as a function of body locus. *Perception & Psychophysics*, *47*(3), 298–304. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2326152

Tedeschi, A. (n.d.). Mix Experience Tools 1. Retrieved August 18, 2015, from http://content.yudu.com/Library/A1qies/mixexperiencetoolsnu/resources/28.htm

Textured Multi Ball Set. (n.d.). Retrieved April 14, 2014, from http://www.digit-eyes.com/upcCode/773554066883.html?l=en#.Vt0NJJx96Uk

What are T-Splines? (n.d.). Retrieved August 18, 2015, from http://www.tsplines.com/products/what-are-t-splines.html

ZBrush. (n.d.). Retrieved September 19, 2015, from http://wired.jp/2015/03/14/zbrush/3/

Zhang, Y., & Wildemuth, B. M. (2005). Qualitative Analysis of Content By. *Analysis*, *1*(2), 1–12.

APPENDICES

APPENDIX A

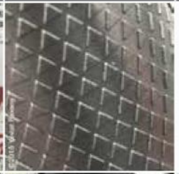
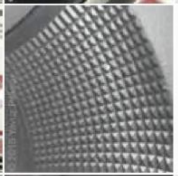
3D SURFACE TEXTURE EVALUATION TABLE

Personal Care Products

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
1.	Shaver	Fakir			Fingers, fingertips	Top of the product, handle part, on/off switch	Repetition of rigidly defined stripes with clear contour of the stripe geometry. The transition between base surface and the surface texture feature has strong contrast. Height difference is more dramatic.	Increases friction to make it easier to hold, indicates place to hold	Looks premium, precisely crafted. Creates contrast with the surface on rest of the product
2.	Shaver	Fakir			Palm, fingers	Sides of the product, handle part	Smooth repetitive hill topology. The transition between base surface and hills are smoothly created. The initiation and ending of the surface features can not be identified by means of rigidity. Height difference is gradual.	Increases friction to make it easier to hold, indicates place to hold	Looks premium, precisely crafted. Creates contrast with the surface on rest of the product
3.	Shaver	Rowenta			Fingers, fingertips	Top of the product, handle part	Repetition of dots with negative space subtracted from base surface. The repetition fashion is constant in both X and Y direction of surface area. The 3D texture feature is differentiated by the property being indented.	Increases friction to make it easier to hold, indicates place to hold	Looks premium, precisely crafted. Creates contrast with the surface on rest of the product
4.	Shaver	Philips			Fingers, fingertips	Top of the product, handle part	Dense repetition of notch texture is placed on certain domain of base surface. Negative and positive features of surface texture are equally distributed. The slimness of the notch element is the feature for the difference.	Increases friction to make it easier to hold, indicates place to hold	Looks premium, precisely crafted. Creates contrast with the surface on rest of the product
5.	Shaver	Braun			Fingers, fingertips	Top of the product, handle part, on/off switch	Smooth repetitive hill topology. The transition between base surface and hills are smoothly created. The initiation and ending of the surface features can not be identified by means of rigidity. Height difference is gradual.	Increases friction to make it easier to slide the switch, indicates place of the switch and its movement axis	The switch looks precise

Surface Texture Evaluation Table: Consumer Electronics 3

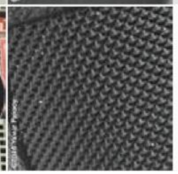
Personal Care Products Continued

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
6.	Shaver	GoldMaster			Palm, Fingers	Lower side of body, front side, handling area	Repetition of polygonal (triangular) shaped hills are added to base surface. The repetition fashion is relative to the shape of each individual element. There is also negative triangle inbetween triangular hills.	Enhanches gripping, indicates places to hold	Feels premium, precisely crafted, gives better tactual experience
7.	Shaver	GoldMaster			Fingertip, Fingers	Slide switch of the product	Repetition of rigidly defined stripes with clear contour of the stripe geometry. The transition between base surface and the surface texture feature has strong contrast. Height difference is more dramatic.	Increases friction to make it easier to slide the switch, indicates place of the switch and its movement axis	Slightly curved stripes make the movement of the switch more natural, looks precise
8.	Shaver	Braun			Tip of Index Finger, Fingers	Above the switch, on the main body	Dense repetition of pyramidal elements with sharp top end is placed on base texture. Negative and positive features of surface texture are equally distributed. The sharpness and precision of each pyramidal element is the feature for the difference.	Makes it much easier to hold it by adding friction to the point where the product will be controlled with index finger, indicated place to put index finger	Feels premium, sophisticated, precisely engraved
9.	Shaver	Braun			Palm, Fingers	Sides of the main body	Repetition of dots with negative space subtracted from base surface. The repetition fashion is constant in both X and Y direction of surface area. The 3D texture feature is differentiated by the property being indented.	Increases friction, enhances handling, indicates way to hold the product	Indented dots looks precisely distributed, looks premium and inviting
10.	Shaver	Braun			Fingertips	Sides of the upper part of the product	Dense repetition of pyramidal elements with sharp top end is placed on base surface. Negative and positive features of surface texture are equally distributed. The sharpness and precision of each pyramidal element is the feature for the difference.	Gives ability to precisely manipualte the product, increases handling	Looks premium, precisely crafted

