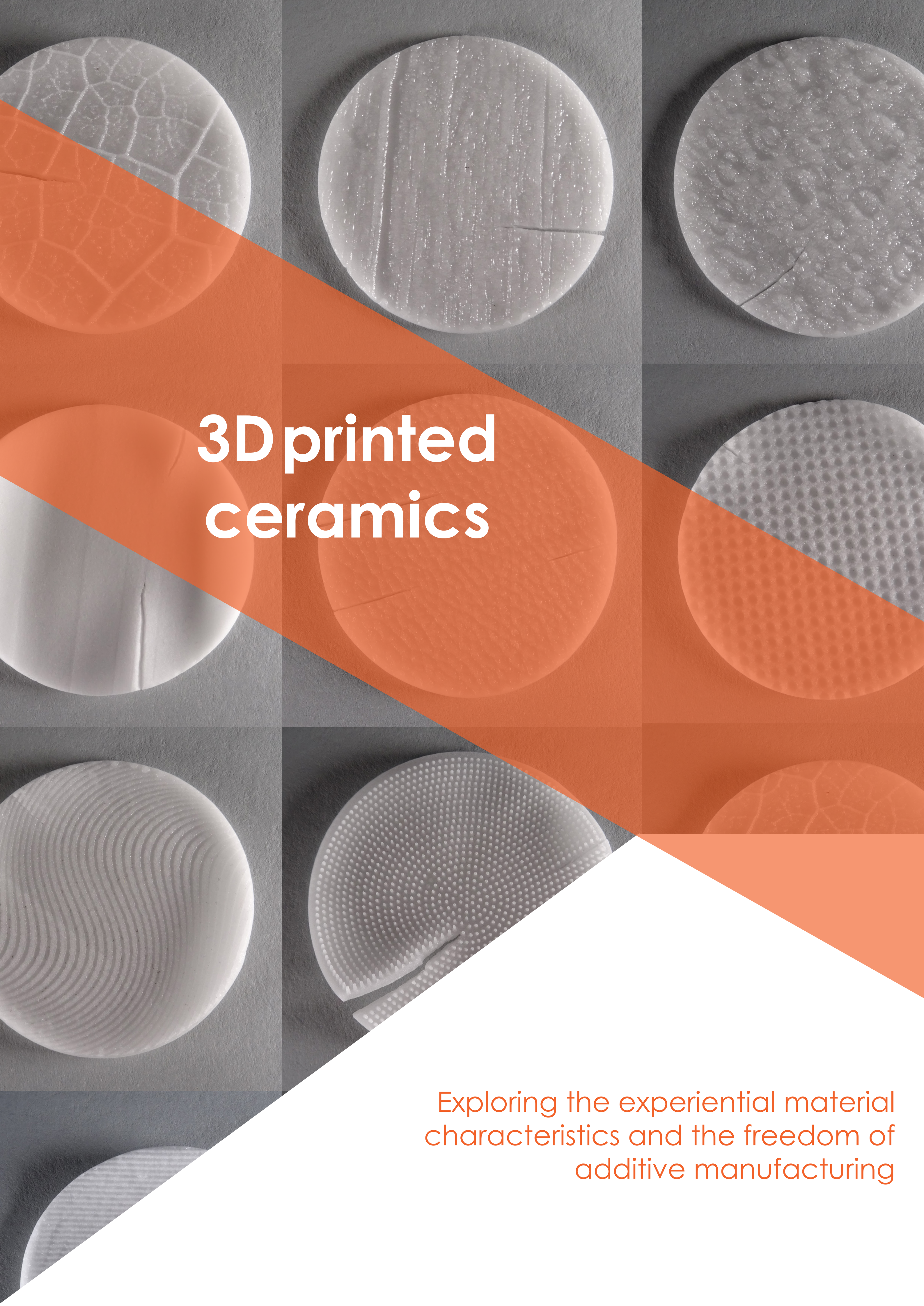
3D printed ceramics



Exploring the experiential material characteristics and the freedom of additive manufacturing

Project

3D printed ceramics: Exploring the experiential material characteristics and the freedom of additive manufacturing.

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PREFRACE

I would like to thank my supervisors Elvin and Tessa for their professional help and guidance.

Furthermore, I would like to thank all the people that have helped me with the user studies.

I would also like to thank everyone at the applied labs for their technical support and in particular Mascha, who helped a lot when machinery was failing on me.

And lastly I would like to thank my parents and my friends for the continous support they gave me during this project.

EXECUTIVE SUMMARY

This master thesis is a graduation project of the master study Integrated Product Design at Delft University of Technology. It was executed in collaboration with the Material Experience Lab in the faculty Industrial Design Engineering. The project follows the Material Driven Design method by Elvin Karana. The material being researched is the Formlabs ceramic resin which was newly developed and has been on the market for approximately a year now.

The Formlabs ceramic resin is a 3D printable ceramic material which uses photopolymerization to solidify the resin into objects. The material requires extra steps and experimenting and is now mostly used in educational and researching environments, because of the challenges it brings. These challenges mainly occur because not enough is known about the material and the way of use. However, the Formlabs material has a great potential of being more user friendly and easier to use than other 3D printable ceramic materials. This is because the material is made for the specific 3D printer allowing them to work together perfectly, increasing the ease of use and success rate.

The main research question for this thesis is:

Which technical and experiential material properties should be emphasized to create unique material-user experiences?

The research started with understanding the material by executing user studies, technical tests and by conducting many tinkering experiments. The tinkering process was based on the information provided by Formlabs. These experiments and tests led to several insights which created a clear overview of unique and interesting material characteristics.

User studies concluded that the material was perceived as rough and tactually offensive but as pure, inviting and aesthetically pleasing because of the mat white colour, translucency and lack of impurities, creating a sensorial incongruence.

Some interesting directions came forth out of the tinkering phase and the user studies.
It is possible to create controlled cracks in the walls of objects. Another interesting opportunity is the possibility to produce hidden Internal structures which play with the translucency of the material. This is possible because of the high precision 3D printing technique used. Lastly digitally modified surface textures can be created which alter the tactual experience of the material.

The translucency of the material and the possibility of digitally modified surface textures were further explored during this project. It was concluded from user studies that people experienced textures inspired by nature as more tactually pleasing. Furthermore, the translucency of the material allows for light to add depth to the more dimensional textures making the experience even more pleasing.

An envisioned material experience was formulated by combining the findings and insights from the tinkering process.
The envisioned role of the material was to attract people and invite and encourage them to interact with the object by touching and holding the surface. The tactile stimulation experienced is pleasant because of the digitally modified surface texture. When interacting with the object a hidden feature becomes visible emphasizing the translucency of the material.
This hidden feature will showcase the opportunities 3D printing of translucent ceramics brings.

User studies and an ideation session was held in order to materialise and realise this envisioned experience. This ideation resulted in a design direction:

Design a product set or a product made up out of different components, which initially look identical but become distinguishable when a hidden feature is unveiled, by emphasizing the material's translucency.

The final product concept came to be a interactive table lamp which encourages people to explore the effects of light on the material. The lamps has digitally modified surface textures which remove the original tactile offensiveness, creating a pleasant tactile experience. It is also made up out of different components which look identical until the lamp is turned on, unveiling hidden textures.

The design was evaluated based on the envisioned experience, elaborate user study and project brief. It was concluded that the product concept has incorporated the envisioned material experience and showcases the limitlessness and uniqueness of this particular material in combination with the high precision manufacturing process. However, it should be validated if it is actually experienced as envisioned.

Lastly a list of recommendations was set up for future research on this material in combination with the production process. Since, this project acts as a starting point for further research and should inspire people to also thinker, explore and play with this material.

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CHAPTER 1
PROJECT DESCRIPTION

This first chapter of the thesis provides an introduction to the project. It gives a brief explanation of the subject, describes the methodologies used and elaborated on the problem statement and its related research questions.

1.1 INTRODUCTION

3D printing of ceramic products was first mentioned by Marcus et al. and Sachs et al. and has been possible since the 1990s (Chen et al., 2019). They use the binder jet or inkjet 3D printing technique and to date, a variety of other printing techniques have been developed for ceramic manufacturing, like fused deposition modelling (FDM) and stereolithography (SLA). First only industrial printers were used by specialised companies and since a couple of years it has been possible to print ceramics at home using desktop FDM 3D printers (All3DP, 2018). Unfortunately, printing ceramics using desktop FDM printers requires a lot of post processing and the objects made are low in heat resistance, are not food safe and have low precision (Van Herpt, n.d.). However, this is all about to change because, Formlabs has developed a ceramic resin made for their Form X desktop SLA printers.

The Formlabs ceramic resin has been on the market for less than a year and is now mostly used for art, prototyping and engineering research since it still is, as stated by Formlabs, an experimental material (figure 1.1-1). The material is more complex compared to other Formlabs materials and more steps and experimenting is required for successful printing (Formlabs, n.d.). This necessary experimenting will be done by the designer during this project. This will result in better understanding of the material, specification of the material properties and possible applications.

Ceramic material made for the SLA printing technique has been developed by other companies as well. 3DCeram and Admatec print ceramic products for customers using industrial printers and Tethon 3D offers a ceramic resin for desktop printers. Lab technicians at the TU Delft have tested the material made by Tethon 3D but the material was not user friendly and a lot of the prints failed. This is why the ceramic resin made by Formlabs is going to be tested now.

Figure 1.1-1 Formlabs ceramic resin examples

From Introducing Ceramic Resin for the Form 2. Retrieved from https://formlabs.com/blog/introducing-ceramic-3d-printing-form-2/. Copyright 2019 by Formlabs

Getting proper printing results requires going through the workflow shown in figure 1.1-3. But successfully executing the steps in box 2 requires the knowledge of all material properties of the ceramic resin. As said these have to be explored further and executing post-processes, like glazing, bring a lot of challenges because of this.

Understanding the material and eventually applying it correctly will be achieved using the material driven design method (MDD) (Karana et al., 2015). The method consists of 4 steps shown in figure 1.1-2. The first step is to better understand the material by executing tests. The second step is to envision the desired user experience for the user-material interaction. Afterwards the designer researches which societal patterns can be found when users experience an emotion or activity. Lastly the material will be implemented in a product and/or service which fits the findings of the above mentioned steps. So, with this method it is not only specified what the material is but also what is does and what it makes us do. This is why the MDD will lead to the optimal application and material property exploration.

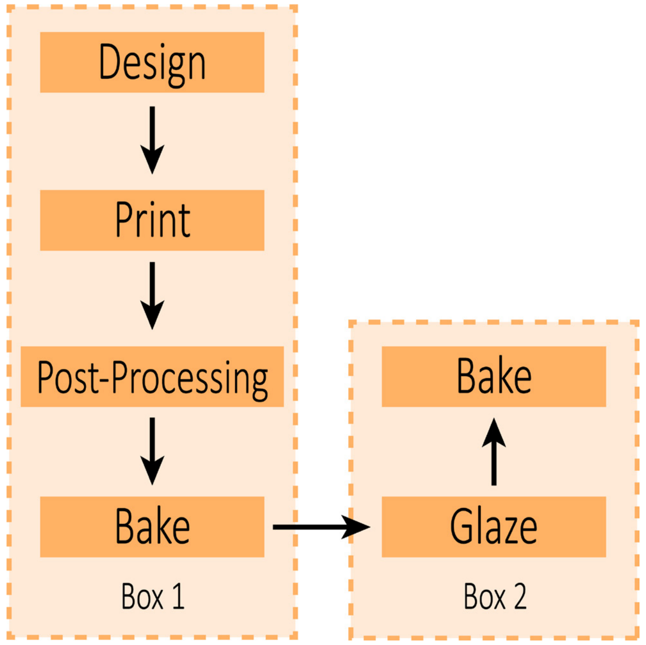


Figure 1.1-3 *Production workflow*

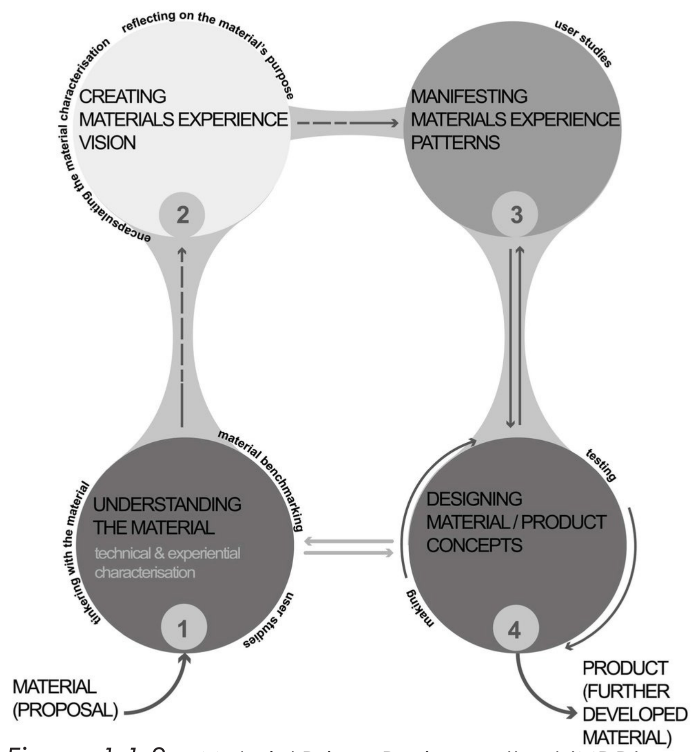


Figure 1.1-2 *Material Driven Design method (MDD)*

Reprinted from "Material driven design (MDD): A method to design for material experiences", Karana et al., 2015, International Journal of Design, 9(2), 35-54. Copyright 2015 by Karana, Barati, Rognoli, & Zeeuw van der Laan.

1.2 PROJECT SCOPE

The Formlabs ceramic resin will be researched during this project and specifically the fired state of the material. So, after it has been in the kiln (ceramics oven).

The material is now mostly used in educational and researching environments and the people using it have knowledge about SLA printing already. Working with the material is not challenge free, even for experienced users. Thjs is because not enough is known about the material and the way of use. Difficulty was found in properly executing the printing, firing and post processes, like glazing. Since the material is not understood properly it cannot yet be applied into meaningful industrial or consumer products / services. Eventually this should be possible but first the material and the production processes have to be tinkered with, explored and researched. This will be done during this project.

MDD
By going through the steps of the MDD method (figure 2) the designer will eventually understand the material. Experiencing the user friendliness of this material in combination with the Formlabs printer is also necessary since this will give knowledge about who can use it eventually.

No post processing
During this project the focus will be on the printing and firing processes and not on the post-processes. There will not be enough time to research and explore the execution of the post-processes but the results of this project can be used for future studies about post-processing 3D printed ceramics. This means that the developed product concept will not be food save since this ceramic material is only food save when glazed (Formlabs, 2018).

Digital modification
The opportunities and possibilities of the 3D printing process will be incorporated into the final material. SLA is a very high precision 3D printing technique and this should be utilized.

1.3 METHODOLOGIES

Material driven design method (MDD)

The MDD method is a methodology which aims to support designers in their journeys through design processes where the material is the point of departure. The designers will become skilled in exploring, understanding, defining and incorporating unique material properties and experiential qualities (Karana et al., 2015). The method leads the designer through a journey from tangible to abstract and from abstract back to tangible.

The method consists of 4 steps visualised in figure 1.3-1. The steps are:
(1) Understanding the material. This step includes tinkering to get insights on the material characteristics, material benchmarking where the material is positioned among similar materials to get knowledge on possible application areas, material experiences and issues and lastly user studies to explore how the material is received by people (Giaccardi & Karana, 2015).

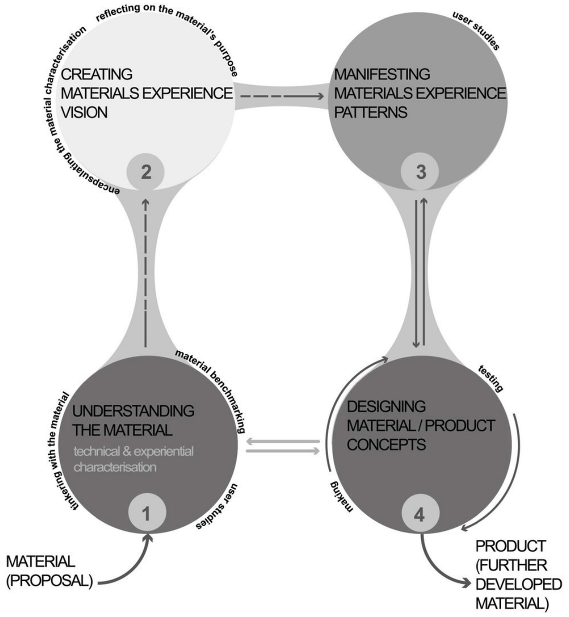


Figure 1.3-1 Material Driven Design method (MDD)
Reprinted from "Material driven design (MDD): A method to design for material experiences", Karana et al., 2015, International Journal of Design, 9(2), 35-54. Copyright 2015 by Karana, Barati, Rognoli, & Zeeuw van der Laan.

(2) Creating materials experience vision. The material experience vision expresses how a designer envisions the material's role. Its role regarding functional superiority, uniqueness of the user experience and its broader purpose in relation to products, people and society as a whole (Karana et al., 2015).

(3) Manifesting materials experience patterns. This step will create understanding about how people experience or interact with the envisioned material. To validate the expected experiences and interactions (Karana et al., 2015).

(4) Designing material / product concept. At this stage of the process the designer integrates all the main findings into a material or product design (Karana et al., 2015).

3D printing

3D printing is a technology which is constantly developing and it has become more accessible and affordable while improving in quality. Allowing for the production of industrial-quality objects. It changes the way businesses look at prototyping, making it easier to iterate, optimize and cut out outsourcing costs (Formlabs, 2019).

There are several different types of 3D printing. The most common 3D printing techniques are Fused Deposition Modelling (FDM), Selective Lase Sintering (SLA) and Stereolithography (SLA) (Formlabs, 2019).

FDM
FDM is the most widely used 3D printing technique among consumers. Mostly because of the large amount of printer brands which offer hobbyist FDM printers. FDM 3D printers build parts by melting and extruding thermoplastic filament, which a print nozzle deposits layer by layer in the build area (figure 1.3-5). The technique is well-suited for fast and low cost prototyping of simple parts. It has the lowest resolution so it is not the best option for printing complex designs or intricate structures (figure 1.3-2) (Formlabs, 2019).

SLS
SLS is the most common additive manufacturing technology for industrial applications. SLS builds parts using a high-powered laser to fuse small particles of polymer powder together (figure 1.3-7). The unfused powder supports the part during printing and eliminates the need for support structures. This makes the technique well suited for the production of complex geometries. SLS parts have a slightly rough surface finish, but almost no visible layer lines (figure 1.3-3) (Formlabs, 2019).

SLA
Stereolithography was the world's first 3D printing technology, invented in the 1980s, and is still one of the most popular technologies for professionals. SLA uses a UV laser to cure liquid resin into hardened plastic in a process called photopolymerization (figure 1.3-6). The technique has the highest resolution and accuracy. Creating the clearest details and smoothest surfaces (figure 1.3-4). This makes the SLA technique well suited for highly detailed prototypes requiring tight tolerances and smooth surfaces (Formlabs, 2019).

The printing technique used during this project is the SLA technique.

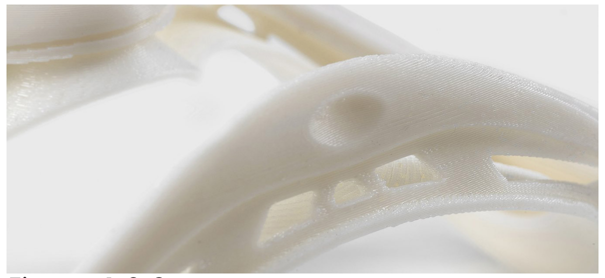


Figure 1.3-2 FDM quality
From 3D Printing Technology Comparison: FDM vs. SLA vs. SLS. Retrieved from https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/. Copyright 2019 by Formlabs

Figure 1.3-4 SLA quality
From 3D Printing Technology Comparison: FDM vs. SLA vs. SLS. Retrieved from https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/. Copyright 2019 by Formlabs

Figure 1.3-3 SLS quality
From 3D Printing Technology Comparison: FDM vs. SLA vs. SLS. Retrieved from https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/. Copyright 2019 by Formlabs

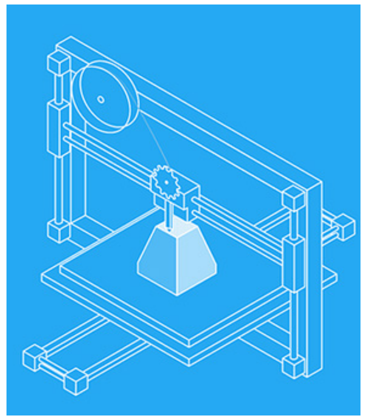


Figure 1.3-5 FDM technique
From 3D Printing Technology Comparison: FDM vs. SLA vs. SLS. Retrieved from https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/. Copyright 2019 by Formlabs

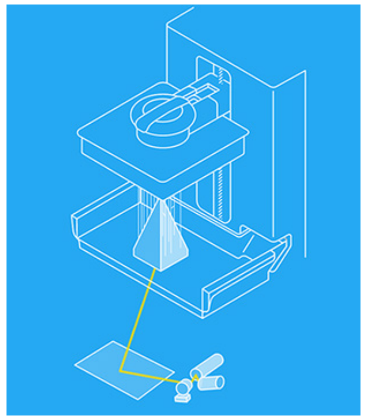


Figure 1.3-6 SLA technique
From 3D Printing Technology Comparison: FDM vs. SLA vs. SLS. Retrieved from https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/. Copyright 2019 by Formlabs

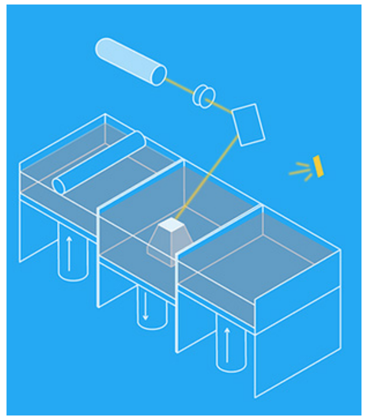


Figure 1.3-7 SLS technique
From 3D Printing Technology Comparison: FDM vs. SLA vs. SLS. Retrieved from https://formlabs.com/blog/fdm-vs-sla-vs-sls-how-to-choose-the-right-3d-printing-technology/. Copyright 2019 by Formlabs

1.4 RESEARCH QUESTIONS

The main research question for this project is:

Which technical and experiential material properties should be emphasized to create unique material-user experiences?

The main research question is divided into sub-questions:

Understanding ceramics

- Can the Formlabs ceramic material actually be labelled as a ceramic material?
- What are traditional ceramics
- what is the composition of traditional ceramics
- What are the properties of traditional ceramics
- How are traditional ceramics produced
- What are the application areas of traditional ceramics

- What is the composition of the Formlabs ceramic resin
- How are objects made from the Formlabs ceramic resin produced
- How does the SLA 3D printing technique work
- What happens during firing

- What are the main technical properties of the Formlabs ceramic material?
- What are the constraints/ opportunities of the technical properties?
- What is the impact strength of the green state and fired material?
- How does the measured impact strength compare to the information given by Formlabs?
- How does the impact strength of the fired material compare to traditional ceramics?
- How does the impact strength of the green state material compare to traditional polymers?
- What is the tensile strength of the green state and fired material?
- How does the measured tensile strength compare to the information given by Formlabs?
- How does the tensile strength of the fired material compare to traditional ceramics?
- How does the tensile strength of the green state material compare to traditional polymers?
- What is the flexural strength of the green state and fired material?
- How does the measured flexural strength compare to the information given by Formlabs?
- How does the flexural strength of the fired material compare to traditional ceramics?
- How does the flexural strength of the green state material compare to traditional polymers?
- What does sintering look like under a microscope?

Experiential characterisation

- What are the experiential properties of the material according to normal people?
- What are the experiential properties of the material according to a ceramics expert?
- What are unique sensorial qualities and which are the most and least pleasing?
- Is the material associated with any other material?
- Does the material evoke any meanings?
- Does the material elicit any emotions?
- How do people interact/behave with the material?
- How to change the characteristics of the Formlabs ceramic material?
- How do the kiln settings influence the material characteristics?

Experience vision

- What is the envisioned role of the material according to the designer?
- Which unique qualities of the material contribute to the vision?
- How does the material compare to similar materials?
- What are some interesting trends?
- How can you emphasize translucency?
- What are the material's to be emphasized in the final application?
- What is the unique contribution of the material?

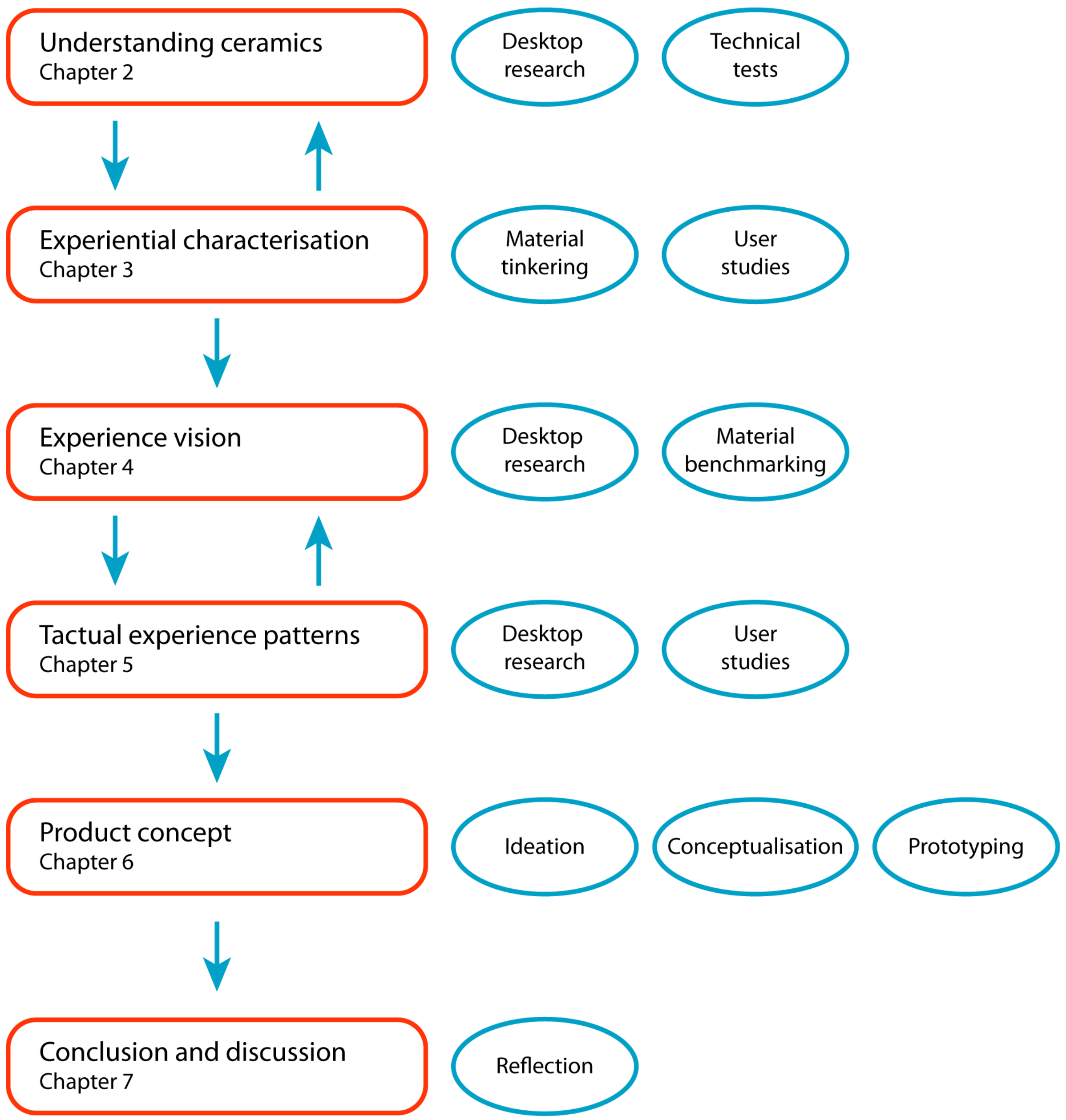
Tactual experience patterns

- Why is touch so important?
- What is touch?
- Which textures are perceived as visually pleasing?
- Which textures are perceived as visually and tactually pleasing?
- Which textures are perceived as visually and tactually pleasing when held in the light?
- Why are these textures perceived as pleasant?

Product concept

- What type of product can showcase the unique technical and experiential qualities of the material?
- What would people create from the material?

1.5 THESIS STRUCTURE



CHAPTER 2
UNDERSTANDING CERAMICS

To be able to apply the 3D ceramic material by Formlabs it is necessary to understand it. The material is labelled as being a ceramic material. The first step of understanding the material is to see if it is actually labelled correctly. So, this chapter will create understanding about traditional ceramics and the Formlabs ceramics and compares them by looking into their composition, technical properties, production processes and possible application areas.

2.1 TRADITIONAL CERAMICS

There are several types of traditional ceramics. These types of ceramics and their characteristics are visualised in this paragraph. They all have different compositions, properties, methods of production and possible application areas and all are known and can be found through material suppliers, or online material databases, like CES. The complete research on traditional ceramics can be found in appendix A.

Ceramic is defined as "Any non-metallic solid which remains hard when heated" (Lexico, 2019). Because of this there is not one standard composition when it comes to ceramics. There are many types and to explain what types there are they will be split up into ceramics with clay and without clay.

Clay based

Composition

These ceramics are made with materials from the earth. In most cases they are a mixture based on the naturally occurring material silica (SiO_2). It will include clay minerals like kaolinite ($Al_2[Si_2O_5][OH]_4$), silica sands and/or feldspars (Science Learning Hub, 2010).

Earthenware	Stoneware	Porcelain	Bone china
• Medium hardness • Opaque • Thermal shock resistance • Poor impact strength • Low impenetrability • Low thermal conductivity	• High hardness • Electrically insulating • Opaque • Thermal shock resistance • Medium impact strength • Medium impenetrability • Low thermal conductivity	• High hardness • Electrically insulating • Semi-transparent • High impact strength • High impenetrability • Low thermal conductivity	• High hardness • Very semi-transparent • High impact strength • High impenetrability • Low thermal conductivity
Low fire type (Tite, 2008). Fired between 1000-1150°C	Mid-fire and high-fire type (Tite, 2008). Fired between 1160-1225°C (mid-fire) or 1200-1300°C (high-fire)	High-fire type (Science Learning Hub, 2010) Fired between 1200–1450°C	High-fire type Fired at max. 1300°C Fired to the point of vitrification at first firing unlike porcelain (Narumi, n.d.)
Porous and course surface texture (Science Learning Hub, 2010)	Smooth surface (Science Learning Hub, 2010)	Smooth, glass like and translucent surface (Science Learning Hub, 2010)	Smooth, glass like and translucent surface (Narumi, n.d.)

Clay based

Production

Earthenware	Stoneware	Porcelain	Bone china
• Mixing • Forming • Drying • Firing o Bisque firing o Glost firing	• Beneficiation (optional) • Batching (optional) • Mixing • Forming • Drying • Firing o Bisque firing o Glost firing (optional)	• Beneficiation • Batching • Mixing • Forming • Drying • Firing o Bisque firing o Glost firing (optional)	• Beneficiation • Batching • Mixing • Forming • Drying • Firing o Bisque firing o Glost firing (optional)
Formed from lump of clay • Pinching • Drawing or beating using a paddle and anvil • Pressing or pounding into a mould (jiggering and jollying) • Building up from coils or slabs • Throwing on a wheel (Tite, 2008).	Formed from lump of clay • Pinching • Drawing or beating using a paddle and anvil • Pressing or pounding into a mould (jiggering and jollying) • Building up from coils or slabs • Throwing on a wheel (Tite, 2008). • Additive manufacturing	• Soft plastic forming, where the clay is shaped by manual moulding, wheel throwing, jiggering, or ram pressing. • Stiff plastic forming, Extruding through a steel die producing a column of uniform girth • Pressing, compact and shape dry bodies in a rigid die or flexible mould. • Slip casting, in which a slurry is poured into a porous mould.	• Soft plastic forming, where the clay is shaped by manual moulding, wheel throwing, jiggering, or ram pressing. • Slip casting, in which a slurry is poured into a porous mould.

Beneficiation: washing, concentrating and milling (sizing particulates) (Mason, 2016)

Batching: calculating the amounts of oxides according to recipe and weighing them (Mason, 2016)

Glost firing: firing the object again to fuse the glaze to the body of the object (Perry, 2011).

Bisque firing

Clay dries completely at 100°C

The water molecules of the clay are driven off from 350°C to 500°C.
Now it is no longer possible to mix the dried clay with water.
Irreversible chemical change known as dehydration.

The quartz crystals rearrange themselves into a slightly different order at 573°C.
Causes a slight and temporary increase in volume.
When fast firing at this stage of the program cracking often occurs.
Change known as Quartz Inversion.

Organic and inorganic materials are burned off at 900°C.

The last step of the bisque firing is semi- or full vitrification.
Shrinkage happens during this stage and clays with fine particle sizes will shrink more than clays with larger particle sizes.

(Big ceramic store, n.d.).

Vitrification / Sintering: Hardening, tightening and finally the partial glassification of the clay.

Non-clay based	
Oxides	**Non-oxides**
Composition Common oxides are alumina (Al_2O_3), zirconia (ZrO_2), silica (SiO_2) and beryllia (BeO) (Peng, 2013). Start as a powder with a certain purity, particle shape and size. Are blended with synthetic chemicals like deflocculants, binders and plasticizers for formability (Ruys, 2019).	**Composition** Common non-oxides are carbides, borides, nitrides and silicides. Examples are boron carbide (B_4C), silicon carbide (SiC), molybdenum disilicide ($MoSi_2$). Also start as a powder and are blended with synthetic chemicals like deflocculants, binders and plasticizers for formability.
• High hardness • Opaque • Electrically insulating • High impact strength • High impenetrability • Low thermal conductivity • Oxidation resistant High-fire type (Science Learning Hub, 2010) Fired between 1300-1400°C Solid state sintering closing pores creating non-porous solid object (Mason, 2016)	• Extreme hardness • Opaque • Electrically conducting • High impact strength • High impenetrability • High thermal conductivity • Low oxidation resistance Very high-fire type (Science Learning Hub, 2010) Fired between 1600-1800°C Solid state sintering closing pores creating non-porous solid object (Mason, 2016)

Deflocculants: prevents the particles from forming a gel by creating robust interconnected networks. By using deflocculants the slurry will become stable and contain the maximum amount of solid particles for the amount of liquid used (Ruys, 2019).

Binders: Increases green strength when the formed material is dry (Ruys, 2019).

Plasticizers: Increases plasticity and flexibility (Ruys, 2019).

Non-clay based	
Production	
Oxides	**Non-oxides**
• Beneficiation • Batching • Mixing • Forming • Drying • Firing • Dry forming Uniaxial die pressing Cold isostatic pressing (CIPing) • Wet forming Powder injection moulding (PIM) Tapecasting Slipcasting Extrusion • Direct manufacturing Green machining Additive manufacturing (3D printing) (Taylor, 2003): Can be fired in oxygen rich environment without oxidising	• Beneficiation • Batching • Mixing • Forming • Drying • Firing • Dry forming Uniaxial die pressing Cold isostatic pressing (CIPing) • Wet forming Powder injection moulding (PIM) Tapecasting Slipcasting Extrusion • Direct manufacturing Green machining Additive manufacturing (3D printing) (Taylor, 2003): Require carefully controlled furnace or kiln conditions to ensure the absence of oxygen during heating as these materials will readily oxidise during firing.

2.2 FORMLABS CERAMICS COMPOSITION

The Formlabs ceramic material is a non-clay based material, unlike most traditional ceramics. The exact composition of the Formlabs material is unknown but the company is not the first to print ceramics using UV light. There have been several papers written about printing ceramics using a photopolymerization process, which explain possible material compositions.

Layani et al., (2018) list several examples of ceramics printed using photopolymerization and states that there are two types of resins, or 'inks' used. The first group of inks contain a polymer which is embedded with ceramic particles and the other group of inks contain preceramic polymers that can be converted into a ceramic material by decomposing them at temperatures of around 1000 – 1300 °C in an inert atmosphere (Layani et al., 2018). The Formlabs material can be fired in an atmosphere containing oxygen and water so the material does not contain preceramic polymers. This leaves the first group of inks.
Felzmann et al., (2012) Doreau et al., (2000) and Griffith and Halloran, (1996) He et al., (2018) Zeng et al., (2018) all reported that this first group of inks is composed of ceramic particles like silica, alumina, zirconia etc., distributed within a monomer and oligomer matrix that is decomposed after printing, by heating at a high temperature in a normal atmosphere (sintering). This monomer and oligomer matrix will contain highly reactive photo initiators and additives like plasticizers, absorbers and non-reactive diluents to increase plasticity, alter the viscosity and keep the ceramic particles retained inside the ink (Felzmann et al., 2012).

As said the ink is composed of ceramic particles which are distributed within a monomer and oligomer base. Over time the ceramic particles and the base will separate and the ceramic particles will aggregate causing potential clogging of nozzles or valves (figure 2.2-1). This is why these types of inks require extensive mixing or stirring before every use (Layani et al., 2018).
The particle loading, meaning the amount of ceramic particles dispersed in the monomer base, influences the viscosity of the ink. A higher particle loading creates a more paste like ink which is more likely to

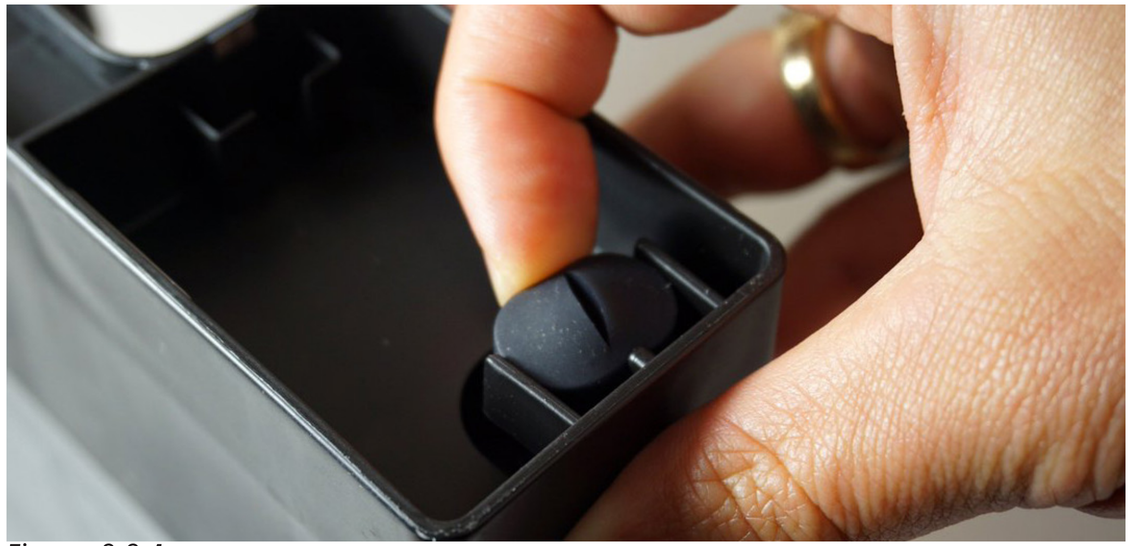


Figure 2.2-1 Cartridge valve
From Formlabs Form 2 Teardown. Retrieved from https://www.bunniestudios.com/blog/?p=4641

clog nozzles or valves and requires tailored machinery (Layani et al., 2018).
So, for easy production a low particle loading is desirable. However, a low loading of ceramic particles will increase shrinkage and allows for cracking during the drying and sintering process (Layani et al., 2018). It is unclear what the particle loading of the Formlabs ceramic material is but when working with the material and measuring the shrinkage it will at least give an inside on if it is high particle loading or low particle loading.

Most reported ceramic inks resulted in the production of non-transparent ceramic objects. However, in 2017, Kotz et al. created an monomer ink made for the SLA printing technique, which contained silica nanoparticles. When sintering this green state material post-printing at a temperature of 1300 °C it resulted in pure transparent silica glass (figure 2.2-2). Since, the Formlabs material is translucent and not opaque, the ceramic particles inside the ink are most likely silica.

So, the composition of the Formlabs material is an ink with a photopolymerizable monomer base which contains ceramic particles, most likely silica, and additives which improve formability.

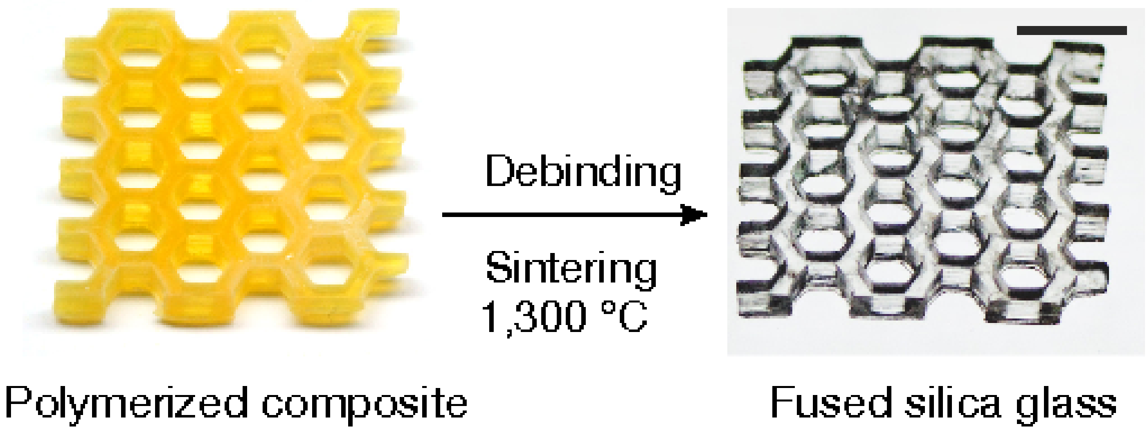


Figure 2.2-2 3D printing of fused silica glass.
Adapted from "Novel Materials for 3D Printing by Photopolymerization", Layani et al., 2018, Advanced Ma-terials, 30(41), 1706344. Copyright 2018 by WI-LEY-VCH Verlag GmbH & Co. KGaA, Weinheim

2.3 PRODUCTION OF FORMLABS CERAMICS

The Formlabs ceramics are produced using a SLA 3D printer. The printer used is from the same company and is called the Form 2. It is made up out of several parts shown in figure 2.3-1.

The production process of the Formlabs ceramics is comparable to the traditional ceramics production process. Each production step for the Formlabs ceramic material is explained in this paragraph.

Beneficiation and batching are done by Formlabs. So, the resin is delivered to the user with the correct particle size, particle loading and concentration between monomer base and ceramic particles.

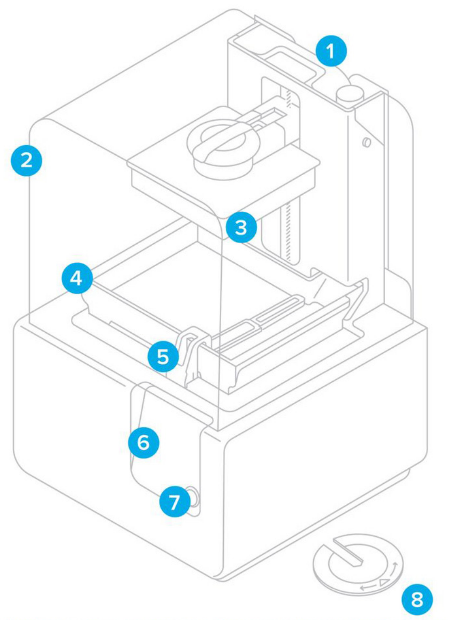


Figure 2.3-1 Printer parts
From Quick Start Guide (Form 2). Retrieved from https://support.formlabs.com/s/article/Quick-Start-Guide?language=en_US. Copyright 2019 by Formlabs

1. Resin cartridge
2. Cover
3. Build Platform
4. Resin Tank
5. Wiper
6. Touchscreen
7. Button
8. Leveling Tool

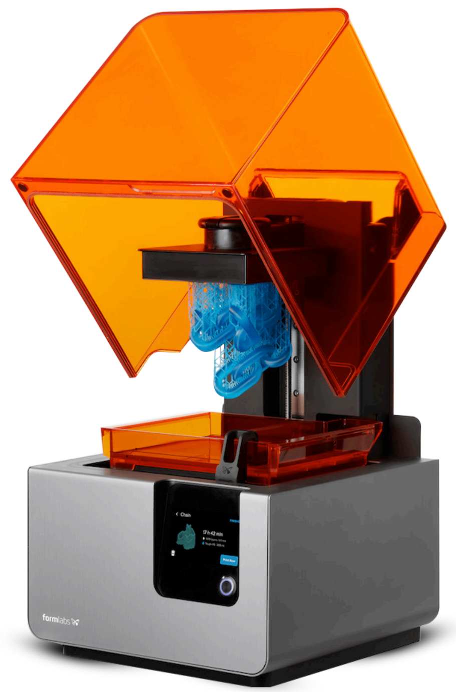


Figure 2.3-2 Formlabs Form 2 printer
From Form 2 The Industry-Leading Desktop 3D Printer. Retrieved from htt-ps://formlabs.com/uk/3d-printers/form-2/. Copyright 2019 by Formlabs

The mixing step is very important for this material. As mentioned before the monomer base and the ceramic particles will sperate and the particles will aggregate, so before every use the resin should be mixed and stirred. the resin tank and the resin cartridge both contain the material so they both have to be mixed before printing. The resin inside the resin tank is mixed by stirring it with a spatula and the resin inside the cartridge is mixed by shaking it vigorously for at least a minute.

The forming step in the production procedure consists of several actions.
The object is first of all digitally formed using a 3D modelling program.
This modelled object is printed by solidifying and adhering layers of resin to the build plate. The object will release itself from the build plate and fall in the resin tank when not adhered sufficiently. To increase print adherence the build plate is sanded before printing (Formlabs, 2018).
Objects will not be printed directly onto the build plate but will have a support structure which will facilitate successful printing by increasing the print adherence (figure 2.3-3). This support structure will hold the actual object and the size and density of the support points can be altered in the PreForm computer program. The object should be properly supported to assure that it will not release itself from the support and drop in the resin tank (Formlabs, 2018).
After properly sanding the build plate and adding sufficient support, the digital models can be printed. The models are printed using the SLA printing technique. The build plate is repeatedly lowered into the resin tank and each time the laser solidifies a thin layer of resin (figure 2.3-4). The resin solidifies because of photo initiators inside the monomer and oligomer base. These photo initiators react to the UV light and form molecular chains, hardening the material (figure 2.3-5).
The final forming step is cleaning the printed model. The model will have uncured resin residue on the walls after printing and this will give the printed part a tacky feel. This uncured residue should be removed and this is done by cleaning the parts using isopropyl alcohol (IPA).

The parts are wet after cleaning, because they have soaked up some of the IPA. When firing parts while wet stresses are created inside the material which will eventually show up as cracks or warping. So, the parts should be completely dry before firing.

Figure 2.3-3 Formlabs support structure
From Using Flexible Resin. Retrieved from https://support.formlabs.com/s/article/Using-Flexible-Resin?language=en_US. Copyright 2019 by Formlabs

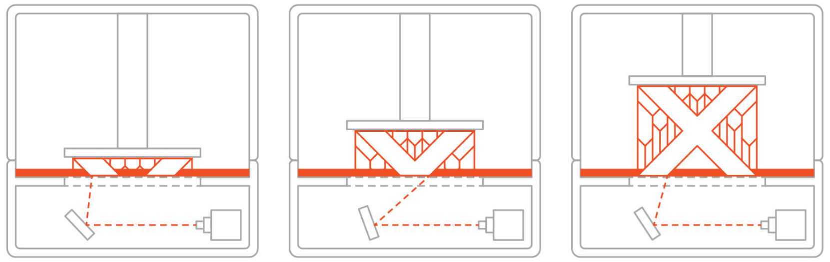


Figure 2.3-4 The SLA 3D printing process
From Introduction to SLA 3D Printing. Retrieved from https://www.3dhubs.com/knowledge-base/introduction-on-sla-3d-printing/.

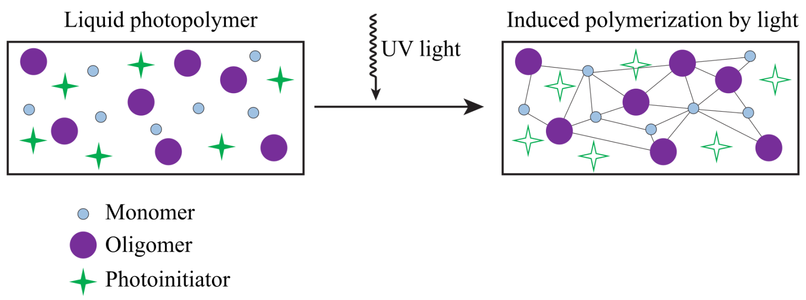


Figure 2.3-5 Photopolymerization
From Wat zijn photopolymeren. Retrieved from https://www.3ddirect.nl/wat-zijn-photopolymeren/.

After drying the parts can be fired. The parts are fired following a specific firing schedule shown in figure 2.3-6.

Ramp 1 slowly heats up the kiln to prepare it for the burnout phase. The monomer and oligomer matrix is removed during the burnout phase. The burnout phase should be long enough to completely remove the matrix. Partial burnout will result in cracks and distortion. Thinner walls (< 6mm) require less burnout time and will have the best surface quality while thicker walls require a longer burnout time and have a higher chance of cracking. The burnout time is set based on the cross sectional thickness of the part. So, a part with a wall thickness of 4 mm should have a burnout time of 4 hours. However parts can be kept in the burnout phase for extra time without issue. After the burnout out phase the kiln is set to a secondary hold at a temperature of 300 °C to ensure that the monomer and oligomer base is completely removed before ramp 2 (Formlabs, 2018).