4 © 2015 Yavuz Paksoy **Master's Thesis: Study 1**

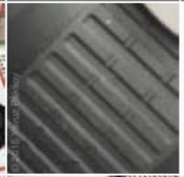
Personal Care Products Continued

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
11.	Shaver	Braun			Fingertip, Fingers	Lower region of the front/ top side, the handle area	Smooth repetitive hill topology. The transition between base surface and hills are smoothly created. The initiation and ending of the surface features can not be identified by means of rigidity. Height difference is gradual.	Increases friction, enhances handling, indicates way to hold the product	The surface texture is visually in relation with its upper neighbor, which makes it look dynamic, masculine, premium
12.	Shaver	Braun			Fingertip, Fingers	Middle/upper region of the front/top side, the switch area	Smooth repetitive hill topology. The transition between base surface and hills are smoothly created. The initiation and ending of the surface features can not be identified by means of rigidity. Height difference is gradual.	Increases friction to make it easier to slide the switch, indicates place of the switch and its movement axis	Slightly curved surface modulation makes the movement of the switch more natural, looks precise
13.	Shaver	BaByliss			Fingers, fingertips	On the top of switch button	Repetition of rigidly defined stripes with clear contour of the stripe geometry. The transition between base surface and the surface texture feature has strong contrast. Height difference is more dramatic.	Indicates place of the switch, the direction to slide is also indicated	The switch looks precise
14.	Hair Straightener	Braun			Palm, fingers	Outer part of body, at the other side of hot ceramic surface	Repetition of rigidly defined stripes with clear contour of the stripe geometry. The transition between base surface and the surface texture feature has strong contrast. Height difference is more dramatic.	Enhanches griping, prevents contact with hot ceramic surface	Looks premium, precisely crafted

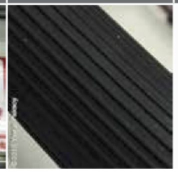
#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
15.	DSLR Camera Lens	Canon			Fingers, palm, fingertips	Around the camera lens ring	Repetitive rectangular extrusion. The transition between base surface and hills are rigidly created. The space between each rectangular extrusion is easy to distinguish.	Increases friction, indicates place to hold, the texture is place perpendicular to the rotation of the ring	The rotation of ring looks precise, infinitely adjustable
16.	Binoculars	Konus			Fingertips Fingers	Inner side of each binocular	Repetition of dot shaped hills added to base surface. The repetition fashion is constant in both X and Y direction of surface area. The 3D texture feature is differentiated by the extrusion.	Indicates the place where fingertips should be located in	Looks precisely protrused, pleasent to touch
17.	DSLR Camera	Canon			Fingertips	On the side, the lid of memory card slot	Repetition of dot shaped hills added to base surface. The repetition fashion is constant in both X and Y direction of surface area. The 3D texture feature is differentiated by the extrusion.	Indicates a special region for certain function, makes it easier to slide the lid	Makes camera look more sophisticated, precisely placed
18.	DSLR Camera	Canon			Fingertips	Around the mode dial of the camera	Dense repetition of pyramidal elements with sharp top end is placed on base texture. Negative and positive features of surface texture are equally distributed. The sharpness and precision of each pyramidal element is the feature for the difference.	Increases exactness with fine details, make it easier to rotate	Looks like jewellery because of the fine details, looks premium
19.	Compact Camera	Nikon			Palm, fingers	Handle part of the camera, side of the body	Dense repetition of pyramidal elements with sharp top end is placed on base texture. Negative and positive features of surface texture are equally distributed. The sharpness and precision of each pyramidal element is the feature for the difference.	Makes it much easier to hold, increases friction	Looks like jewellery because of the fine details, looks premium