Ramp 2 increases the kiln temperature to prepare for sintering. The ramp rate (increase in temperature per minute) has effect on if the part is heated uniformly. Formlabs recommends a ramp rate of 3 °C per minute. A part with large wall thickness differences will benefit from a slower ramp rate and parts designed with thin uniform walls can be ramped more quickly (Formlabs, 2018).

After ramp 2 the part is sintered. During sintering the silica particles inside the resin will fuse together, forming a solid part. The particles will become semi liquid, allowing them to shrink together, becoming denser (figure 2.3-7). Formlabs states that the ceramic resin will shrink approximately 15% during sintering, reaching a density from up to 90%. Parts printed using the ceramic resin are fired at temperatures between 1250 °C and 1300 °C. The parts are sintered by holding these temperatures for 5 minutes. Increasing or decreasing the hold time or sintering temperature will influence the translucency and surface texture of the part (Formlabs, 2018).

After sintering the parts are cooled down. First the parts will go through a free fall cool down. Going from the maximum firing temperature to 900 °C. This fast cool down limits additional slumping. Afterwards the parts are slowly cooled down at a controlled rate of 1 °C per minute, from 900 °C to room temperature. This slow cool down ensures that the parts will not get any structural cracking (Formlabs, 2018).

The last step is glazing. Glazing will alter the aesthetics of the object and make it food save and watertight. The Formlabs ceramic material is already watertight after firing this is why glazing is an optional step.

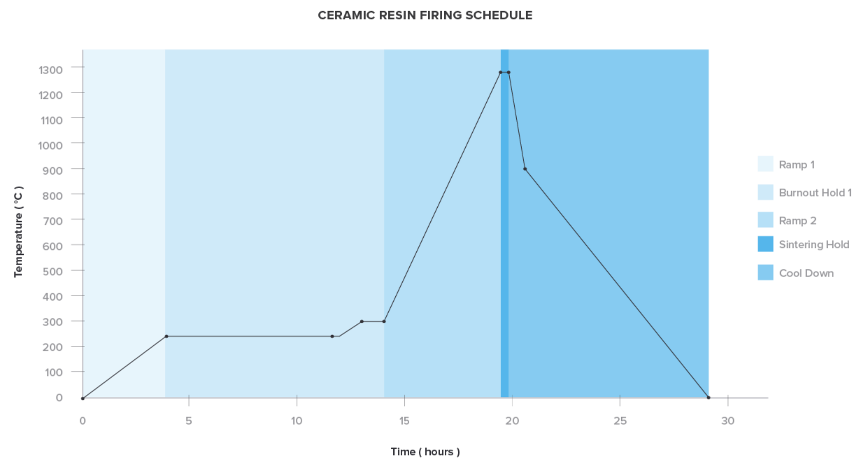


Figure 2.3-6 Ceramic resin firing schedule
Reprinted from "USAGE AND DESIGN GUIDE: Ceramic Resin". Formlabs, 2018. Copyright 2019 by Formlabs

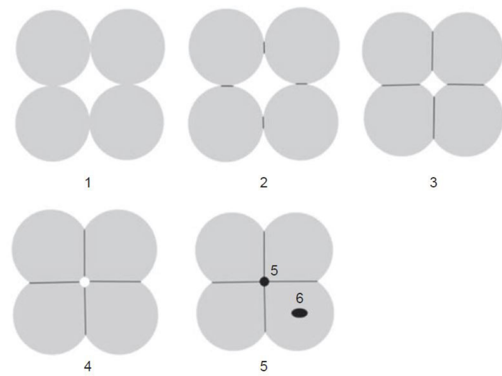


Figure 2.3-7 Sintering process
Reprinted from "Processing, structure, and properties of alumina ceramics", Ruys, A, 2019, Alumina Ceramics, 71–121. Copyright 2019 by Elsevier Ltd.

2.4 TECHNICAL CHARACTERISATION

Unlike the traditional ceramics not everything is known about the Formlabs ceramic material. Formlabs has offered some information about the technical properties of the material but this data can vary depending on the production settings. So, these uncertainties about the material characteristics call for technical research and this research is executed following the MDD method.
The technical characterisation has to provide answers on the following questions:

- What are the main technical properties of the Formlabs ceramic material?
- What are the constraints/ opportunities of the technical properties?

Formlabs lists a lot of technical properties that this material supposedly has. Not everything can be tested during the available time for this project. So, choices have to be made. The most important and relevant technical aspects which have to be explored are the strength of the material and the structure of the material. These technical aspects are researched by executing tensile tests, impact tests, three point bending tests and microscopy examination. The complete technical characterisation can be found in appendix B and the production of the technical test samples can be found in appendix G.

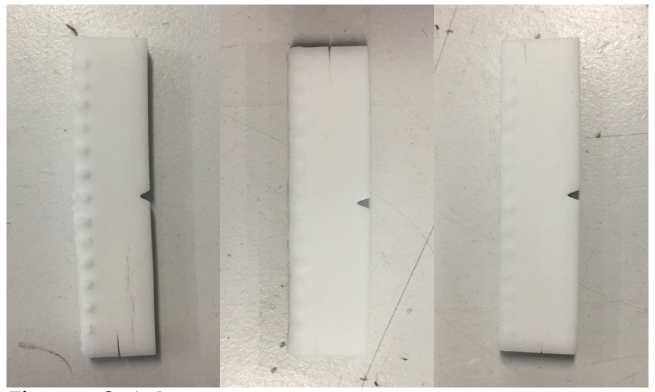


Figure 2.4-1 Fired state samples.

Impact test

Purpose

Ceramic materials are traditionally brittle and will break when dropped. To understand if this Formlabs ceramic material can withstand being dropped an impact test is executed. The impact test will measure the material's ability to withstand intense force or shock applied over a short period of time. Done by giving an indication on the energy required to break a standard test specimen with one pendulum swing. The impact test helps answering the following questions:

- What is the impact strength of the green state and fired material?
- How does the measured impact strength compare to the information given by Formlabs?
- How does the impact strength of the fired material compare to traditional ceramics?
- How does the impact strength of the green state material compare to traditional polymers?

Method

The test is executed following international standard D256-10 (Determining the Izod Pendulum Impact Resistance of Plastics). However, some alterations were made because of the complex and time consuming production process. Less samples were made and the dimensions of the samples were altered to assure for successfully produced samples.

Three fired samples and two green state samples were tested (figure 2.4-1 & 2).

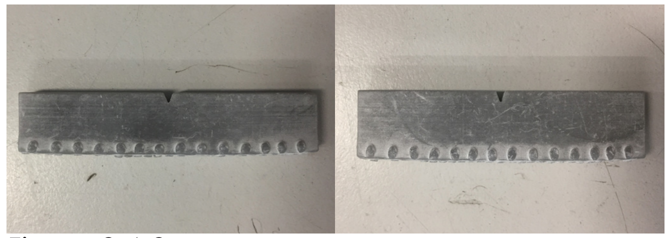


Figure 2.4-2 Green state samples.

The samples were accurately measured before testing (height, width, depth) to ensure for a proper comparison. The samples were printed horizontally (figure 2.44), so the pendulum will hit the samples perpendicular to the printed layers (figure 2.4-5).
A Zwick Izod pendulum impact tester was used to execute the test (figure 2.4-3).

Results

All samples successfully broke meaning a break where the sample separates into two pieces.
The average impact resistance measured for the green state material is 5.85 kJ/m2 which is 70.4 J/m. The average impact resistance measured for the fired material is 2.33 kJ/m2 which is 24.2 J/m.

Discussion

The measured impact resistance for the green state material was compared to the data gathered by Formlabs. The green state results of the impact test are not comparable to the Formlabs data at all (green state = 18.42 J/m). This can be because of the printing direction. As said, the pendulum swung perpendicular to the printed layers requiring more energy than when swung parallel to the layers (figure 2.4-6).

The green state material has a medium impact resistance in comparison to other polymers. It is comparable to lots of other plastics and elastomers (figure 2.4-7). So, the impact resistance does not make the material unique.

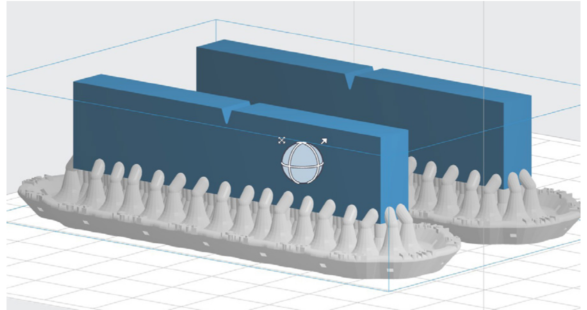


Figure 2.4-4 Print orientation

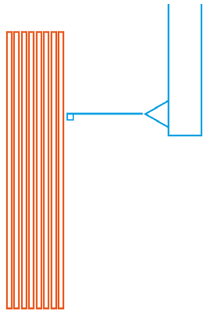


Figure 2.4-5 Perpendicular impact

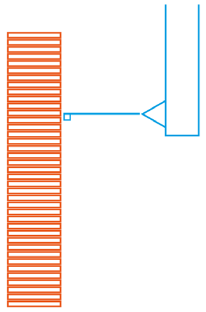


Figure 2.4-6 Parallel impact

Figure 2.4-3 Zwick Izod pendulum impact tester

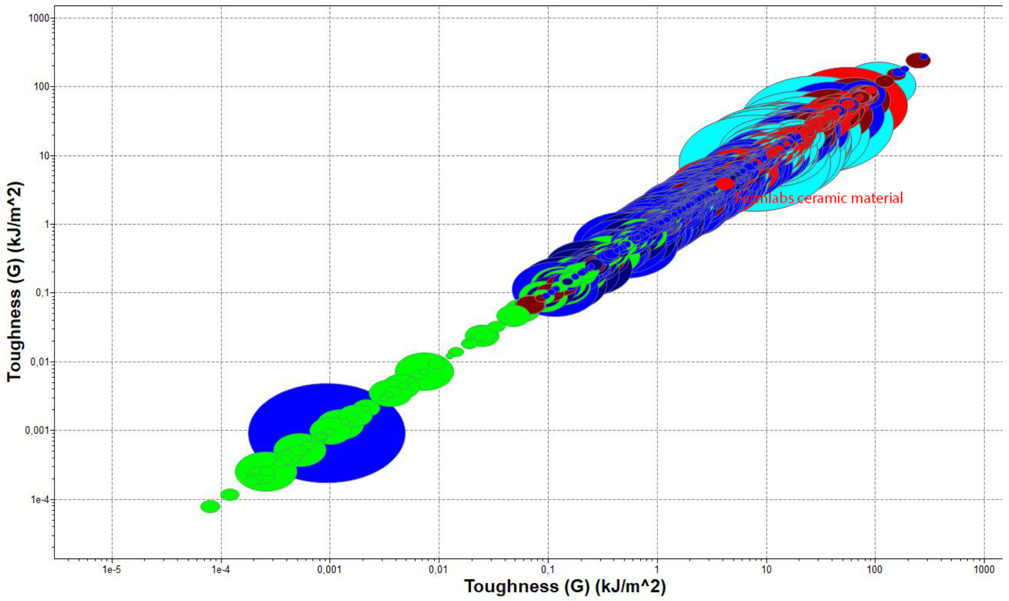


Figure 2.4-7 Impact resistance of the green state material compared to polymers.

The fired material actually has a high impact resistance in comparison to other ceramics, both traditional and advanced (CES Edupack). The Formlabs material can resist impact as well as advanced and composite ceramics (figure 2.4-8). Its impact toughness is comparable to the impact toughness of high translucent Zirconia (ZrO2), which is used for dental crowns, cutting tools and bearings. So, the material is definitely better fit for impact applications compared to traditional ceramics. However, it is still a ceramic material so rubbers, materials, and soft plastics are of course still better fit for impact applications.

Tensile test

Purpose

Ceramic materials generally have a low strength. To test if this is also the case for the Formlabs material tensile tests are executed. This is done by measuring the tensile stress that can be applied on the material sample before it permanently deforms (yield strength) or breaks (tensile strength) (Corrosionpedia, n.d.). The sample will return to its original shape if a stress level is applied which is lower that the yield strength. The sample will be permanently deformed when the stress level applied exceeds the yield strength. The sample will break when the applied force exceeds even the tensile strength. The test will provide the answers on the following questions:

- What is the tensile strength of the green state and fired material?
- How does the measured tensile strength compare to the information given by Formlabs?
- How does the tensile strength of the fired material compare to traditional ceramics?
- How does the tensile strength of the green state material compare to traditional polymers?

Method

The test is executed following international standard D638-14 (Tensile Properties of Plastics). However, some alterations were made because of the time consuming production process and the size restriction of the printer. Less samples were made and the dimensions of the samples were altered to assure for successfully produced samples.

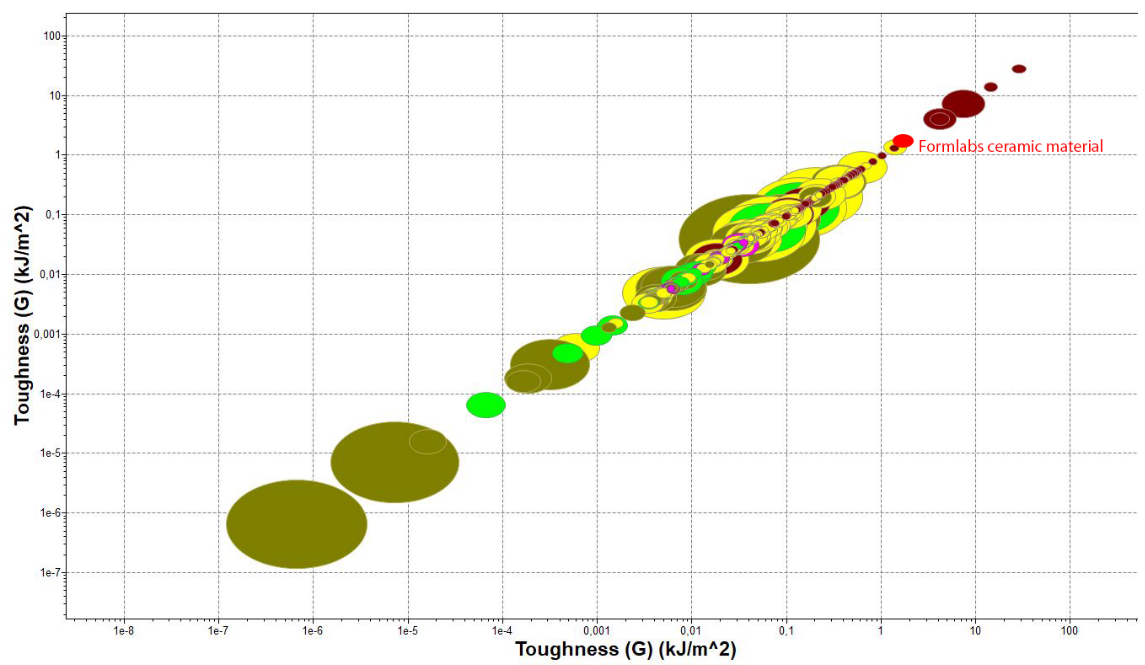


Figure 2.4-8 *Impact resistance of the fired material comparted to ceramics.*

Three fired samples and four green state samples were tested (figure 2.4-12 & 13). The samples were accurately measured before testing (height, width, thickness) to ensure for a proper comparison. The samples were printed horizontally (figure 2.4-10), so the tensile testing machine will exercise the pulling force parallel to the layers (figure 2.4-11).
A Zwick Roell Z010 tensile testing machine was used to execute the test (figure 2.4-9).

Results

Only the green state samples were successfully put through the test and successfully broke. The fired samples had slight warping which made it impossible to properly secure them between the fixed grips. The samples would break before they could be properly clamped in (figure 2.4-14). So, when executing the tensile test the samples would slip out of the grips rather than actually being subject to tensile stresses.

The average tensile strength measured for the green state material was 5.43 MPa and the average Young's modulus measured was 0.24 GPa.

Discussion

The measured tensile strength and Young's modulus for the green state material were compared to the data gathered by Formlabs. The measured tensile strength is comparable to the Formlabs data, so this confirms that the test was executed correctly. The Young's modulus is lower compared to the data made available

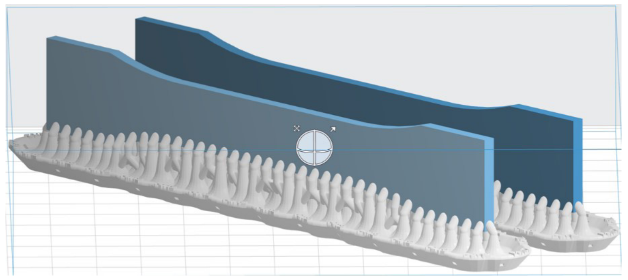


Figure 2.4-10 *Print orientation*

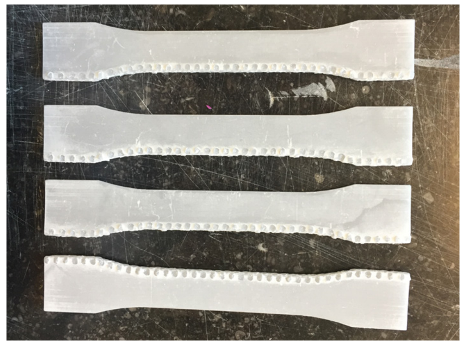


Figure 2.4-12 *Green state samples*

Figure 2.4-13 *Fired samples*

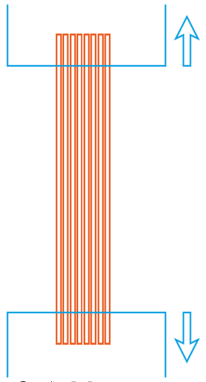


Figure 2.4-11 *Parallel pulling force*

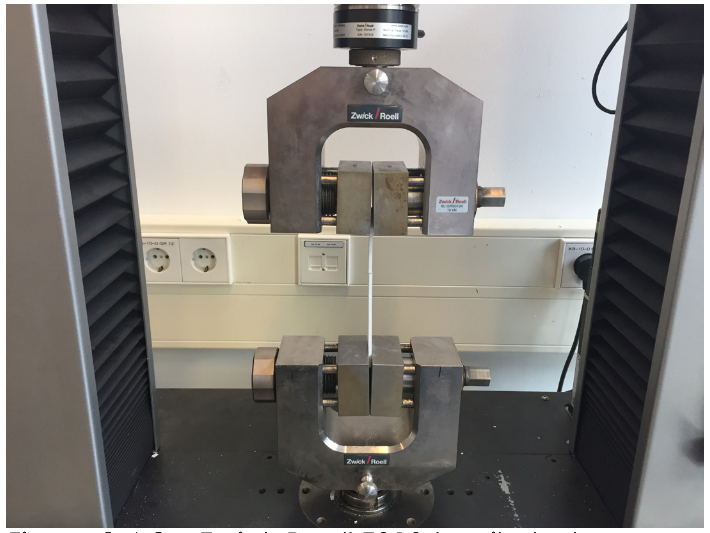


Figure 2.4-9 *Zwick Roell Z010 tensile tester*

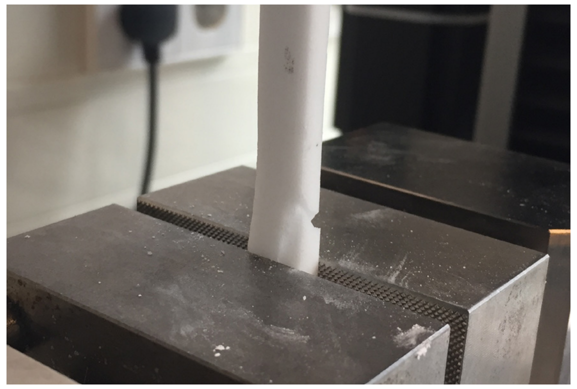


Figure 2.4-14 *Unable to test with fired material*

by Formlabs (Young's modulus = 1.03 GPa). This means that measured strain is significantly different. This could be caused by a different print orientation but this is unsure and should be tested.

The green state Formlabs material has a low tensile strength and Young's modulus compared to other polymers (figures 2.4-15 & 2.4-16). Meaning it is low in strength and low in stiffness compared to other plastics. This exact combination of tensile strength and Young's modulus is however unique and is not comparable to anything.

Since it was not possible to execute this test for the fired material a 3 point bending test was executed afterwards.

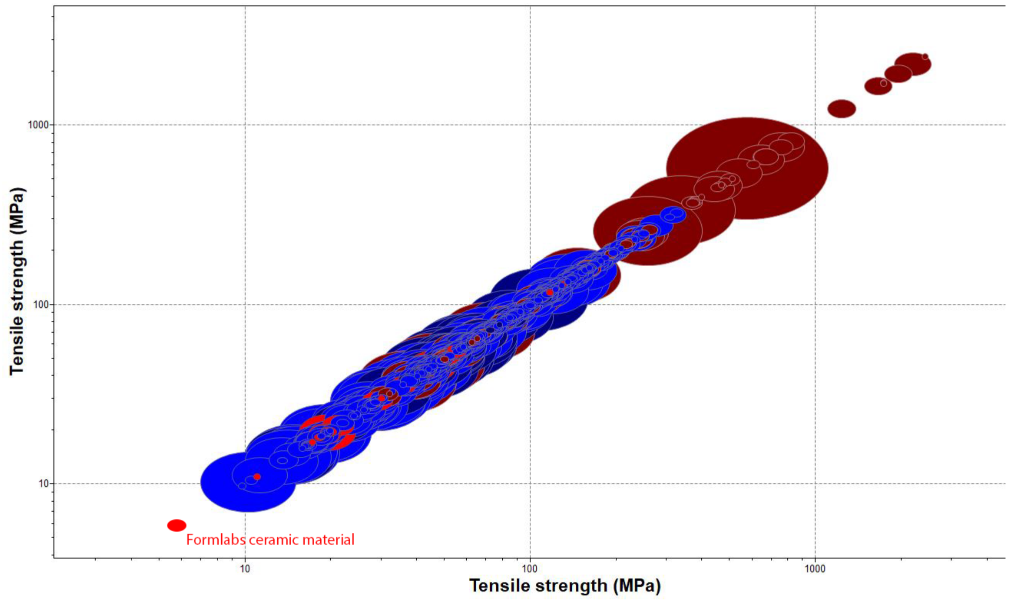


Figure 2.4-15 *Tensile strength of the green state material compared to plastics.*

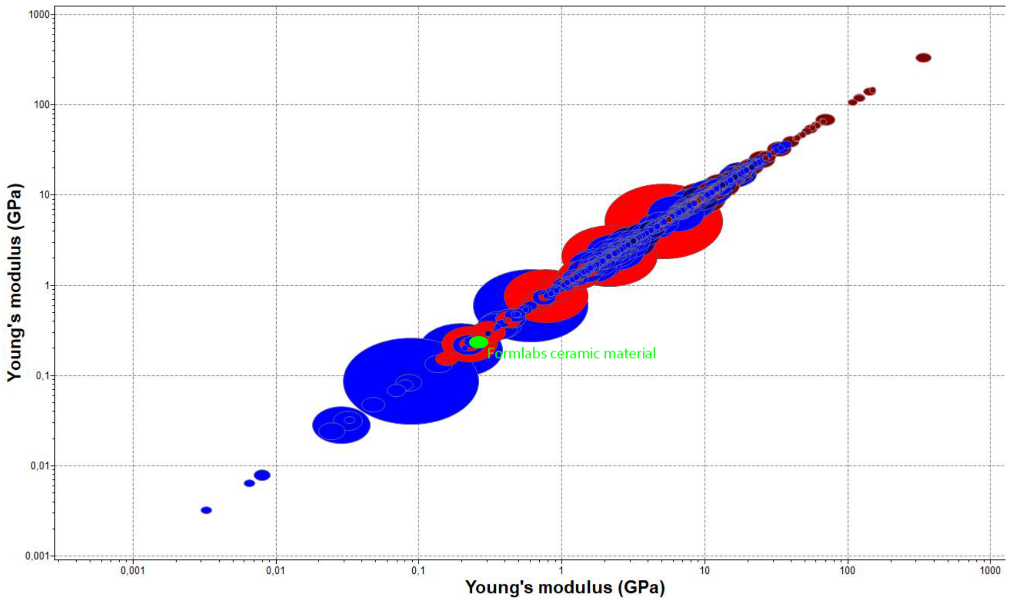


Figure 2.4-16 *Young's modulus of the green state material compared to plastics.*

3 point bending test

Purpose

As said ceramic materials generally have a low strength. Since It was not possible to measure the strength of the fired material using the tensile tests, 3 point bending tests are now executed. The type of strength measured during this test is the flexural strength. The flexural strength is the amount of force or stress an object can withstand before breaking or permanently deforming (Johnson, 2018). The test will provide the answers on the following questions:

- What is the flexural strength of the green state and fired material?
- How does the measured flexural strength compare to the information given by Formlabs?
- How does the flexural strength of the fired material compare to traditional ceramics?
- How does the flexural strength of the green state material compare to traditional polymers?

Method

The test is executed following international standard D790-03 (Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials). However, some alterations were made because of the time consuming production process and the size restriction of the printer. Less samples were made and the dimensions of the samples were altered to assure for successfully produced samples.

Three fired samples and four green state samples were tested (figure 2.4-19 & 20). The samples were accurately measured before testing (height, width, thickness) to ensure for a proper comparison. The samples were printed horizontally (figure 2.4-21), so the 3 point bending testing machine will exercise the pushing force perpendicular to the layers (figure 2.4-18). A Zwick Roell Z010 3 point bending testing machine was used to execute the test (figure 2.4-17).

Results

All samples successfully broke, meaning a break where the sample separates into two pieces.

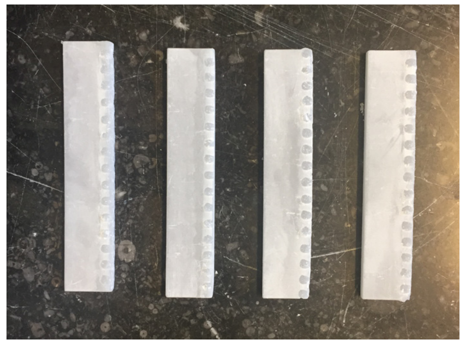


Figure 2.4-19 *Green state samples*

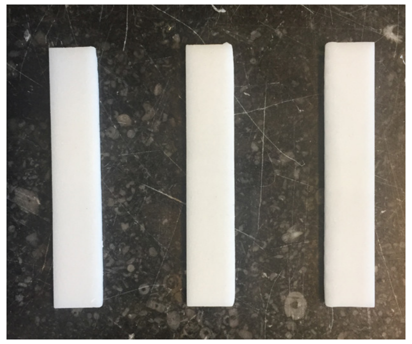


Figure 2.4-20 *Fired samples*

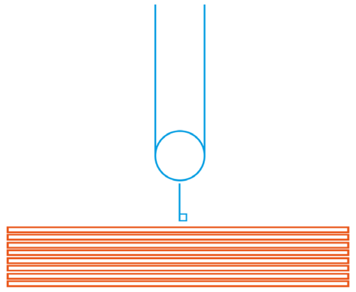


Figure 2.4-18 *Perpendicular pushing force*

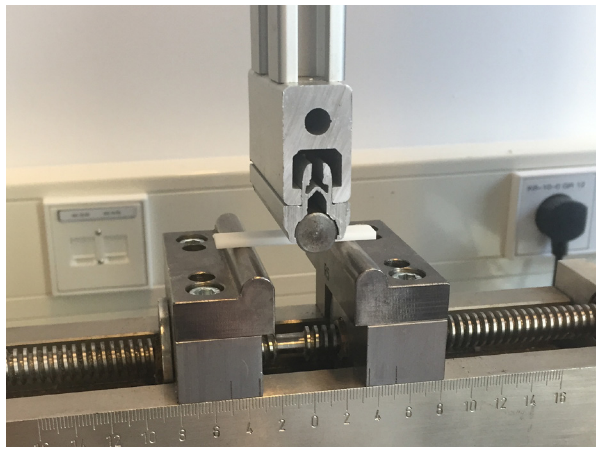


Figure 2.4-17 *Zwick Roell Z010 3 point bending tester*

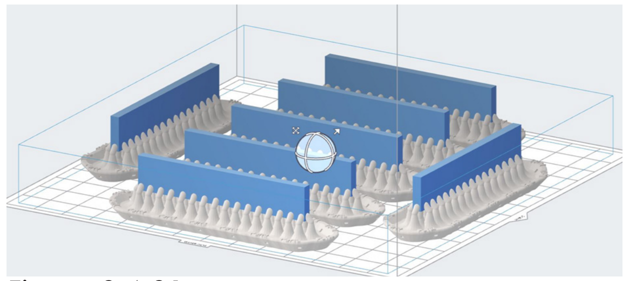


Figure 2.4-21 *Print orientation*

The average flexural strength measured for the green state material was 9,07 Mpa and the flexural modulus was 0,61 GPa.
The average flexural strength measured for the fired material was 25,61 Mpa and the flexural modulus was 22,77 GPa.

Discussion
The measured flexural strength and flexural modulus for both materials were compared to the data made available by Formlabs. Both the measured flexural strength and flexural modulus of the green state material are comparable to the Formlabs data, so this confirms that the test was executed correctly. The flexural strength of the fired material was lower compared to the data made available by Formlabs (flexural strength = 33.5 MPa). This could be caused by a different print orientation but this is unsure and should be tested.

The green state Formlabs material has a very low flexural strength compared to other polymers (figure 2.4-22). The flexural strength of the material is lower than all plastics and is more comparable to the flexural strength of foams.
The flexural modulus of the green state material is also low compared to other polymers (figure 2.4-23). However, there are still several plastics with a comparable flexural modulus. So, the green state material had a very low strength and is flexible but not as flexible as rubber or foam

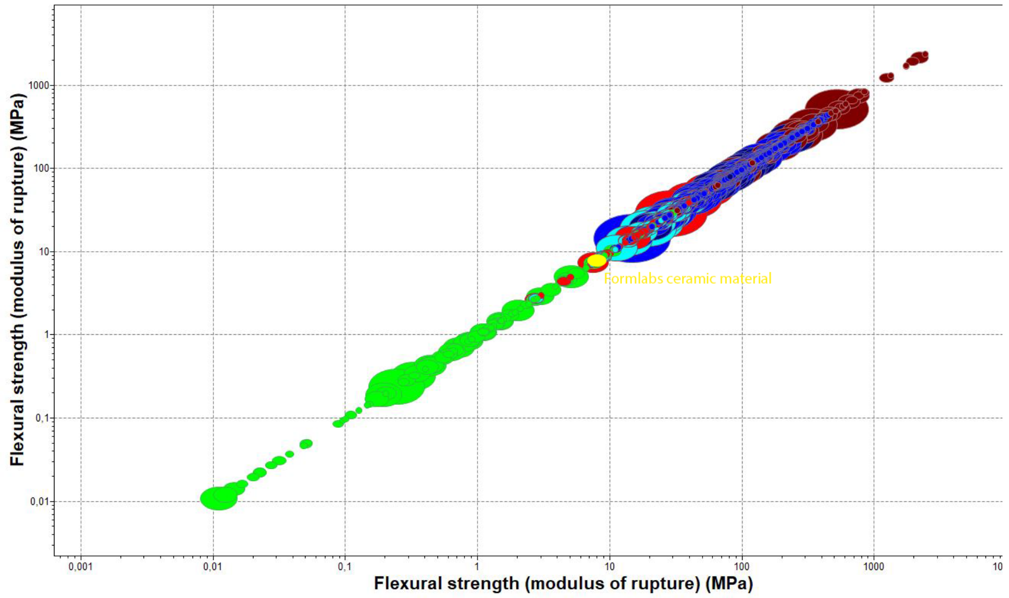


Figure 2.4-22 *Flexural strength of the green state material compared to polymers.*

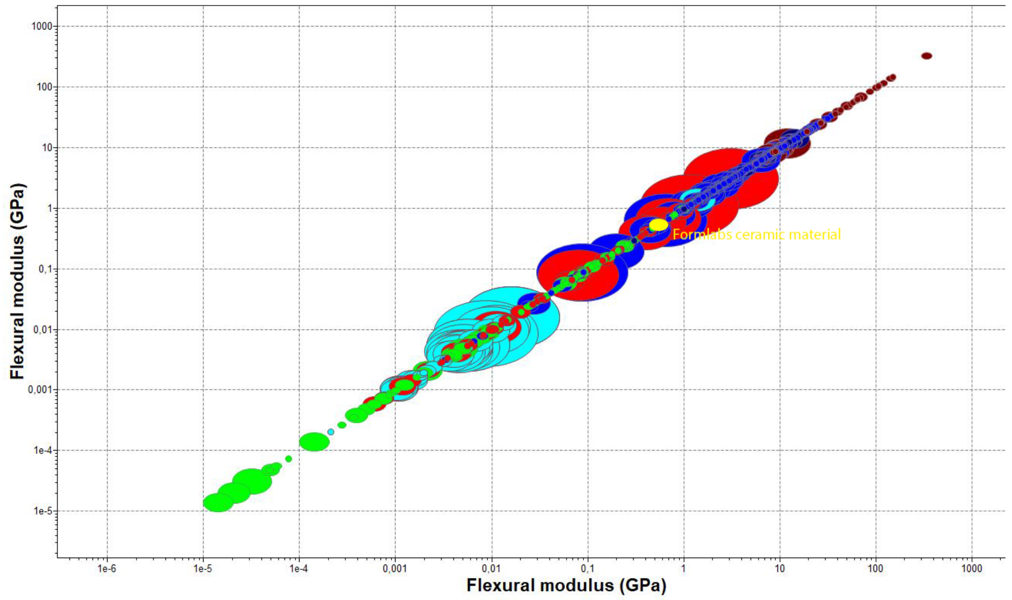


Figure 2.4-23 *Flexural modulus of the green state material compared to polymers.*

The fired Formlabs material has a low flexural strength compared to other ceramic materials (figure 2.4-24). The measured strength is a bit higher than traditional ceramics but lower than most advanced ceramics and composites. The flexural modulus of the fired Formlabs materials is low compared to other ceramic materials (figure 2.4-25). Most traditional and advanced ceramics have a higher flexural modulus. So, the fired material had a low strength and is quite flexible for a ceramic material.

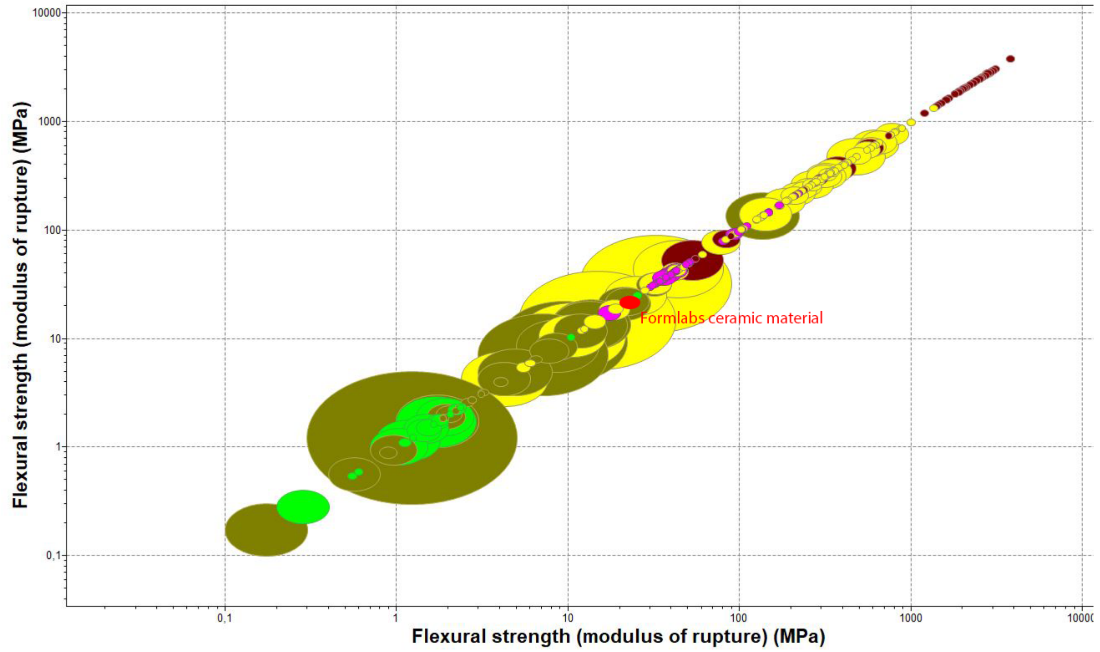


Figure 2.4-24 *Flexural strength of fired material compared to ceramics.*

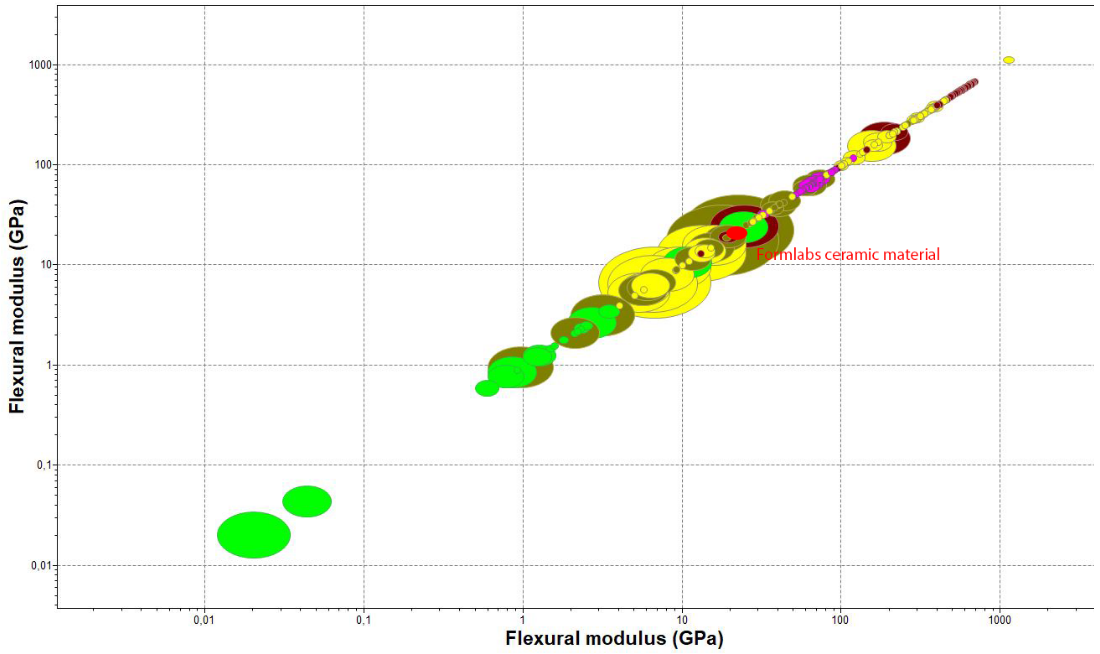


Figure 2.4-25 *Flexural modulus of fired material compared to ceramics*

Microscopy examination

Purpose

The purpose of the microscopy examination was to understand sintering. Theoretical knowledge has been gathered on sintering. But it is unclear what sintering looks like in practice from up close. It has to become clear what sintering actually does to the material and what the difference is between the green state material and the fired material. There are also different levels of sintering and using the microscope it can be examined how sintered the samples are. The last thing that is going to be examined is if the printing layers are actually visible when looking at the green state material under a microscope.

Method

Multiple samples were looked at underneath a microscope, for both green state and fired materials.
Both intact and broken samples were examined. Several magnification settings were used. A magnification of 10, 20 and 50 times.

Results

The green state material appears to be made up out of crystals (figure 2.4-26). The material particles reflect the light a lot, making them look sparkly. The particles do not look densely packed and almost seem like they are floating.
The fired material is completely different (figure 2.4-27). Parts of the material look melted together creating river like shapes. Some parts look more melted together than others. The reflective particles are completely gone.

Discussion

The material is not completely sintered because large surfaces still look rough and porous. For the material to be completely sintered a larger surface should have been melted and merged. The samples which were examined had quite thick wall thicknesses so this can be why the material was not completely sintered.

The reflective particle are goes so they were most likely part of the polymer base.

There is a big difference between the two materials. Even though the fired material is not sintered completely it is still clear that this material is a lot denser and that the surface of the fired material looks more like a whole instead of loose particles.

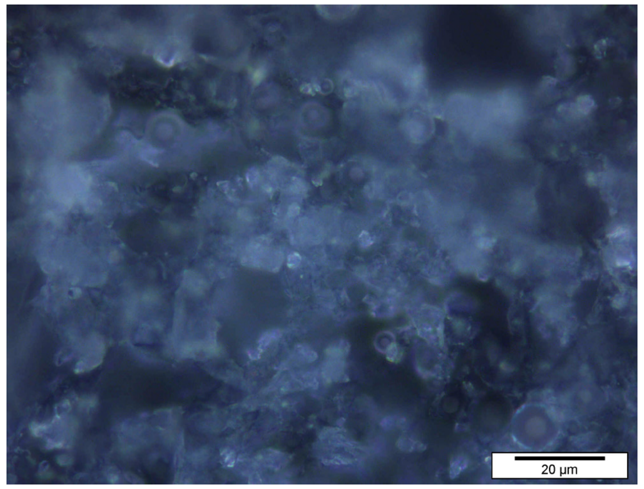


Figure 2.4-26 Green state material under a microscope.

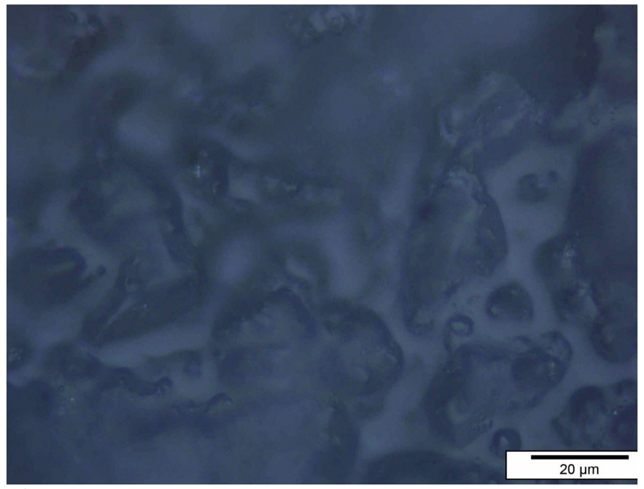


Figure 2.4-27 Fired material under a microscope.

Other technical properties

Formlabs lists some other technical properties the Formlabs ceramic resin supposedly has. These properties are (Formlabs, n.d.):

- High temperature resistance (up to 1000 °C)
- High thermal and electrical insulation
- High resistance to corrosion and wear
- Chemical inertness
- High dimensional stability

There was not enough time to confirm all these technical properties during this project, so this can be done in future research. The focus will not be on these properties during this project only confirmed properties will be highlighted in the final concept.

2.5 CONCLUSION

Composition
When comparing the composition of the Formlabs material to the compositions of traditional ceramics it is most comparable to non-clay based ceramics, since it does not contain materials from the earth, like clay. It is in particular comparable to oxide based advanced ceramics.

First of all it is comparable to oxide based advanced ceramics since, as mentioned before, the ceramic particles of both material compositions contain oxygen and are often composed of silica, alumina, zirconia, etc..
Furthermore, it can be fired in an atmosphere containing oxygen without oxidizing.
Besides these points both the Formlabs material and the advanced oxide ceramics contain additives which make it formable even though for one of them it is polymer based and for the other it is organic or inorganic mineral based.
For both oxide advanced ceramics and the Formlabs ceramic material, these additives will be removed by firing at a high temperature. Leaving the pure ceramic particles, which are of comparable composition for both ceramic types.
So, the Formlabs slurry and the oxide based advanced ceramics slurry are comparable.

Production
The material is made for additive manufacturing specifically SLA 3D printing. Since the material is most comparable to oxide based advanced ceramics the production process of the Formlabs material will be compared to the production processes of oxide based advanced ceramics.

Advanced ceramics can also be 3D printed, as mentioned before. However, most additive manufacturing processes used are powder based, so, they cannot be compared to SLA printing, except for direct inkjet 3D printing. Both manufacturing processes use a slurry. The difference is that for inkjet printing the slurry is placed on a printing bed and for SLA the printing bed is lowered into a slurry bath. Furthermore, how the slurry is solidified is also different. Instead of using UV-light, the mineral based slurry, containing binders and solvents, is solidified using heat (Derby, 2015).

A similarity between the two is that both materials need drying after forming and for the materials to reach a high level of hardness they need to be fired/sintered at very high temperatures of between 1250°C and 1600°C (Ruys, 2019).

So, after comparing the manufacturing methods it is clear that they are comparable.

Opportunities
Although direct inkjet 3D printing and SLA are similar SLA has advantages and opportunities. It is a more fool proof process since proper and uniform solidification of the material is easier to reach. With inkjet printing, solidification problems can occur because the build-up consists of separate droplets. Droplets are organic in shape and have height differences. This can cause a non-uniform solidification (Derby, 2015).
SLA also offers great formability and high precision. The high precision of the printing technique creates objects which, even though they are made up out of layers, do not have any visible layers. The high precision and great formability also allow for the creation of delicate structures and thin walled and tiny objects.
Furthermore, the SLA technique is available in desktop form so it is easy to use in a non-industrial context like at home or at an university.

So, 3D printing oxide based advanced ceramics using a slurry was already possible but this new material makes it possible to print high precision oxide based advanced ceramic in a non-industrial environment for a relatively low price.

Constraints
The production process also brings some constraints. Producing objects using this production process is time consuming. Modelling, printing, drying and firing take up a lot of time and the production of an object will at least take 5 days. It is not possible to speed up the process. So, when printing, multiple samples should be printed at once so they can be fired at once making the production time per object shorter.
The printing process also has a size constraint. The build plate has a fixed dimension (14.5 × 14.5 × 17.5 cm) making it impossible to print larger parts. Modelled objects should also not use more than 100 mL of ceramic resin per print, adding an extra size constraint besides the fixed dimension of the build plate (Formlabs, 2018).
The last constraint is that it is easier to produce ceramic objects using the SLA process compared to the direct inkjet 3D printing process. However, it is still more complex than FDM or SLA printing plastic materials. The production process requires a lot of experimenting before successful printing is possible.

Properties
The focus for this research is on the fired Formlabs ceramic material. The technical characteristics of the fired material bring opportunities and constraints.

Opportunities
Mechanically the high impact toughness and the relative flexibility bring opportunities. The material can now be used in more interactive applications, where the object is subject to use and forces instead of being purely decorative.
The fact that the material supposedly is heat and wear resistant, electrically and thermally insulating and chemically inert also brings opportunities. These characteristics are however not tested jet. So, these characteristics should be confirmed before wanting to use them in applications.
The last opportunity of the material is that it has a non-porous glass like surface. This glass like surface is watertight and can be implemented as is so without glazing. This brings the opportunity to use the aesthetic and sensorial characteristics of the raw material since it does not have to be covered up with glaze.

Constraints
Mechanically the low strength which is comparable to the strength of stoneware is a big constraint. Most material properties found are comparable to properties of advanced ceramics but the weakness of the Formlabs material makes it inferior to advanced ceramics and makes it unfit for a lot of advanced and technical applications.
The last constraint or challenge found is the shrinkage of the material during sintering. Formlabs states that parts will have approximately 15% shrinkage. This shrinkage makes it harder to create parts with strict tolerances.

CHAPTER 3
EXPERIENTIAL CHARACTERISATION

Understanding the material also requires gaining knowledge about the material's experiential characteristics. Only with the knowledge of both technical and experiential characteristics the unique role of the material can be articulated (Karana et al., 2015). The experiential characteristics of the material are found when tinkering with the material and when executing user tests.

3.1 FOCUS GROUP

The complete methodology of the focus group can be found in appendix E.

Purpose

Executing a user test will create understanding about how the material is received by people and what it makes people do based on four different experiential levels: sensorial, interpretive (meanings), affective (emotions), and performative (actions, performances) (Giaccardi and Karana, 2015). These levels will create an understanding of the material experience, categorized in four different experiential qualities. However, these material experience levels are intertwined and experienced as a whole, influenced by each other, time and the context of use (Karana, Pedgley and Rognoli, 2014; Giaccardi and Karana, 2015).

The results from the user test will provide guidance on how people are likely to experience and interact with a particular material when applied in a future product and will give inspiration during the ideation phase of the project.

Participants

5 participants joined the focus group whereof 60% male and 40% female. 4 participants were 24 years and 1 was 29 years old. All were IDE students, since there was no specific target group and this target group was easily accessible for the designer. Lastly there were snacks and drinks available during the test as a thank you.

Stimuli

11 different samples were used for this test (figure 3.1-1). 5 pairs of an unfired and fired sample in different shapes and sizes and 1 organically shaped fired sample. These particular shapes were chosen because they do not resemble objects which are currently made from ceramics, like cups for example. Using neutral and organic shapes, which do not resemble any products on the market, ensures that people do not associate the material with ceramics just because of the shape of the object.