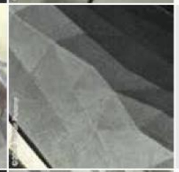
Surface Texture Evaluation Table: Consumer Electronics 7

Cameras and Camera Accessories Continued

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
20.	DSLR Camera Lens	Nikon			Fingers, palm, fingertips	Around the camera lens ring	Repetitive rectangular extrusion. The transition between base surface and hills are rigidly created. The space between each rectangular extrusion is easy to distinguish.	Increases friction, indicates place to hold, the texture is place perpendicular to the rotation of the ring	The rotation of ring looks precise, infinitely adjustable
21.	Mirrorless Camera Lens	Samsung			Fingers, palm, fingertips	Around the camera lens ring	Dense repetition of notch texture is placed on certain domain of base surface. Negative and positive features of surface texture are equally distributed. The slimness of the notch element is the feature for the difference.	Increases friction, indicates place to hold, the texture is place perpendicular to the rotation of the ring	Precise stripes make it look professional, infinitely adjustable
22.	Mirrorless Camera	Samsung			Fingertips	Around the mode dial of the camera	Dense repetition of notch texture is placed on certain domain of base surface. Negative and positive features of surface texture are equally distributed. The slimness of the notch element is the feature for the difference.	Increases exactness with fine details, make it easier to rotate	Precise stripes looks premium, professional
23.	Mirrorless Camera	Sony			Palm, fingers	Handle part of the camera, side of the body	Repetition of dots with negative space subtracted from base surface. The repetition fashion is constant in both X and Y direction of surface area. The 3D texture feature is differentiated by the property being indented.	Makes it much easier to hold, increases friction	The indentation of the dots make it look more inviting, more pleasent to touch
24.	Mirrorless Camera	Samsung			Fingertips	Around the mode dial of the camera	Dense repetition of notch texture is placed on certain domain of base surface. Negative and positive features of surface texture are equally distributed. The slimness of the notch element is the feature for the difference.	Increases exactness with fine details, make it easier to rotate	Precise stripes looks premium, professional

Cameras and Camera Accessories Continued

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
25.	Selfie Stick	Cellular Line			Palm, fingers	Around the handle	Repetitive rectangular extrusion. The transition between base surface and hills are rigidly created. The space between each rectangular extrusion is easy to distinguish.	Makes it much easier to hold camera, increases stabilization	Looks well defined, precisely crafted, premium

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
26.	Mice	Logitech			Fingertips	Around the mode dial of the camera	Dense repetition of notch texture is placed on certain domain of base surface. Negative and positive features of surface texture are equally distributed. The slimness of the notch element is the feature for the difference.	Increases preciseness with fine details, make it easier to rotate	Precise stripes looks premium, professional
27.	Mice	Logitech			Thumb, thumb tip	Side of the product, thumb area	Repetitive surface fraction on base surface that defines the surface modulation. The modulation on the base surface are dramatically change in different directions.	Provides comfortable, non sharp rest area for thumb, the texture shape increases the friction	Unique, non repetitive texture makes it look hand-made, premium
28.	Portable HDD	Seagate			Fingers, Palm, Fingertips	On top of the product	Repetitive surface fraction on base surface that defines the surface modulation. The modulation on the base surface are dramatically change in different directions.	Provides non slippery area for better handling	Reflective texture with surface modulation makes it look like jewellery, premium feel
29.	Mice	Logitech			Thumb, thumb tip	Side of the product, thumb area	Repetition of polygonal (triangular) shaped hills are added to base surface. The repetition fashion is relative to the shape of each individual element. There is also negative triangle inbetween triangular hills.	Provides comfortable, non sharp rest area for thumb, the texture shape increases the friction	Repetitive triagles make it look elegant, technical, precise, unique, premium
30.	Portable HDD	Samsung			Fingers, Palm, Fingertips	On top of the product	Repetitive surface fraction on base surface that defines the surface modulation. The modulation on the base surface are dramatically change in different directions.	Provides non slippery area for better handling	Reflective texture with surface modulation makes it look like jewellery, premium feel