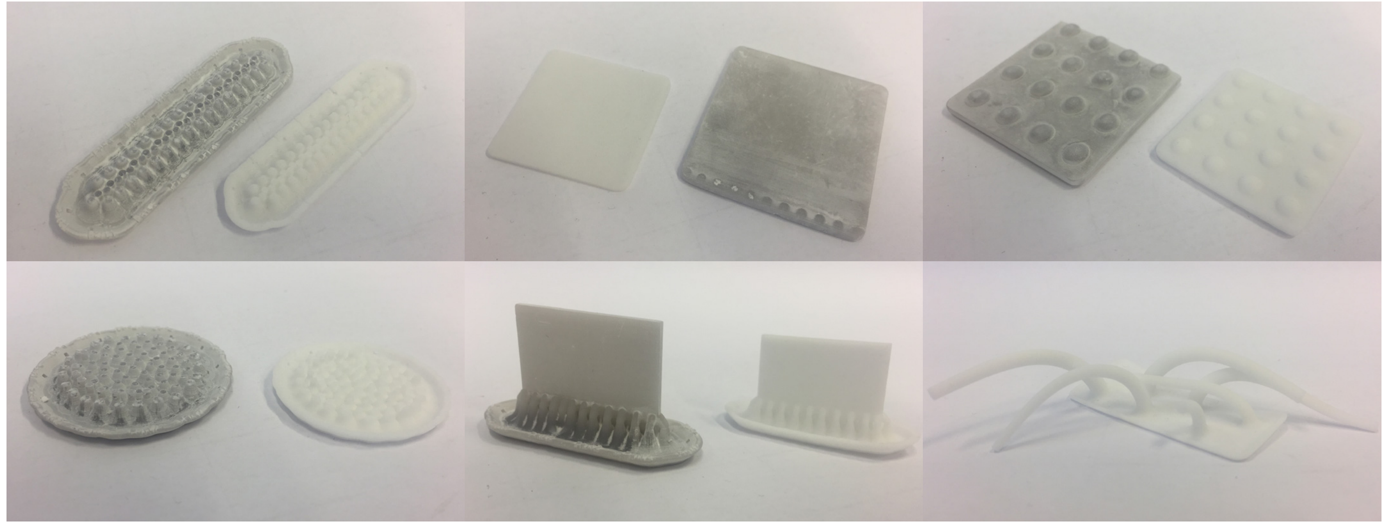


Figure 3.1-1 *Focus groups stimuli: 5 pairs of green state and fired material and one fired organic shape.*

Besides the 11 samples a semantic differential scale was used (Osgood et al., 1957). On this scale pairs of polar adjectives are listed. Using these adjectives the meaning of the material can be measured. The participants will communicate their attitude towards the material by choosing positions on the scale. The semantic differential scale used for this test can be found in appendix G.

To be able to measure the sensorial properties of the material a list of sensory terms was used. This list contains sensorial properties which are more commonly used to assign meaning to materials (Karana et al., 2009). These specific sensorial properties are listed in appendix F.

Apparatus

The focus group was held in the Product Evaluation Lab (PEL) at the faculty of IDE (figure 3.1-2). This room is equipped with two camera's which are placed opposite from each other. These cameras record the participants during the focus group from two different sides capturing everything that is happening. The room is also equipped with multiple microphones which record everything that is said during the focus group.

Procedure

The focus group was made up out of 2 rounds. During the first round the participants explored the green state material (unfired) and during the second round the participants explored the fired material.

The participants were first asked to explore the samples visually, for both the green state and the fired material. During and after the visual exploration the participants were asked to communicate what they experienced using the provided forms and by discussing and thinking out loud. Afterwards they could touch the samples and have a complete experience. They were again asked to communicate what they experienced during and after this complete exploration.

Measures

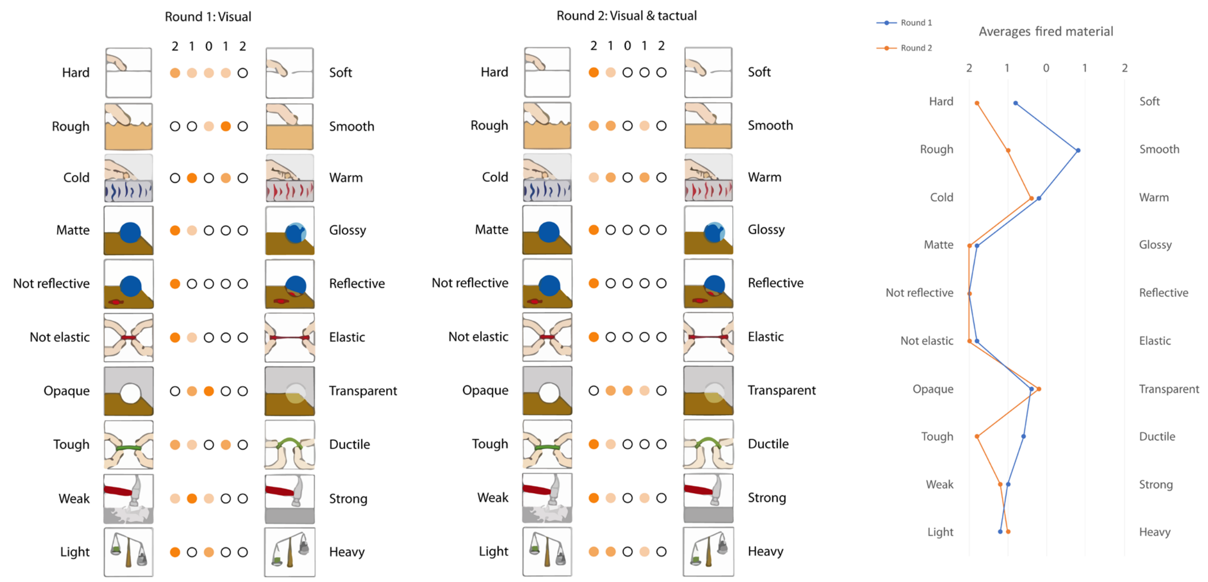
The focus of this research was to understand how the material is experienced by people. This understanding is created by measuring people's attitude towards the four different experiential levels: sensorial, interpretive (meanings), affective (emotions), and performative (actions, performances).

Figure 3.1-2 *Focus group setup*

Results

Both materials, green state and fired, were tested during this focus group but the focus for this project is going to be on the fired material. So, below the results of the fired material are shown. All the results can be found in appendix E.

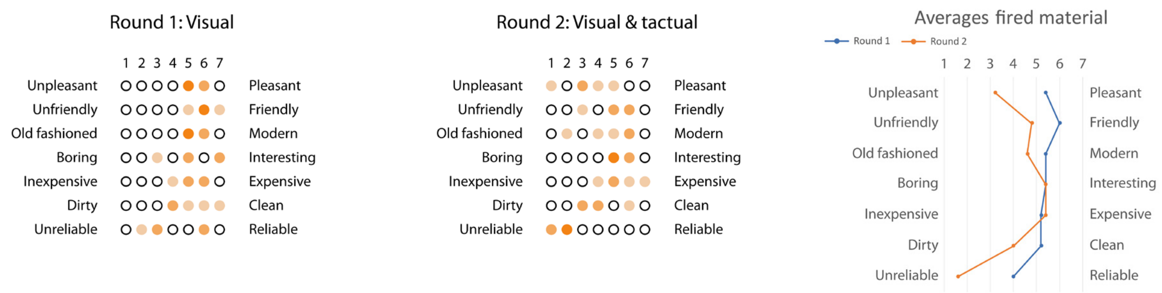
Sensorial



Interpretive

During the visual exploration the participants experienced the fired material as pleasant and friendly. This was because it looked soft and the white colour of the material gives it a fresh and pure appearance. The pureness and freshness of the material also made the material look modern according to the participants. Furthermore, the fired material was found less interesting than the green state material because it was associated with known objects like bathroom tiles and old tableware. The material was experienced as clean because of the colour and the visual smoothness but not as clean as a high shine material.

When touching the fired material the participants experienced it as unpleasant, less friendly and dirty because of the unexpected roughness. It also became less modern because the participants associated it with ceramics, a nail vile, chalk boards and sanding paper. Lastly the material was experienced as unreliable because it was associated with ceramics and felt brittle but also because of the visible cracks.



Affective

The fired material elicits several emotions. During the visual exploration it became clear that the participants found this material visually pleasing and friendly creating a feeling of pleasure and calmness. The material was also experienced as less interesting since it was comparable to known materials. The fact that it looks recognisable created the feeling of slight boredom and also of comfort.

When actually touching the material all participants were surprised because it felt rougher than expected. This surprise was a negative surprise for all participants. None of the participants found it a pleasant experience and this created a feeling of discomfort for all participants.

All participants communicated this discomfort with uncomfortable looks, cries and even goose bumps and they all felt disapproval towards the material and its roughness. Two participants even felt disgust when touching the samples and this sensation was so intense that it created a pullback reaction resulting in the participants dropping the samples.

The last emotion felt was distrust. This was felt because of the visible cracks in the samples but also because of the unexpected roughness. The participants thought they could predict what it would feel like when looking at it but the actual sensation was completely different.

Performative

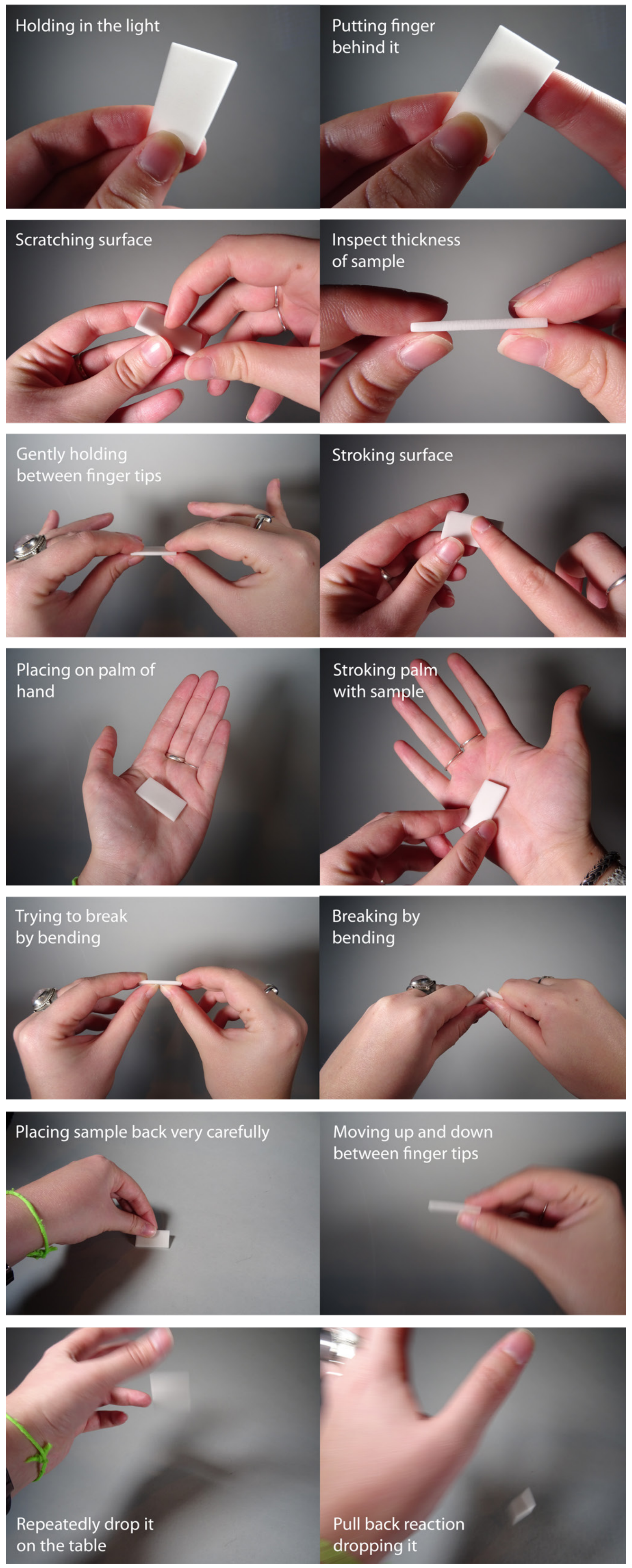


Figure 3.1-3 Performative level of Forlabs ceramics experience

Discussion

Sensorial

The participants mentioned that the mat surface of the material makes it looks soft while it actually is a hard material. So, maybe people associate mat to soft and glossy to hard.
The material has no visible textures and is white with no impurities so participants expect it to be smooth while it actually is rough. This creates an incongruence between senses. This incongruence can be removed by making the material either look rough and feel rough or look smooth and feel smooth.
The high translucency of the material was only visible when held in the light or when covering something (finger). So, this is why it was not visible for all participants during the visual exploration.
The participants expected the material to be more ductile than it actually is. This could be because the mat surface makes it look more like plastic than ceramics but this is not sure.

Interpretive

The meaning of the material was very positive during the visual exploration because it was friendly, aesthetically pleasing, clean, reliable and modern. But when touching the material the meaning became more negative. It became less friendly, unpleasant, dirtier, unreliable and less modern. So, this material should be used in a visual product or the meaning should be altered.
The material was found less interesting than the green state material because it was recognisable. This recognition can bring comfort and confidence but also boredom so it might be nice to change the meaning of the material into more interesting.

Affective

The emotions felt during the visual exploration are in general positive. Emotions like pleasure, calmness and comfort were felt but also light boredom because of its recognisable aesthetic. However, the emotions felt during the complete exploration became negative. Emotions like negative surprise, discomfort, disapproval, disgust and distrust were felt.

The aesthetic properties of the material elicited the positive emotions. And the negative emotions were mostly caused by the unexpected roughness of the material and the visible cracks. So, the material should have a complete positive affective experience when the incongruence between senses is removed.

Performative

Stroking and scratching of the material was used to be able to explore the texture of the material.
Holding the samples in the light or placing fingers behind it was used to explore the translucency of the material. Every participant held and handled the samples with caution. They were held between finger tips and placed back on the table very carefully. The participants also mentioned a lot that they were afraid of breaking it. One participant became less cautious with time. Eventually dropping the samples on the table repeatedly to test the strength of the material and to explore the sounds it makes. All participants had the urge to bend the samples. This was probably to test when they would break. Some of the participants also mentioned that they had the urge to break it and at the end some participants broke some samples.

3.2 INTERVIEW

The purpose of the interview was to understand how the material is received by a person that actually works with traditional ceramics on a daily basis. A traditional ceramics expert will probably experience the material differently compared to a normal user. The interview will answer the following questions:

- How is the material experienced sensorially?
- What is the material associated with?
- Is the material associated with traditional ceramics?
- Would she ever use this production method and material?

All the interview questions can be found in appendix H.

The person interviewed is Ellen Rijsdorp. Ellen has been practicing ceramics for 28 years and has studied at the art academy and the educational institute for ceramics. She has been an independent ceramist for 18 years now, has her own workshop (figure 3.2-1) and teaches ceramics and pottery at different organisations.

Figure 3.2-1 Personal workshop of Ellen Rijsdorp

Ellen creates objects (figure 3.2-2). This is because, in the Netherlands, no money can be made selling utensils and tableware. The Dutch culture does not have traditions when it comes to ceramic tableware, unlike the English and the Japanese. People will just buy there ceramic tableware at the Blokker for example.

The objects Ellen creates are made from high fire stoneware. She likes using this type of ceramics because of its impurities, colour and strength. The raw material is always visible in her products and the roughness of the material really complements the design of the objects. The objects are produced by turning on a turning table. The roughness and the hardness of the material make it more challenging to use this forming technique but the technique offers great from freedom which Ellen needs for her designs (figure 3.2-3).

Figure 3.2-2 Object made by Ellen

From Ellen Rijsdorp – 25 jaar keramiek. Retrieved from http://www.ellenrijsdorp.nl/keramiek/en/portfolio-2/. Copyright 2019 by Ellen Rijsdorp - WordPress Theme by Kadence Themes

Figure 3.2-3 Form freedom necessity

From Ellen Rijsdorp – 25 jaar keramiek. Retrieved from http://www.ellenrijsdorp.nl/keramiek/en/portfolio-2/. Copyright 2019 by Ellen Rijsdorp - WordPress Theme by Kadence Themes

Ellen mentioned that she experiences a lot with the material. She experiments with shape, glazing and surface texture during production and this can be seen when looking at her product portfolio. It contains a wide variety of shapes, colours and surface textures (figure 3.2-4).

Ellen interacted with the Formlabs material during the interview. She noticed the transparency of the material and identified the material as a blend of plastic and ceramics. She definitely did not associate it with porcelain despite the translucency of the Formlabs material. According to Ellen, porcelain elicits a more delicate meaning, because of its smooth and soft surface texture. The Formlabs material is to rough to be able to elicit the same meaning. Ellen associated it more with stone. She also mentioned that if she would use this material she would definitely glaze it before implementing it in an use product, because of the tactile unpleasantness.

Lastly Ellen mentioned that she finds the material and production process very interesting. She knows that this brings more form freedom and allows you to make objects which can not be manufactured in a traditional way. However, she would most likely not use it mainly because of the threshold of learning how to work with a 3D modelling program. She would also mis the direct interaction with the raw material during production. Ellen designs and alters shapes during production because everything can be altered on the spot this is not possible with this production process anymore and she sees this as a creativity constraint.

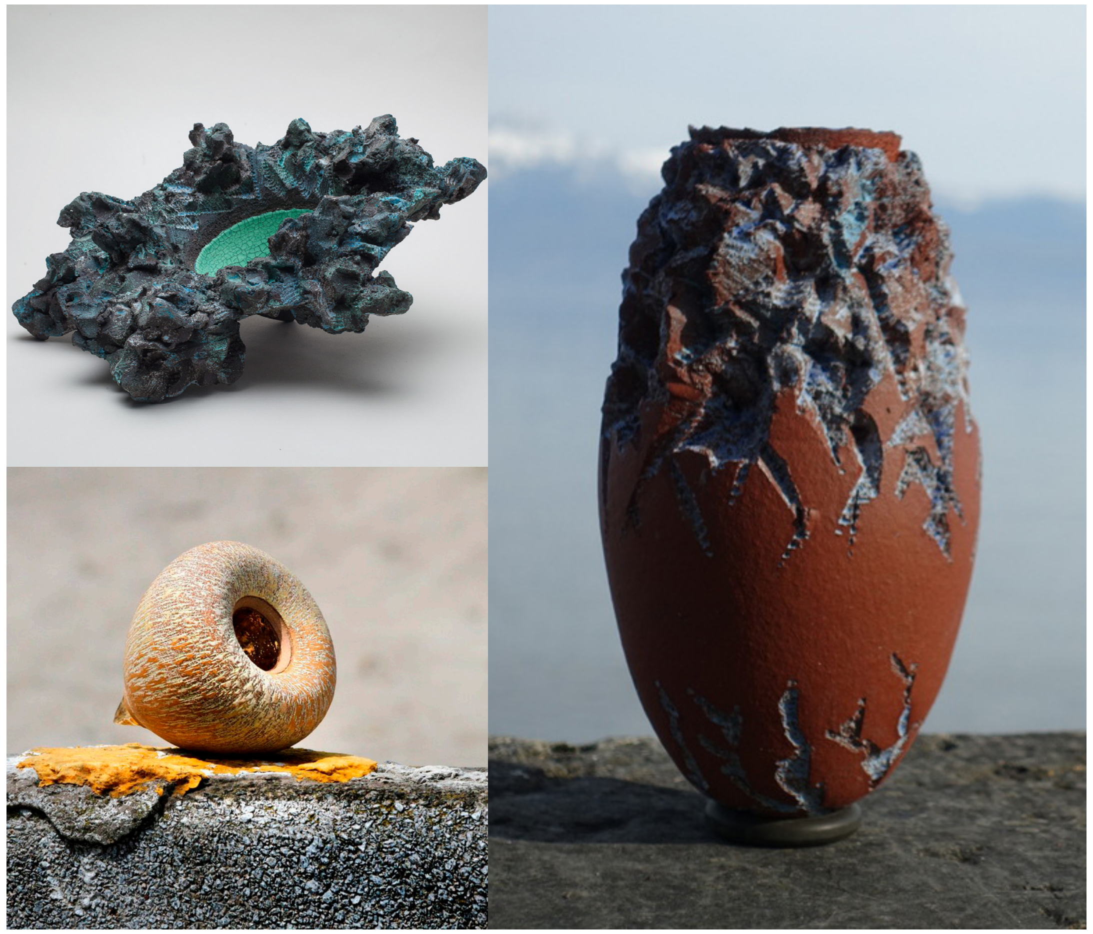


Figure 3.2-4 Varying portfolio

From Ellen Rijsdorp – 25 jaar keramiek. Retrieved from http://www.ellenrijsdorp.nl/keramiek/en/collection-2017/. Copyright 2019 by Ellen Rijsdorp - WordPress Theme by Kadence Themes

3.3 TINKERING WITH CERAMIC MATERIAL

The tinkering process has two phases. The explorative phase and the focused phase. The purpose of the explorative phase is to gather and summarise some basic knowledge about the printing and firing principles and the behaviour of the Formlabs ceramic material in provided conditions.

There are several variables which can be influenced during the tinkering process and these are visualised in the material taxonomy (figure 3.3-1).

The variables which are highlighted with an asterisk are the variables which were found most interesting for the tinkering phase. The material taxonomy can change during the tinkering process since new variables can be found which can influence the final outcome.
These chosen variables are the basis for the topics covered in the explorative phase and the focussed tinkering phase. The topics covered during the tinkering process are visualised in the illustration below. The complete tinkering diary can be found in appendix I.

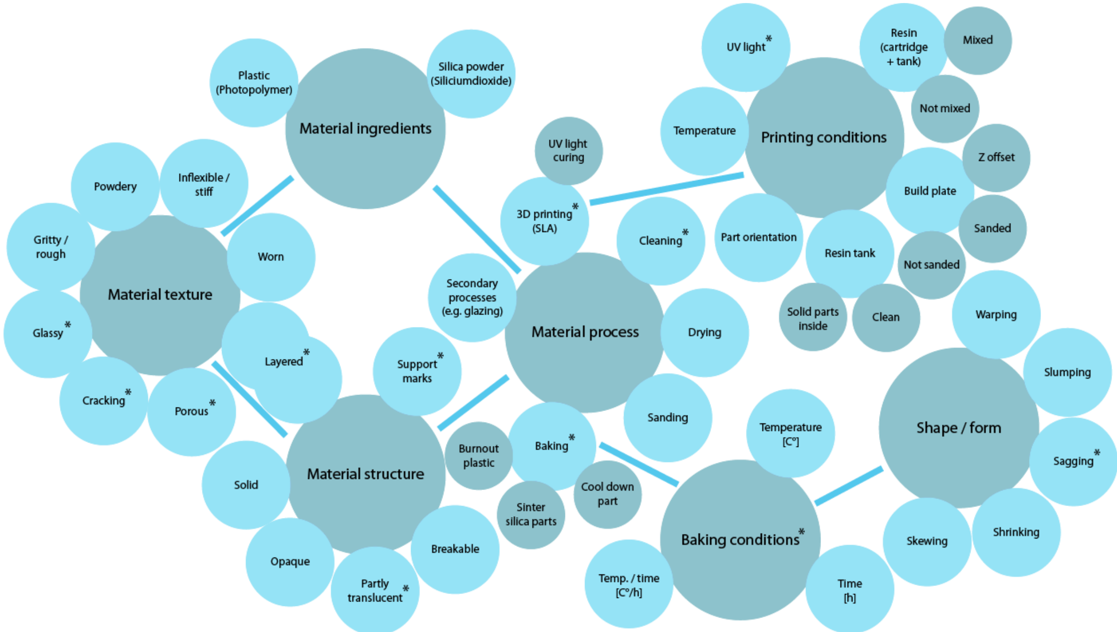
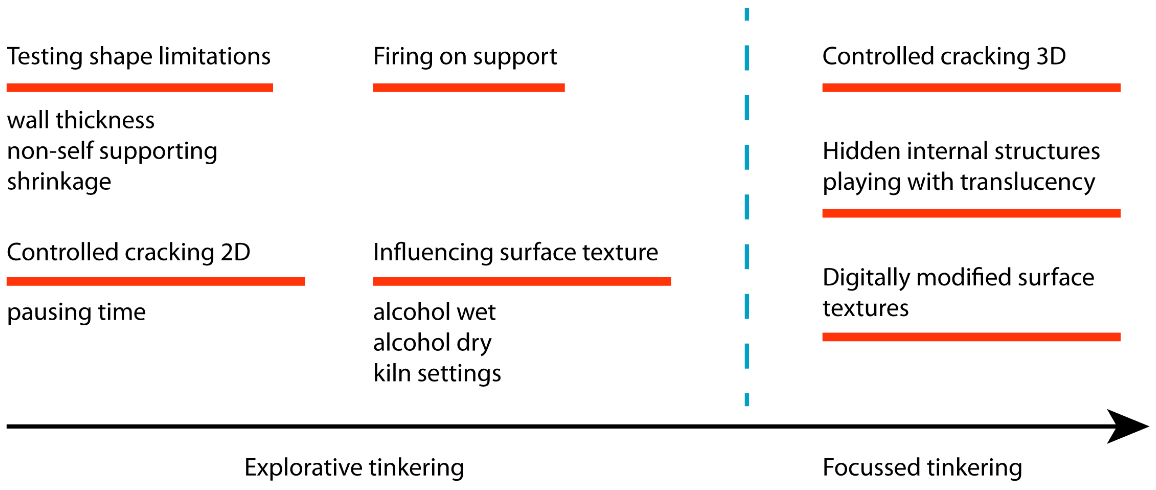


Figure 3.3-1 *Material taxonomy*



Each topic was inspired by research or an accidental findings.

Testing shape limitations
There are several design limitations listed by Formlabs in their printing guide. These limitations inspired the shapes printed and fired during these tests. The shapes do not follow the limitations and by printing and firing them, understanding can be created about the behaviour of the material when used in hard or impossible to produce shapes.

Controlled cracking
Exploring controlled cracking was inspired by a prominent line which was visible on a failed print. When doing some research it was found that Formlabs had some information on how this prominent lines is created. They also mentioned that these lines can cause cracks during firing and this was interesting since this meant that it became possible to control where the sample would have cracks.

Influencing surface texture
This topic was inspired by looking at the material under the microscope and doing some research about vitrification and sintering. The particles of the material look like they are melted together creating the glass like non porous surface. But this can be influenced by altering several different variables like the oven temperature.

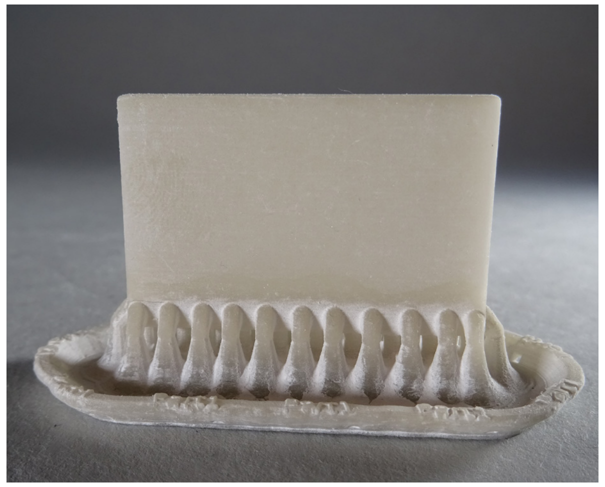


Figure 3.3-2 *Sample still on support structure*

Firing on support
Printing went more easily after a while and it was possible to remove samples from the build plate without breaking the support structure. Creating samples with an interesting support base (figure 3.3-2). These samples were the inspiration for this topic. The support structure is quite thin and fragile and this raised the question if it would actually be possible to fire samples on this structure or if it would fail.

Translucency
This topic was inspired by the results of the focus group and interview. The materials translucency was found interesting and created attraction. This positive experience is interesting and could possibly be part of the final concept. To be able to use the materials translucency, it should first of all be explored more. The exploration will, among other things, utilize the form freedom and high precision of additive manufacturing.

Digitally modified surface texture
The support structures were the inspiration for this topic. The material is experienced as rough and tactually unpleasant. However, this tactile unpleasantness actually became less when touching the irregular, pointy structure of the support parts (figure 3.3-3). This insight led to the idea of printing samples with digitally fabricated surface textures to influence the tactile experience and ideally improve it.

The manufacturing processes used with this material take some getting used to and there are some do's and don'ts which are listed in appendix C & D and in the tinkering diary in appendix I.

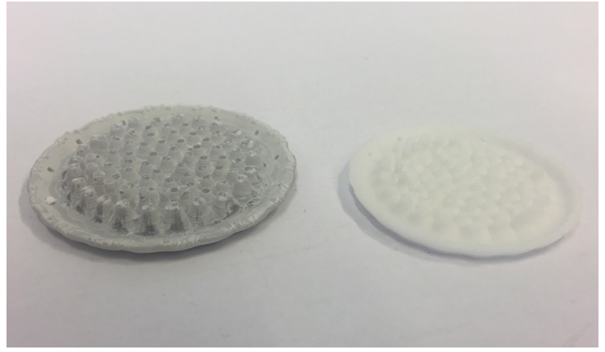


Figure 3.3-3 *Round support structures*

3.4 FINDINGS

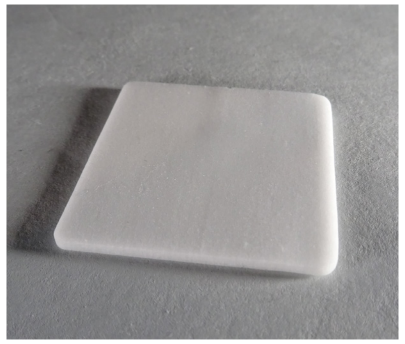
III Testing shape limitations

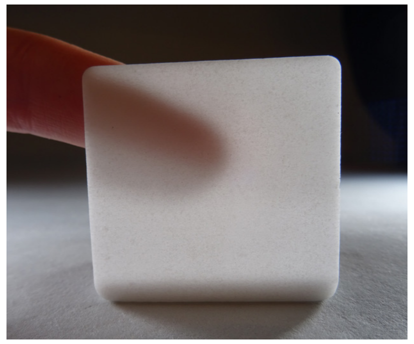
Wall thickness

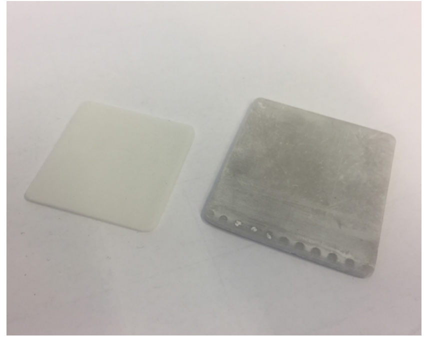
Very thin samples with a wall thickness of 2 mm or less print and fire successfully without warping or cracks. They fire even better than samples with a wall thickness > 3 mm.

Shrinkage

It can be confirmed that the sample shrinks the most in the z direction as was mentioned by Formlabs in printing guide.





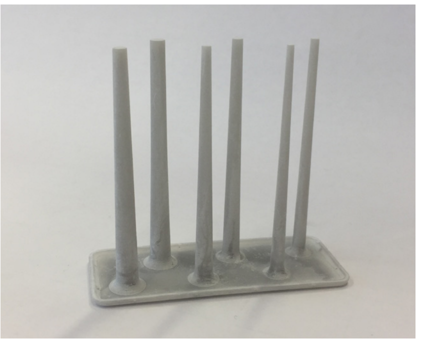


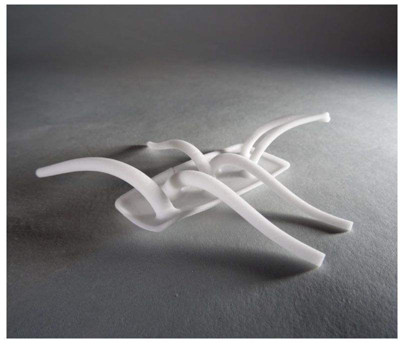
	Green state [mm]	Fired [mm]	Shrinkage [%]
Thickness (x)	1,88	1,70	9,6%
Length (z)	45,32	37,36	17,6%
Width (y)	44,85	39,00	13,0%

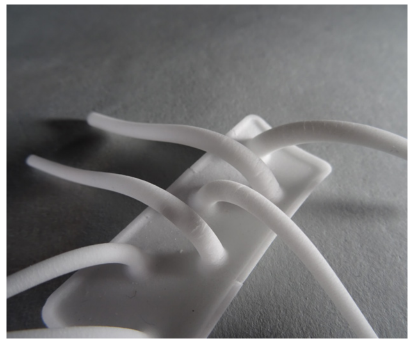
Sagging

Wire like shapes which are not self-supporting will sag during firing. The shapes are exceedingly deformed resulting in the layers splitting, creating deep cracks. The cracks are in the direction of the layers. So, the material cannot withstand these types of deformations and should not be used in objects with walls which are not self-supporting.

Multiple samples with identical wire dimensions were printed and fired. They did not sag and deform the same way so the sagging is not consistent and cannot be predicted.





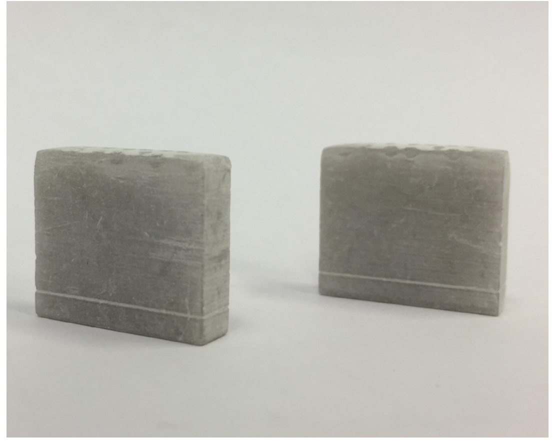


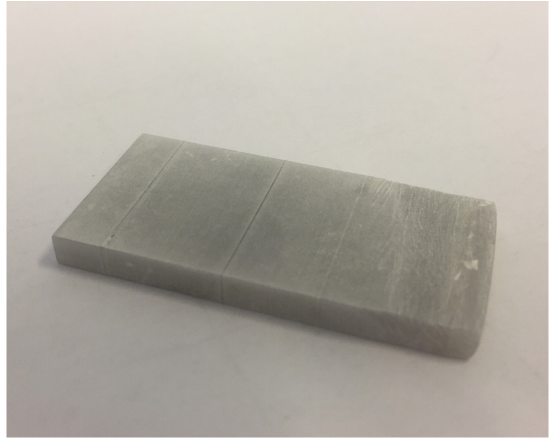
IV Controlled cracking 2D

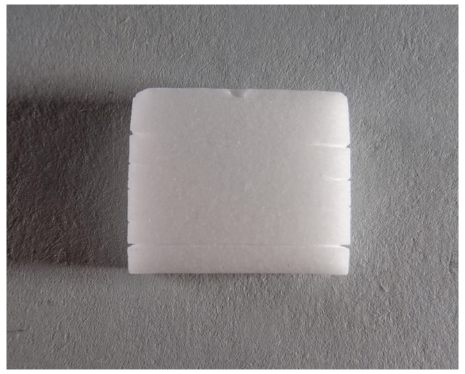
The prominent lines, created by pausing the printer mid print, will turn into a deep clean crack during firing.

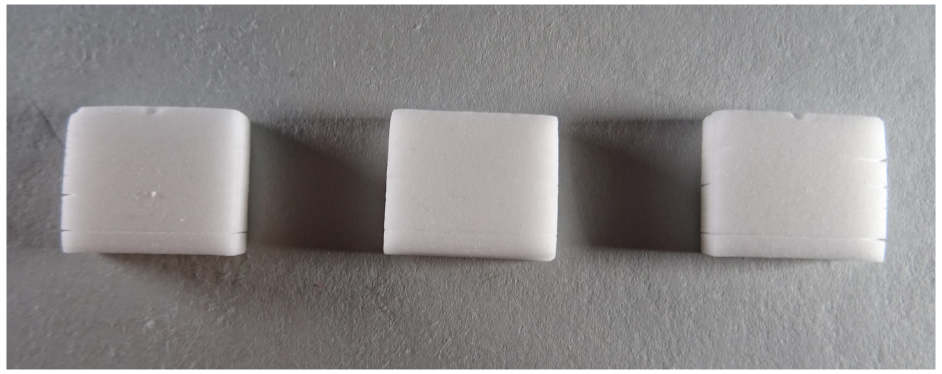
Pausing time influences the intensity of the cracks. A pause of 5 minutes creates the deepest crack. A pause of 10 minutes creates a more shallow crack and a pause of 20 minutes does not create a crack only a visible line.

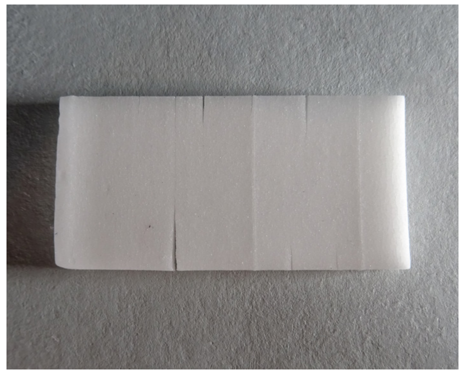
The samples also had small cracks throughout the surface in the direction of the layers. These cracks arise because the wall thickness of the samples is too thick (4 and 5 mm).

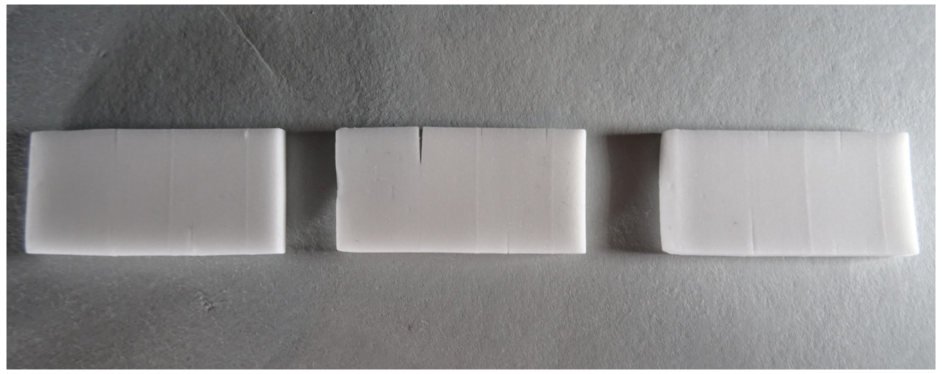










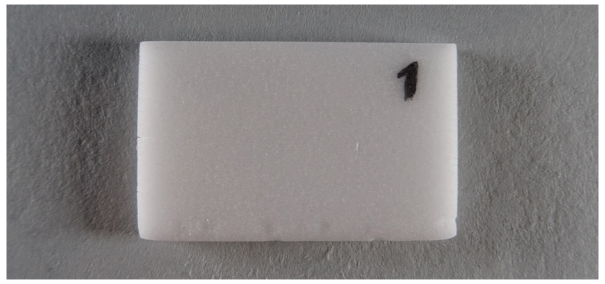


V Influencing surface texture

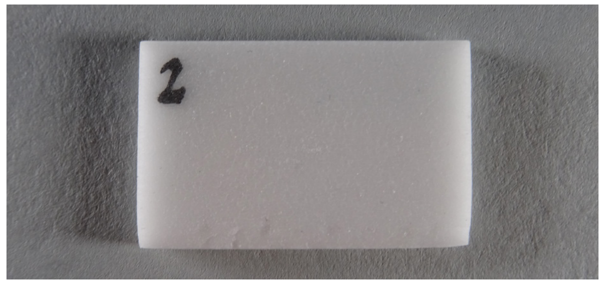
Alcohol dry

Alcohol has an effect on the surface texture of the samples. Even when the samples are dried before firing. It makes the surface more porous but only when soaked in alcohol for at least 2 hours.

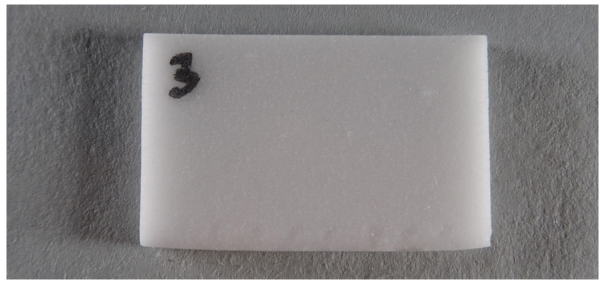
Sample 1
Soaked in alcohol for 10 min
Dried 2 days
Non-porous surface texture



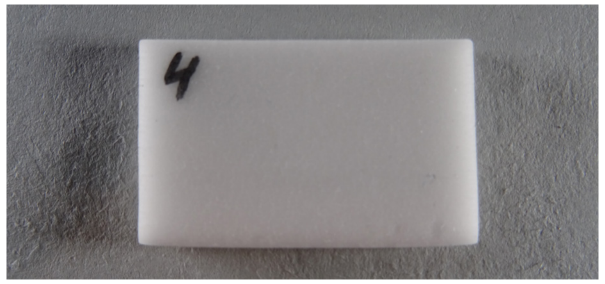
Sample 2
Soaked in alcohol for 30 min
Dried 2 days
Non-porous surface texture



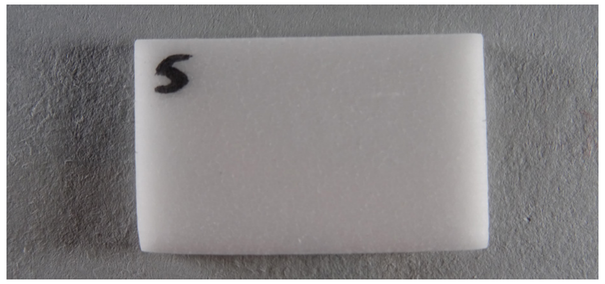
Sample 3
Soaked in alcohol for 1 hour
Dried 2 days
Non-porous surface texture

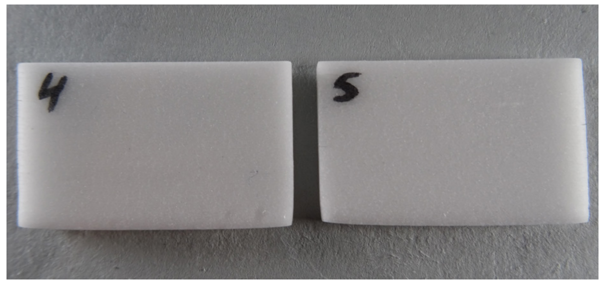


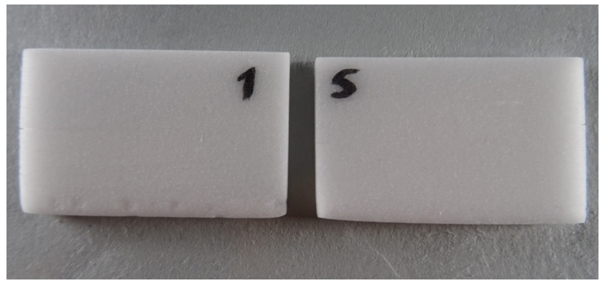
Sample 4
Soaked in alcohol for 2 hours
Dried 2 days
Semi-porous surface texture



Sample 5
Soaked in alcohol for 24 hours
Dried 1 day
Porous surface texture



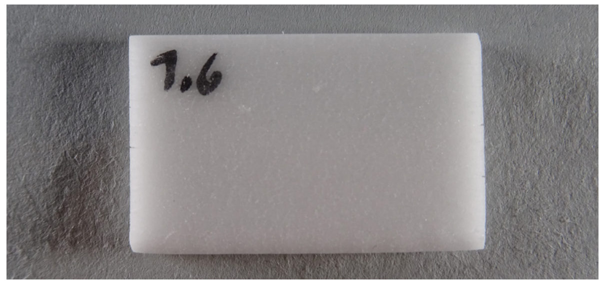




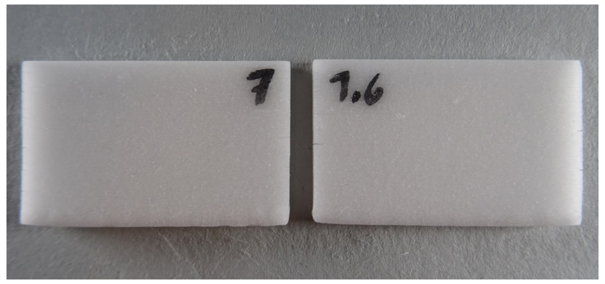
Alcohol wet

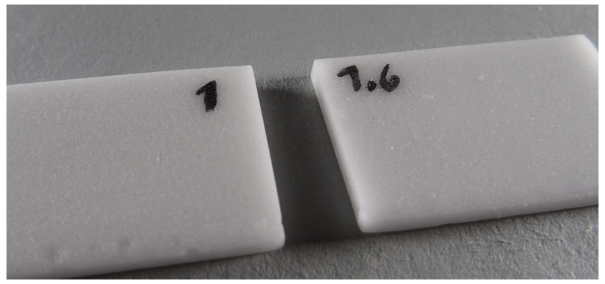
Samples get a very porous surface texture when fired wet. Even more porous than the surface texture of the samples which were soaked in alcohol and fired when dry. The surface texture does not appear to becomes more porous when soaked for longer.

Sample 6
Soaked in alcohol for 24 hours
Fired wet
Very porous surface texture



Sample 7
Soaked in alcohol for 48 hours
Fired wet
Very porous surface texture

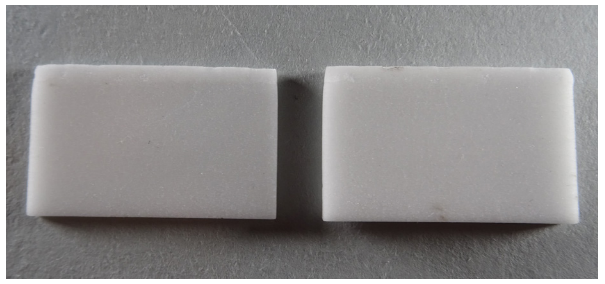


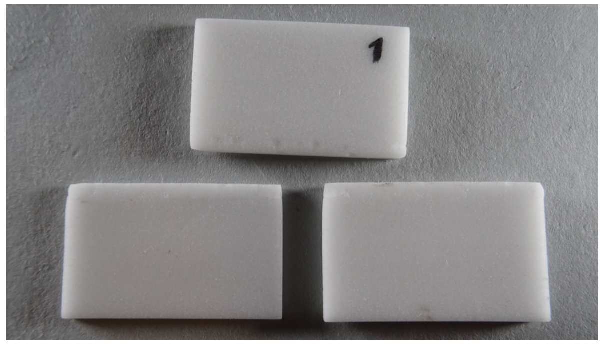


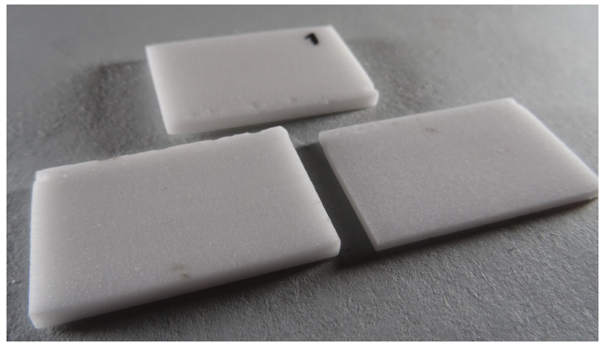
Altering kiln settings

The surface texture becomes more porous and rough when sample are fired at a temperature of 1250 °C instead of 1271 °C. So, firing samples at a temperature of 1250 °C will not sinter the material completely. The porosity of the material is even more obvious on thin walls (< 2mm).

It was planned to also fire samples at 1300 °C and at 1271 °C with a sintering hold of 10 minutes instead of 5, to analyse the effect on the material surface. Unfortunately, the oven broke down making it impossible to execute these tests. However, the difference in surface texture between the tested samples can indicate that the surface becomes even more glass like when firing at an even higher temperature.

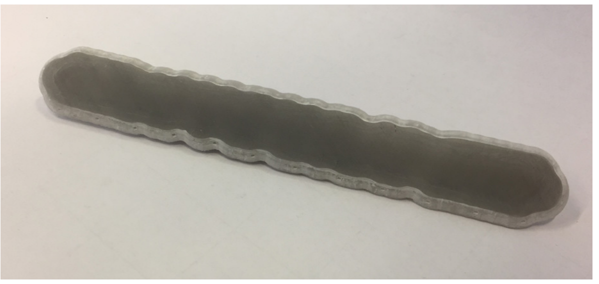


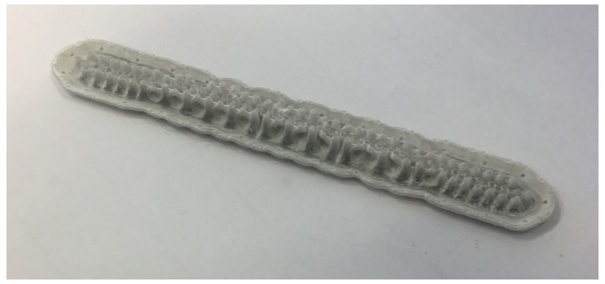


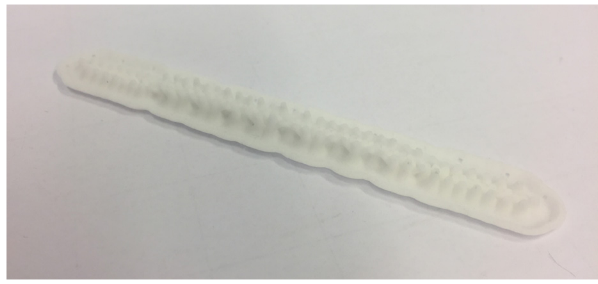


Smooth build plate surface

Surfaces made smooth before firing, during printing or after printing, will not stay smooth after firing. They appear a bit less porous but are still rough and unpleasant to the touch. So, smoothing out the material surface should be done another way most likely after firing, by polishing for example.