Surface Texture Evaluation Table: Consumer Electronics 11

Computer HIDs and Storage Devices Continued

#	Type	Brand	Whole Product	Surface Texture	Body Contact	Location on Product	Properties of Texture	Functional Improvement	Hedonic Improvement
31.	Keyboard	Microsoft			Palm, wrist, fingers	Lower part of the body, the side of the user	Repetition of polygonal (triangular) shaped hills are added to base surface. The repetition fashion is relative to the shape of each individual element. There is also negative triangle inbetween triangular hills.	Increases friction for hands, provides better typing experience	Causes leisure activity when the keys are not in use, precisely shaped, looks and feels premium

APPENDIX B

REPERTORY GRID FORMAT

Yüzey Dokusunun Ayırt Edici Özellikleri **Tarih:**

Katılımcı No: **Yaşı:** **Cinsiyeti:** ☐ **K** ☐ **E** **Bölümü:** **Görüşme Süresi:**

Lütfen aşağıda kodları yer alan 9 yüzey dokusunu (YD-01, YD-02, YD-03, YD-04, YD-05, YD-06, YD-07, YD-08, YD-09), sizin tarafınızdan tanımlanan karşıt özelliklerini birbirinden bağımsız olarak ne kadar taşıdığına dair **1'den 5'e** (düşükten yükseğe) kadar değerlendiriniz.

1 — 2 — 3 — 4 — 5

[IP] TUTUM SOL	YD-01	YD-02	YD-03	YD-04	YD-05	YD-06	YD-07	YD-08	YD-09	[EP] TUTUM SAĞ

APPENDIX C

LIST OF DYADS

P01	YD-4-2	YD-1-6	YD-9-8	YD-3-5			
P02	YD-1-3	YD-6-8	YD-4-5	YD-2-7			
P03	YD-1-2	YD-7-8	YD-9-5	YD-3-4	YD-6-9		
P04	YD-2-5	YD-1-6	YD-3-8	YD-4-9	YD-5-7	YD-5-4	
P05	YD-7-5	YD-6-1	YD-8-3	YD-5-4	YD-2-1	YD-4-9	
P06	YD-2-8	YD-4-9	YD-1-6	YD-7-5	YD-2-3	YD-4-5	
P07	YD-3-7	YD-9-5	YD-2-6	YD-1-8			
P08	YD-4-3	YD-1-7	YD-6-2	YD-8-9	YD-5-3		
P09	YD-6-8	YD-1-4	YD-7-9	YD-3-6	YD-2-9	YD-8-5	YD-3-8
P10	YD-5-6	YD-2-4	YD-1-9	YD-3-8			
P11	YD-1-5	YD-6-7	YD-3-9	YD-8-9			
P12	YD-5-4	YD-2-6	YD-3-8	YD-2-3	YD-9-2		
P13	YD-3-4	YD-5-7	YD-1-6	YD-6-8	YD-7-9		
P14	YD-8-9	YD-2-9	YD-5-2	YD-4-9	YD-1-4		
P15	YD-2-8	YD-1-4	YD-1-9	YD-5-1			
P16	YD-3-5	YD-2-6	YD-3-9				
P17	YD-2-7	YD-1-3	YD-6-8	YD-4-5			
P18	YD-6-8	YD-1-4	YD-1-3	YD-6-7			
P19	YD-7-9	YD-2-8	YD-2-6	YD-4-5	YD-5-9		
P20	YD-3-4	YD-3-6	YD-4-8	YD-1-5			
P21	YD-2-4	YD-1-8	YD-2-9	YD-5-7	YD-4-7		
P22	YD-1-9	YD-1-5	YD-3-6	YD-2-6	YD-7-8		
P23	YD-5-6	YD-4-7	YD-2-9	YD-3-8	YD-3-7	YD-2-4	
P24	YD-7-9	YD-5-8	YD-1-9	YD-1-7			
P25	YD-6-7	YD-2-8	YD-1-4	YD-1-3			
P26	YD-1-5	YD-3-6	YD-1-9				
P27	YD-4-7	YD-2-9	YD-5-6				
P28	YD-2-8	YD-1-5	YD-4-8	YD-7-9			
P29	YD-4-8	YD-1-5	YD-4-6				
P30	YD-1-4	YD-2-9	YD-2-4	YD-3-7			