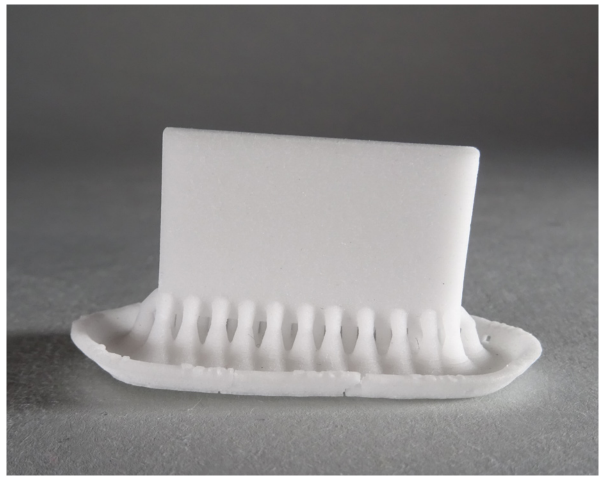


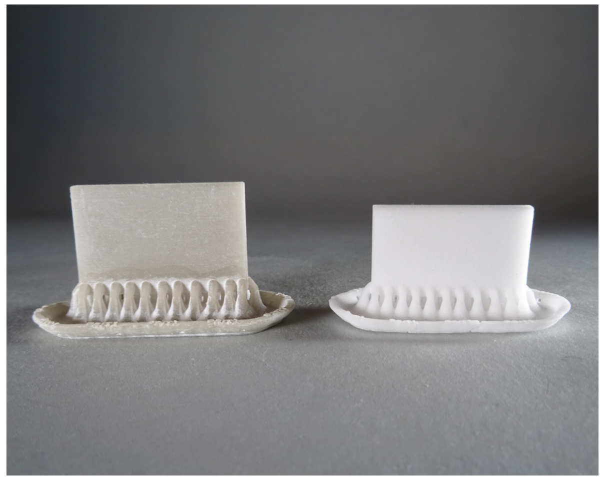




VI Firing part on support

Firing a sample on the support is possible. Only slight warping occurs. So, parts with thin, tube like structures can be fired as long as they are self-supporting and can even support solid objects without collapsing or cracking.





VII Hidden chambers incorporated in a cup

It is possible to print objects with internal chambers. However, there is a chance that a very small amount of non-solidified resin is left inside the chambers. When firing this small amount of resin will create cracks. To avoid resin being left inside the chambers small holes can be implemented in the structure which let the resin flow out of the chambers during printing.

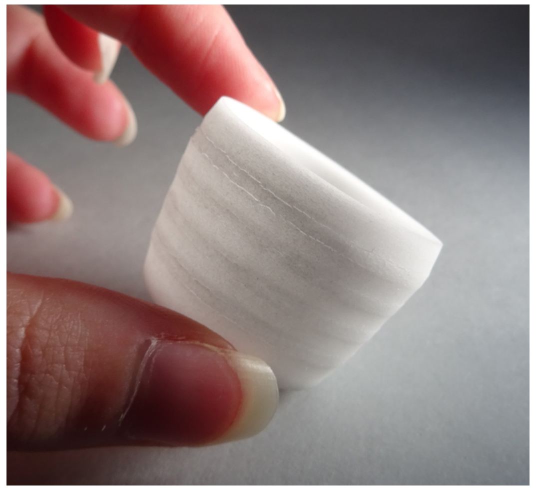
3D objects with continues internal chamber will deform during firing. This is because of uneven shrinkage. The chambers shrink less than the parts without internal chambers. Because of this the cup became more rounded.

The walls also cracked during firing. This can be because of several reasons:

- The walls were to thin (1mm before firing).
- The liquid resin inside the chambers created gasses which create pressure resulting in cracks.
- The air inside the chambers creates pressure resulting in cracks.

The deformation made the chambers visible even when not held in the light. It is interesting to test if internal structures incorporated in non-deformed objects are also visible when not held in the light or if they are invisible.

The support points at the bottom of the object were sanded away before firing but are still visible when the object is held into the light.



3.5 TAKEAWAYS

Thin walled objects
Objects with wall thicknesses of 3mm or less will have the best printing and firing results with small to no chances of warping and cracking.

Shrinkage
The samples will shrink approximately 15% during sintering, so samples should be scaled before printing to account for this shrinkage.

Controlled cracking
Flat objects can be produced with controlled clean cracks in the walls. This is done by pausing the printer for 5 minutes mid print.

Surface texture
Most additions or alteration will influence the surface texture in a negative way, making the texture more porous and rough.
Positively altering the surface texture of the material is possible. It is done by changing the kiln settings or post processing after firing.

Figure 3.5-1 *Wire like structure supporting a solid object.*

Typological optimization
Self-supporting tube or wire structures will fire without deformation or cracking and can be used as a base supporting solid objects (figure 3.5-1). The fact that this is possible brings the opportunity of using this material and production process to manufacture objects with topologically optimized wire like structures. Topology optimization is a technique which optimizes a certain material distribution with given boundary conditions like types of supports and loads (Lift Architects, 2012) (figure 3.5-2).

Internal structures playing with translucency
The 3D printing process allows for the production of internal hollow structures incorporated into an object. These hollow structures will unveil when the object is held into the light. This was already the case for the deformed sample created during the broad tinkering phase, so would most likely be the case for non-deformed objects as well.

The support points, even when sanded away, can still show up especially when holding an object in the light. This can be seen as a flaw but it can also be embraced and add to the design of the object.

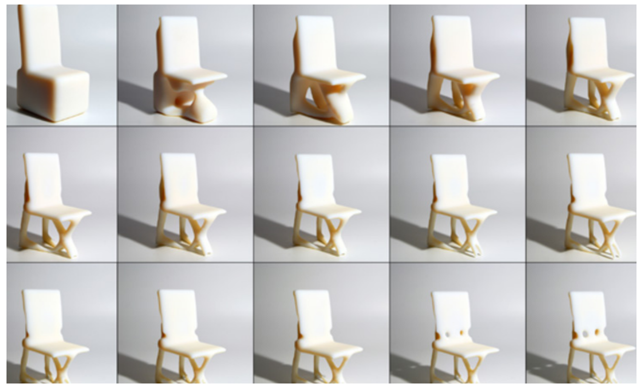


Figure 3.5-2 *Topological optimization of a chair by Lift Architects.*

From 3D Printing materials distribution. Retrieved from http://www.liftarchitects.com/blog/2012/5/28/3d-printing-material-distributions. Copyright © 2007 - 2018 All rights reserved.

3.6 FOCUSSED TINKERING

Some of the samples created during the broad tinkering phase stood out more than others. These samples perfectly made use of and combined the material characteristics and the opportunities brought by the free form, high precision production process.

Controlled cracking

The first samples which bring potential were the controlled cracking samples (figures 3.6-2).

Functional
The cracks are the weakest spots and will break when subject to impact or force. This weakness can be used as a functionality. These cracks can be placed on controlled spots throughout the object and when the user applies force new shapes or functionalities arise (figure 3.6-1).

Performative
During the focus group it was observed that people had the urge to break the material. These clean controlled cracks will feed into this urge and will encourage users even more to break the material.

Figure 3.6-1 *SLASH LAMP by Dragos Motica*

From Home Lighting "/" SLASH LAMP. Retrieved from https://ubikubi.ro/product/slash-lamp/

Translucency

The sample with hidden chambers also brings potential (figure 3.6-3).

Functional
The chambers create a hidden feature. This particular hidden feature is not functional but this can of course be made functional. Hiding messages, functional information or images for example.

Performative
One of the actions taken by users when interacting with the material is playing with the translucency of the material. Objects with hidden internal structures create the opportunity to play with the translucency of the material since the hidden structures are only unveiled when the translucency is emphasized by either light, contrast, liquid etc..

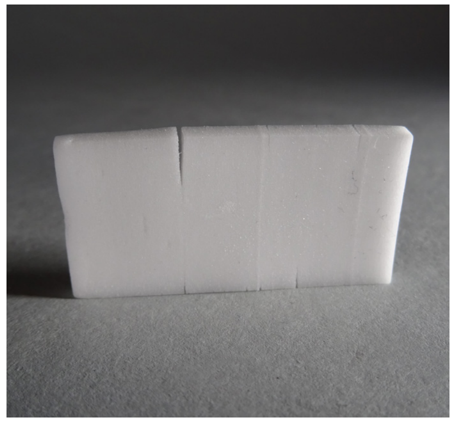


Figure 3.6-2 *Controlled crackin*

Figure 3.6-3 *Hidden chambers*

Sensorial
The translucency is a very attracting property of the material and makes it possible to implement the internal hidden features. If the material would have been opaque this would not have been possible.

Interpretive
The translucency of the material is only noticeable when it is emphasized. However, light hitting it or movements from the environment can give sneak peeks of the translucency. This in turn will also unveil small parts of the hidden feature creating attraction and curiosity.

Digitally modified surface textures

The support structures in particular the one shown in figure 3.6-5 also brings potential. The Formlabs material was experienced as tactually unpleasant and rough during the focus group. However, this particular support structure was not experienced as tactually unpleasant as the untextured material. leading to the belief that applying high precision, digitally produced textures on a surface might actually alter the tactual experience in a positive way (figure 3.6-4). So, applying digitally produced textures on the surface of an object brings potential.

Functional
These digitally modified surface textures make the material actually fit for tactual products. It can alter the tactual experience making the material customizable to fit any application.

Performative
The users were continuously stroking the material to understand the sensation created by the surface texture. Implementing surface textures will encourage people even more to stroke the surface. Since, actively exploring textures is naturally done by stoking.

Sensorial
Users experienced a sensorial incongruence and an offensive tactility when exploring the material. implementing digitally produced surface textures will remove the sensorial incongruence because people will expect relief and some level of roughness. The tactual experience will also be improved by implementing surface textures. The material will be perceived as less rough, as is the case when touching the support structure.

Interpretive
Depending on the implemented textures, different associations and meanings can be elicited. This makes the material customizable to fit any situation and desired material-user experience.

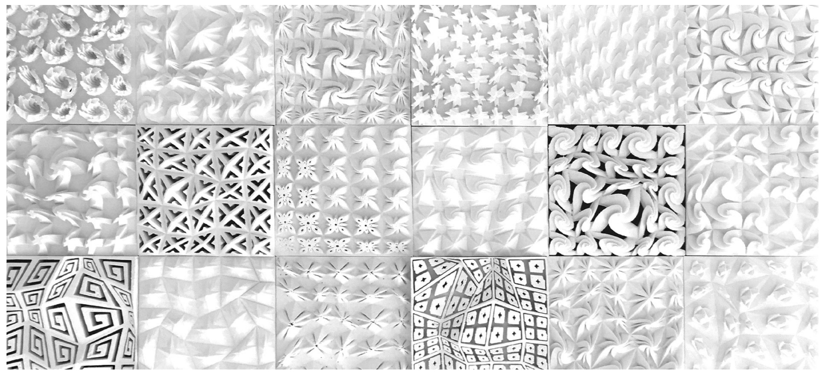


Figure 3.6-4 *Digitally modified surface textures*

From Miles of Tiles 3D Printed Patterned Landscapes of Cyprus. Retrieved from https://all3dp.com/3d-printed-patterned-landscapes-cyprus/. CC Licensed by All3DP under a Creative Commons Attribution 4.0 International License

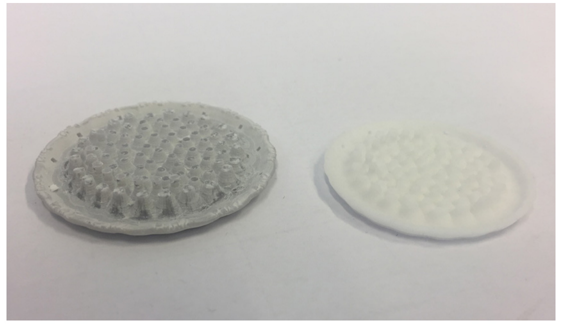


Figure 3.6-5 *Round support structures*

VIII-1 Controlled cracking 3D

The previous controlled cracking tests have been executed used flat samples. Controlled cracking has not yet been tested with a 3D shapes which has continues surfaces. So, during this test controlled cracking on a shape with continues surfaces is tested.

The prominent lines are visible when holding the cups in the light but no clear cracks can be seen (figure 3.6-7). This means that controlled cracking is possible for non-continuous surfaces like walls but not on continuous surfaces like cups.

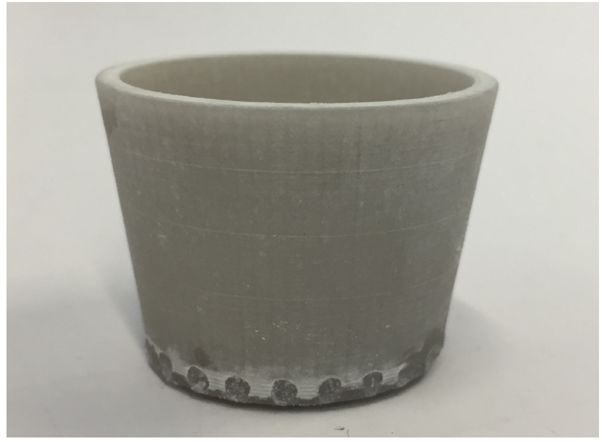


Figure 3.6-6 *Green state controlled cracking sample*

Figure 3.6-7 *No cracks occured during firing*

VIII-2 Internal structures playing with translucency

Flat walls with internal hollow structures can be fired without deformation. However, the external walls do crack during firing (figure 3.6-9 & 10). This can again be because of the following reasons:

- The walls were to thin (1mm before firing).
- The liquid resin inside the chambers created gasses which create pressure resulting in cracks.
- The air inside the chambers creates pressure resulting in cracks.

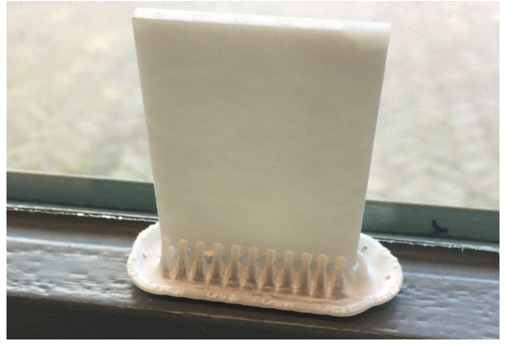


Figure 3.6-8 *Green state internal hollow structure*

Figure 3.6-9 *Cracks throughout the surface after firing*

Figure 3.6-10 *Cracks throughout the surface after firing*

The internal structure becomes a bit more apparent after firing making them more visible even when not held in the light (figure 3.6-14). But the internal structure is still most apparent when the translucency of the material is emphasized by, for example, light (figure 3.6-15 & 16).

The shrinkage of the material should be kept in mind when making the internal structures. When making them too small they will not translate clearly (figure 3.6-16).

Hollow spheres with debossed or embossed textures on the inside can be printed and fired without complications. Hollow shapes will slightly deform during firing but the material surface does not crack (figure 3.6-12). The hidden texture is not visible when the material translucency is not emphasized by light for example (figure 3.6-12). When held in the light the texture becomes visible unveiling the hidden feature (figure 3.6-13).

Figure 3.6-11 *Green state hollow sphere with internal structure*

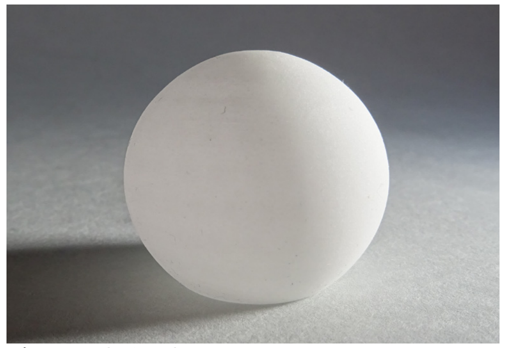


Figure 3.6-12 *Smooth surface and invisible internal structure when not in the light*

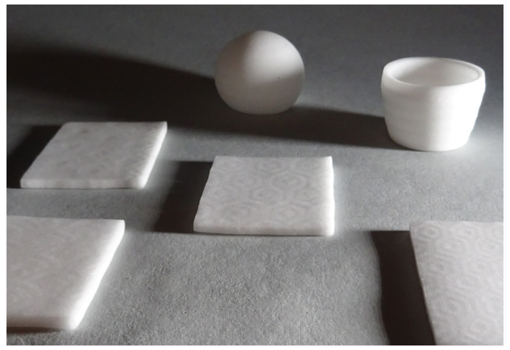


Figure 3.6-14 *Internal structures also visible when not in direct light*

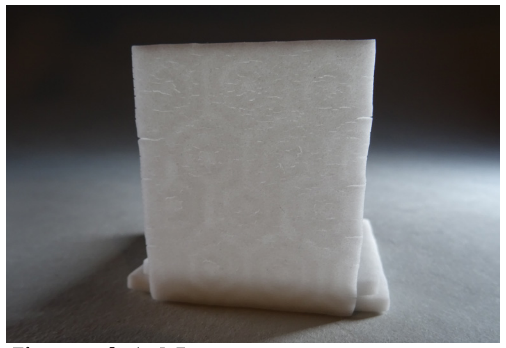


Figure 3.6-15 *Internal structures become more apparent when in the light*

Figure 3.6-16 *When internal structure is too small it will not translate clearly*

Figure 3.6-13 *Hidden structure unveiled when held in the light*

VIII-3 Digitally modified surface texture

Applying digitally produced textures onto a surface will alter the tactile experience. The surface texture shown in figure 3.6-17 creates a smooth sensation making the tactile experience more pleasant. This perceived smoothness is probably created because of the smaller contact area. The user is in contact with less material compared to an untextured surface.

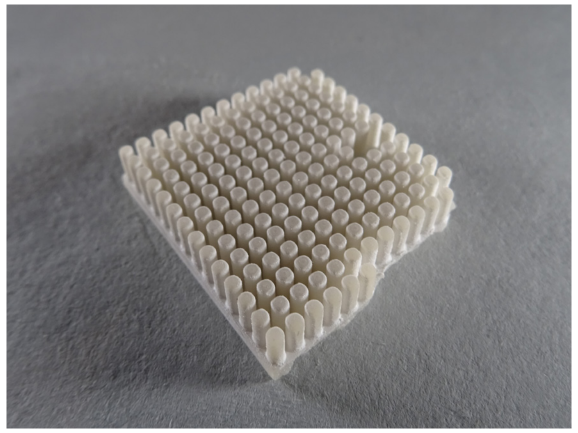


Figure 3.6-17 *Sample with digitally modified surface texture*

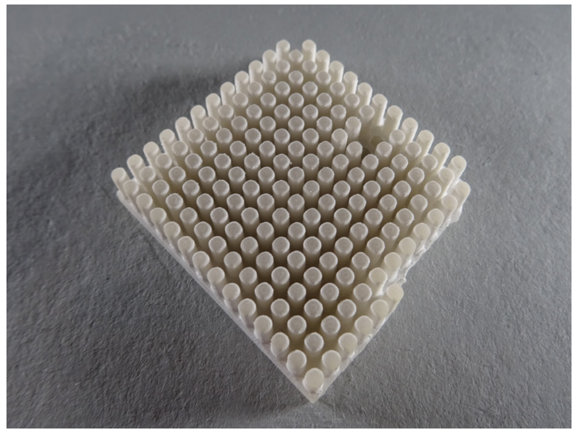


Figure 3.6-18 *Sample with digitally modified surface texture*

3.7 CONCLUSION

The user tests concluded that the material had a soft looking aesthetic because of the mat surface. Furthermore, the pureness, white colour, and the visibly smooth looking surface created an expectation of the material being smooth. It was however experienced as rough leading to an incongruence between senses and an offensive tactile experience, making the material deceptive.
The meaning of the material became unfriendly, dirty, unpleasant and unreliable because of this incongruence and the material was associated with sanding paper and stone.
Lastly the high translucency of the material was only visible when held in the light or when covering something which is unfortunate since this is a nice material characteristic.

The tinkering phase led to some nice material characteristics and directions.
The material in combination with this printing process allows for great formability. Furthermore, the surface texture can be altered by altering variables in the production process, making the surface texture more or less porous.
Controlled cracking can only be possible on flat surfaces, not on continuous surfaces like cups.
The support points created by the support structure can be sanded away and become visible however when holding the object in the light some can still become visible creating 'flaws'.

The high precision and form freedom of the Formlabs printing process brings the opportunity of digitally altering the surface texture of the material, in turn altering the tactile experience of the material.
Lastly the high precision and form freedom of the Formlabs printing process also bring the opportunity to create hidden internal structures. This in interesting since the material is translucent which allows for the unveiling of the hidden structures when the translucency is emphasized.

It was decided to focus on experimenting with digitally modified surface textures. This is because of the deceptive and textually unpleasing experience of the material which can be improved and even taken away by implementing these modified surface textures.

The offensive tactile experience could also be altered by glazing of polishing the material surface but it is interesting to see if modifying the surface can also lead to a tactual experience. If so, this allows for the raw material to be used without a layer covering it, bringing the opportunity to showcase the material characteristics, like the pure white colour and the translucency.

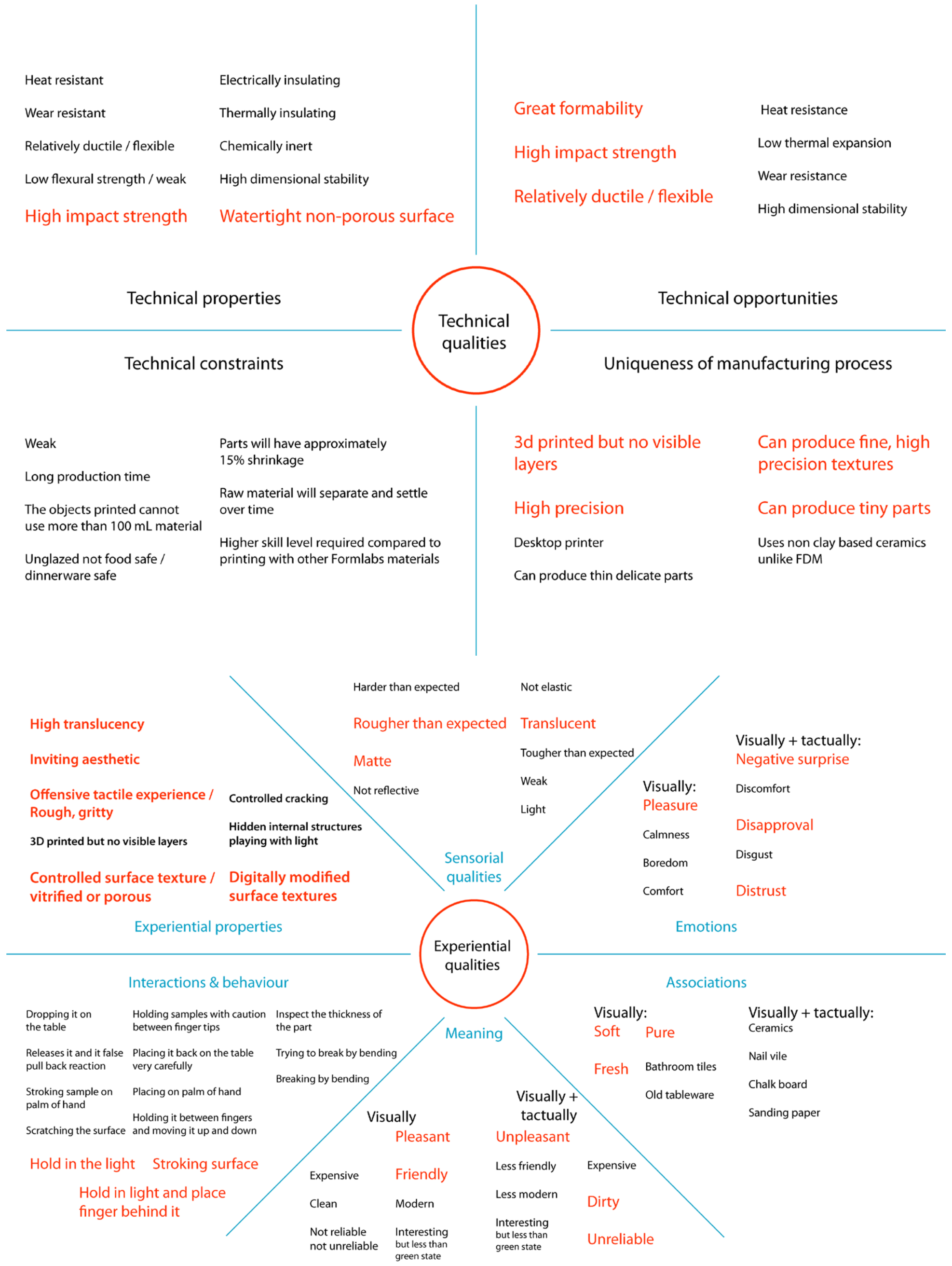
CHAPTER 4
EXPERIENCE VISION

The material characteristics, both experiential and technical can be used for several applications. Finding the optimal application requires a material experience vision. This vision will describe the role the material will have according to the designer. It will specify how the material will contribute to the functionality, how it will contribute to the unique user experience and finally what the purpose of the material is in relation to other products, people and context (Karana et al., 2015).

In this chapter all experiential and technical characteristics of the material are listed, a material benchmark is set up, the ideal context is formulated and relevant trends regarding ceramics, 3d printing and 3d printing ceramics are listed. Leading to the formulation of the material experience vision.

4.1 MATERIAL CHARACTERISTICS

The technical characteristics of the material are based on the technical tests executed, the information gathered from Formlabs and the printing and firing experience gathered during this project so far.
The experiential characteristics of the material are based on four experiential levels: sensorial, interpretive (meanings), affective (emotions) and performative (actions, performances) (Karana et al., 2015). Furthermore, they are based on the focus group, the interview with the traditional ceramics expert and the tinkering process.
Below both technical and experiential characteristics are visualised.
The most promising characteristics are highlighted in the visuals.



These characteristics emphasize the unique qualities of the material in combination with the flexibility and high precision of the 3D printing process.

The material was experienced as deceptive because of an incongruence between senses. Visually having inviting aesthetic qualities, being super white, having no impurities and looking smooth and soft. But having an offensive tactile experience, being coarse and rough like sanding paper or a chalk board.
Furthermore, it is very translucent making it even more inviting but this is only visible when emphasized by holding the material in the light or by covering something (finger).
The material also elicited positive surprise since it was not expected that the samples were 3D printed since no layers were visible.
The technical qualities of the material and the production process enables the production of high precision, thin walled objects with high impact resistance and non-porous, glass like surfaces.

Combining the characteristics, a product with a unique mix of technical qualities but deceptive material-user experience can be developed.

The roughness of the surface texture can be altered and influenced using the full potential of the kiln settings and the flexible, high precision 3D printing process. The printing process could be used to implement computer modelled textures. These textures could improve the experience by removing the sensorial incongruence and/or by altering the surface texture in such a way that the actual tactile experience becomes more pleasant.

So, a technically unique and experientially pleasant product can be developed by combining the original experiential qualities, the digitally enhanced experiential qualities and the technical qualities.

4.2 EMPHASIZING TRANSLUCENCY

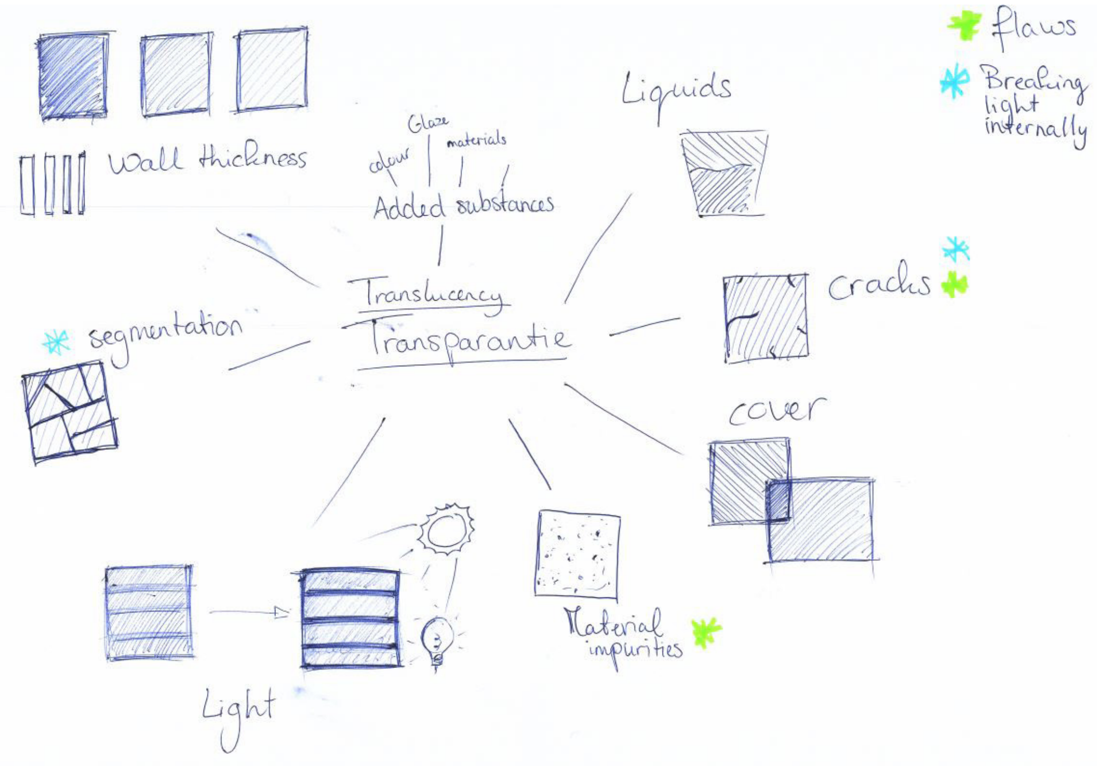
As mentioned before, the material has high translucency. This is however, only visible when it is emphasized. Translucency can be influenced and emphasised in many different ways. A mind map was made, visualising everything that can influence and emphasize translucency (appendix J).
The results were that material translucency can be influenced and emphasised by:

- Liquids
- Light
- Wall thickness
- Covering, shielding and dividing
- Segmentation
- Cracks and impurities
- Adding substances

Resulting in some interesting directions:

- Hidden features
- Flaws
- Breaking light internally
- Shielding, dividing

The most interesting direction is the hidden features one since this fits the opportunities made possible by the high precision 3D printing technique. Furthermore, statement pieces which experiment with manufacturing or material flaws and light breaking internally, have already been developed. So, implementing hidden features, only possible to produce with 3D printing, makes this product unique.



4.3 BENCHMARKING

The purpose of the material benchmarking is to position the material alongside similar materials and their applications. It will give an inside on potential application areas, possible experiential issues and experiential qualities relevant for comparable materials (Karana et al., 2015).

The material benchmark made visualises the possibilities of ceramics. The categories researched are texture, light, 3D printing, unique manufacturing processes and advanced ceramics. The complete benchmark can be found in appendix K.

After analysing the technical tests, executed during the experiential characterisation phase of this project, and the benchmark it becomes extra clear that the Formlabs ceramics material is not fit for advanced bio ceramics or any other advanced ceramics. So, the unique technical qualities of the material will most likely be used for more consumer products comparable to other non-advanced ceramic materials.

Figure 4.3-1 Seams by Benjamin Hubert

From Bitossi Accessoires en verlichting. Retrieved from https://kroonbergskarthaus.nl/collectie/accessoires-en-verlichting/bitossi/

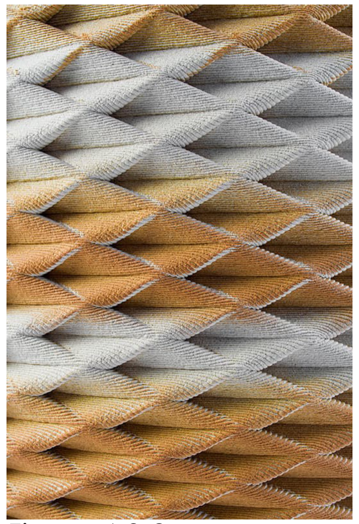


Figure 4.3-2 FDM printing 'flaws' by Olivier van Herpt

From Functional 3D Printed Ceramics Explorations in functional 3D Printing Ceramics. Retrieved from http://oliviervanherpt.com/functional-3d-printed-ceramics/. Copyright 2019 by Olivier Van Herpt

Furthermore, it is clear that most experiential properties in the benchmark are alterations during the manufacturing process. Unfortunately this is not possible with this manufacturing process. The manufacturing alterations during this project will be executed before manufacturing, in the 3D modelling programs, and after manufacturing, during firing.
Furthermore, the raw material will not be altered.
The surface texture and the translucency of the printed material can be altered and this is done after manufacturing, during the firing process. So, most experiential properties will be based on experimenting with CAD modelling and the firing process.

Seams by Benjamin Hubert, shown in figure 4.3-1 focusses on an interesting experiential issue. It focusses on the creation of mass produced, one-off products by using the production flaws. In general 3D printing also brings production flaws as is beautifully showcased in the designs of Olivier van Herpt (figure 4.3-2). But the technique used for the new Formlabs ceramics material does not leave layer traces throughout the surface. The only 'flaws' visible are the support points. These can make the product one-off and do show traces of the production process but are not as apparent as visible layers. They can also easily be sanded away and afterwards disappear completely when fired. One has to know this specific 3D printing process to be able to recognise that a product is made using the SLA technique. So, for the common user it will not be clear that the products are 3D printed.

Olivier van Herpt (figure 4.3-3) also showcases the form freedom of 3D printing. More complicated texture and shapes can be created and the ceramic material and manufacturing machines he uses allow for the development of large objects. Creating large objects is not possible with the Formlabs printers but they do offer form freedom and high precision. The FDM printer Olivier van Herpt uses can only print with opaque stoneware, as is the case for most desktop FDM ceramic printers. 3D printing translucent ceramics on desktop printers does not occur. Translucent ceramics have been 3D printed but mostly on industrial printers with high costs. So, the fact that the Formlabs material is translucent and can be printed on a desktop printer makes it very unique. It allows for the manufacturing of form free, high precision translucent objects with relatively low costs.

The designs of Leah Kaplan (figure 4.3-4) are also interesting. Since porcelain is like a blank canvas it can easily be altered in such a way that it can imitate other materials. This is inspiring since the new Formlabs ceramics material is also like a blank canvas and in combination with the flexible and very precise 3D printing technique all textures can me mimicked.

Figure 4.3-3 Statement pieces showing form freedom by Olivier van Herpt

From Functional 3D Printed Ceramics Explorations in functional 3D Printing Ceramics. Retrieved from http://oliviervanherpt.com/functional-3d-printed-ceramics/. Copyright 2019 by Olivier Van Herpt

The TOU-LIGHT by Hikaru Yajima (figure 4.3-5) inspires since it is a product which plays with light. This is possible because of the translucency of the material and the flexible production process. The Formlabs material is also very translucent and the 3D printing technique is even more flexible. Creating the possibility for the development of the sandwich structures which initially hide patterns, shown and tested in the experiential research (chapter 3).

So, ceramics is mostly used in decorative statement pieces, advanced fields like bio ceramics, lighting and table ware. The Formlabs material could be used for similar applications except for advanced ceramics. However, when implementing the Formlabs material it is important that the unique, material and production method combination is highlighted. The uniqueness of manufacturing translucent ceramic objects using a form free, high precision desktop SLA 3D printer.

Figure 4.3-4 Mimicking well know texture by Leah Kaplan

From Experimenting Texture by Leah Kaplan. Retrieved from https://through-objects.com/blog/ceramics-by-leah-kaplan/. Copyright 2019 by Through Objects

Figure 4.3-5 Playing with translucency by Hikaru Yajima

From TOU-LIGHT Large. Retrieved from http://market.arpiece-factory.com/?pid=110143646. Copyright by Ar piece factory Co.,Ltd.

4.4 TREND ANALYSIS

A trend analysis was executed. This was necessary to be able to understand the broader picture. Finding technological, societal, ecological, political and/or economical events which can influence the application area or method of this material. Furthermore, it can also give an inside on current societal preferences regarding materials and design.

Trends related to ceramics are mostly bio ceramic and advanced ceramic based. Since this Formlabs material cannot be used as a bio or advanced ceramic trends like these are not interesting for this research. So, more design and societal trends are searched.

Tactile Interactions

The most relevant trend found was the demand for design with tactile interactions. Through touch we explore the physical world and since the development of smooth touch screen devices, tactility as a sense has been neglected and forgotten (Merleau-Ponty, 1962). Humans need tactile interactions as a basis for their emotional well-being and to be able to connect to the physical world (Fields, 2003). Because of this a move towards tactility can be seen. It is seen in, among other fields, architecture, design and fashion (Milis, 2018). Designers investigate and explore human centred design. Playing with experiential materials, textures, structures and form. Some examples are soft furnishing, Happy concrete by OLASOL and Concrete cubes by Emese Orban (Greenwood, 2019) (figure 4.4-1 & 4.4-2).

Figure 4.4-1 Concrete cubes by Emese Orban

From Emese Orbán: HUMANE BETON. Retrieved from https://digitalcraftlab.mome.hu/project/emese-orban-humane-beton/

Figure 4.4-2 Happy concrete by OLASOL

From OLASOL-FUR-CONCRETE-WALL-TILE-CON177-1. Retrieved from https://materialdistrict.com/material/fur-concrete-wall-tile/olasol-fur-concrete-wall-tile-con177-1/. Copyright 1998-2019 by MaterialDistrict

4.5 EXPERIENCE VISION

The unique characteristics of the material, the findings from the material benchmarking and the material and design trends lead to the material experience vision.

The material is very white and has no material or manufacturing impurities giving it a smooth and inviting aesthetic. This aesthetic invites people to touch and hold but the rough surface texture creates an offensive tactile experience. It also has high translucency but this is only noticeable when emphasized by, for example, light, liquids or shielding.

The freedom and high precision of the 3D printing technique brings opportunities. The roughness of the surface texture can be altered by implementing customized modelled surface textures. These varying surface textures can lead to different tactile experiences and could alter the offensive tactile experience of the material.

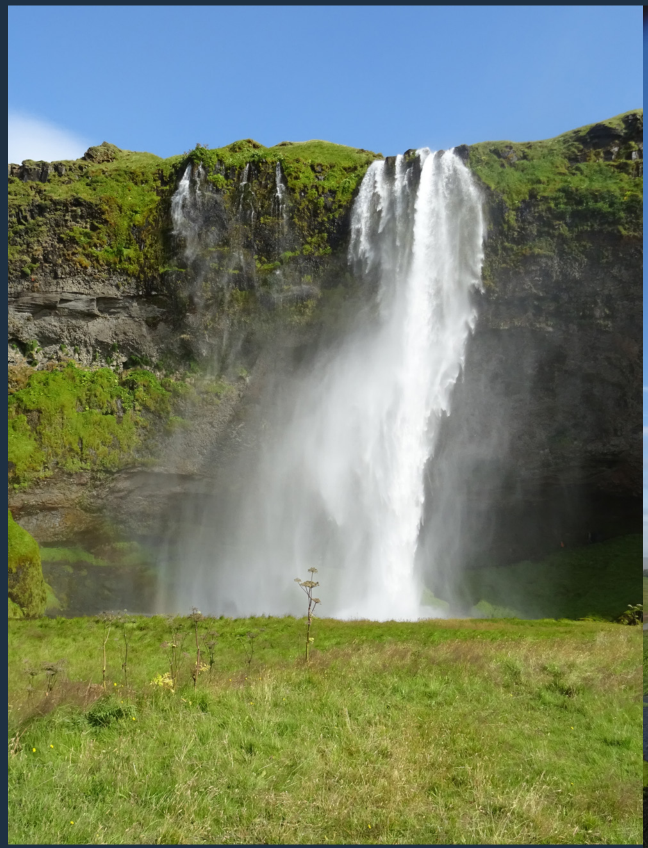
The benchmark shows that it is important to emphasize and showcase the uniqueness of 3D printing translucent ceramics on a high precision desktop 3D printer at relatively low costs.

The translucency of the material and the freedom of the 3D printing technique allow for the creation of products with hidden features. These features could be messages, information, textures and images and are unveiled by emphasizing the translucency of the material.

Lastly the trend analysis shows that there is a demand for products which stimulate the tactual sense because of the lack of tactile stimulation in our daily used products.

So the material will be implemented into a interactive consumer product.
The envisioned role of the material will be to attract people and invite and encourage them to interact with the object by touching and holding the surface. The tactile stimulation experienced is pleasant because of the digitally modified surface texture. When interacting with the object a hidden feature becomes visible emphasizing the translucency of the material.
This hidden feature will showcase the opportunities 3D printing of translucent ceramics brings.

METHAPHOR



So, the envisioned material user experience should be like walking behind a waterfall. The waterfall is already inviting and beautiful and being able to walk behind it allows for exploration and a surprisingly new experience full of beauty.

CHAPTER 5

TACTUAL EXPERIENCE PATTERNS

Now that the material experience vision has been formulated, understanding has to be created about material experience patterns. This means understanding if and why an experiential or technical material quality elicits comparable meanings and emotions between different people in society. For this research the focus will be on understanding the influence of varying tactual stimulations on different people to be able to find patterns.

The following chapters will describe the findings of the literature research on touch, textures and pleasant tactility, the 2 tests and the meeting with a haptics expert.

5.1 TACTILITY

Why tactility

Tactility will be the focus because the material was experienced as deceptive due to an incongruence between senses. Being visually pleasing and tactually offensive. The free form, high precision printing process brings the opportunity to remove this sensorial incongruence and alter the tactual experience. Altering the material experience in such a way that it could actually be used in tactual consumer products without having to glaze or polish the surfaces.

The visual aesthetics of the Formlabs material make it possible to alter the sensorial experience. The whiteness and pureness of the material make it a blank canvas that can mimic of be formed into anything.

The tactual experience will be altered by implementing digitally produced surface textures. The form free, high precision production process allows for the production of recognizable surface textures which mimic textures of known objects.

Lastly a trend was found that, these days, tactual stimulations are missing from daily used products. The products society is mostly in contact with contain smooth displays and, when possible, buttons are removed to make the surfaces even more smooth.

So, the societal trends, material characteristics and production properties highlight the opportunity and importance of experimenting with tactual stimulation in daily used products. To be able to use tactual stimulations in the final application some research has to be done about touch and tactility.

importance of touch

First off all it was researched why touch and tactual stimulation is so important as is said in the trend found in chapter 4.

First of all this is because, it used to create awareness of oneself (Sonneveld & Schifferstein, 2008). The tactual sense allows us to interact with the world and it involves the whole body. Touching and being touched creates the awareness of being a physical body and physical interactions let people sense their body instead of only seeing it (Bermudez, Marcel, Eilan, 1995).

Furthermore, it can be used to learn (Sonneveld & Schifferstein, 2008). Touch is the only sense that lets people explore the materiality of the physical world. The other senses let people see, smell, hear and taste the world but only when touching someone can learn about its weight, temperature, hardness, texture, etc.. So, people need touch to know and understand the world (Lakoff and Johnson, 1999).

Another reason touch is used is for the development of feelings and emotions (Sonneveld & Schifferstein, 2008). Touch is necessary during the first years of a person's life. A person will only develop into a healthy and empathic human being when being subject to loving and protecting touch as a child. It is the foundation for the development of affectionate and intimate feelings (Fields, 2003). During a research with rats it was shown that a lack of intimacy and touch during the first phases of life can lead to growth retardation and withering (Montagu, 1971). The need for loving touch will stay important throughout someone's life, this is called touch hunger (Fields, 2003). These findings apply to interpersonal touch but human-product interactions can also have effect on the emotional and affective development of people. As an example, Winnicott (1964) described teddy bears and blankets as objects that make the child feel safe when the mother is temporarily absent.

Lastly touch is used to communicate interpersonal affection (Sonneveld & Schifferstein, 2008). Touch means being in contact. Unlike seeing and hearing, which are distant senses, touch includes bodily involvement, making it our most social sense. It can tell us whether we are safe and have value (Fields, 2003). There are different kinds of touch and Fagan (1998) has made a distinction between ritual touch, athletic touch, punishing touch, nurturing touch, intimacy-evoking touch and sexual touch. These types of touch can overlap and for someone to be able to function properly in society the language of touch should be expressed and understood correctly. Besides tactile communication between people, it is also possible to interact and have contact with products. As for interpersonal touch, human-product interactions can elicit different meanings and emotions ranging from functional to intimate (Sonneveld & Schifferstein, 2008).

So, when using touch as described above, it will help to create a social, emotionally stable person who understands the physical world.

5.2 PLEASANT TACTILITY

Purpose

As mentioned before, the material was experienced as deceptive due to an incongruence between senses. Being visually pleasing and tactually offensive. These characteristics are not favourable for a material used in tactual consumer products. So, the material should be used in non-tactual products or the material characteristics should be altered. Possibly altering the material characteristics was the inspiration for this research and led to the purpose of this test.

The purpose of this test was to research the effect of light and digitally manipulated surface textures on the perceived sensorial pleasantness of the material.

So, the perceived transparency of the material and the perceived visual and tactual pleasantness of the varying surface textures is measured.

It is expected that the perceived sensorial pleasantness of the material will be influenced by textures and light. Two hypotheses for this research are:

Hypothesis 1

Now the material looks smooth so a pleasant tactility is expected. However, the material feels rough and not smooth creating incongruence.
When the material is implemented in an object with a texture more relief and roughness is expected so visual input and tactile input will match more creating a more pleasant experience.

Hypothesis 2

When the material is incorporated in a flat surface the users comes in contact with a big surface area creating stick and resulting in a bad tactile experience. When incorporated in a texture the actual contact area is less creating slip resulting in a surface being perceived as smoother.

Participants

15 participants participated in this test whereof 46.7% male and 53.3% female. All with an age between 23 and 30 years old and none with neurological damage or diseases which decreased the tactual sensitivity. All participants were students or just finished their studies, since there is no specific target group and this target group was easily accessible for the designer. Lastly all participants received a snack afterwards as a thank you.

Stimuli

Nine samples were tested during this test (figure 5.2-1). All nine samples had different surface textures, but were all similar in size (diameter of approx. 60mm), thickness (approx. 2mm) and shape (round) and had the same colour.

The material was not altered only the surface texture and this was done through 3D modelling. The 3D modelling program Rhinoceros 5 was used for the creation of the textures (figure 5.2-2). The displacement function in Rhino allows for the creation of 3D printable textures on objects.

The samples had cracks and some were warped because of oven failure and some printing flaws. This was communicated to the participants before the samples were shown. This way they were prepared and would not base their ranking on these flaws.

A lot of textures could have been tested during this test. The decision was made to test nine and after doing some literature research, meeting with an haptics expert and executing a small test (appendix N) these specific textures were chosen.

- Original untextured sample
- Straight lines
- Wavy lines
- Holes
- Cones
- Leaf
- Wood
- Leather
- Moon surface

The textures can be divided into two categories:

- Symmetrical patterns
- Nature patterns

The sample of the original material was added as reference. Making it possible to compare the sensorial experience of each texture to the sensorial experience of the original material.

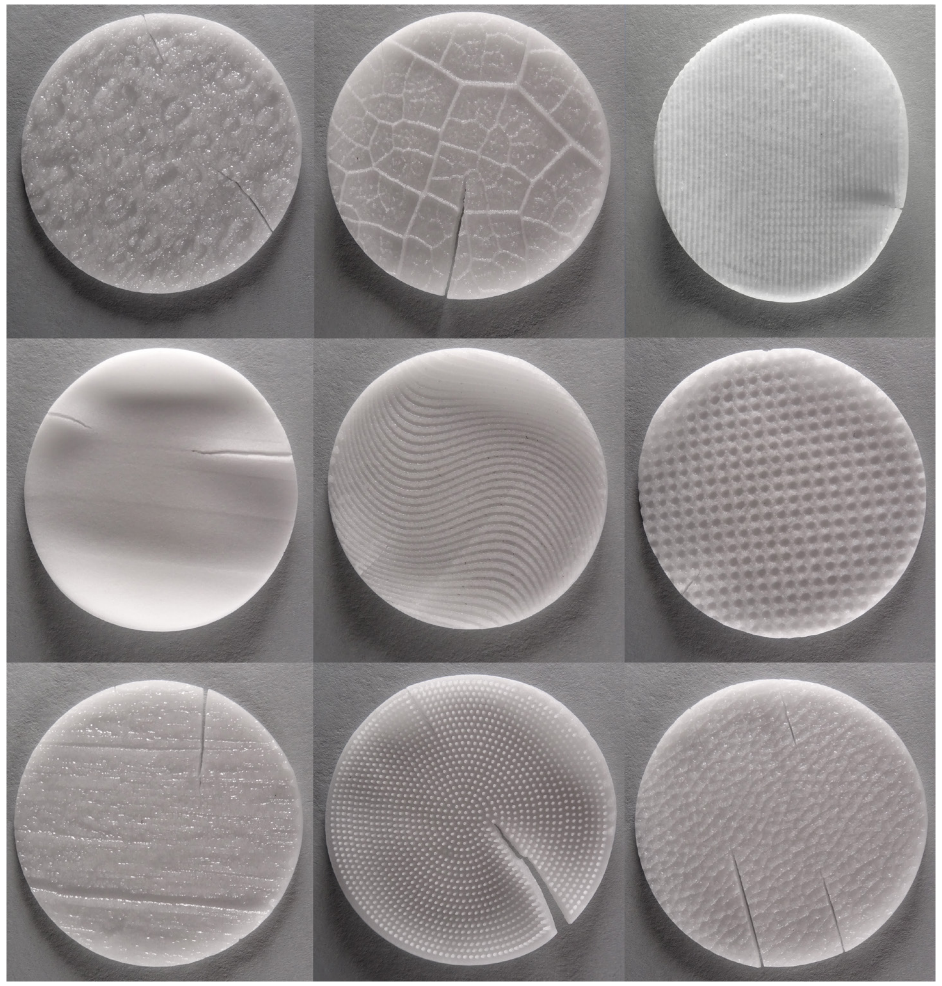


Figure 5.2-1 *All 9 samples used during the tactility test*

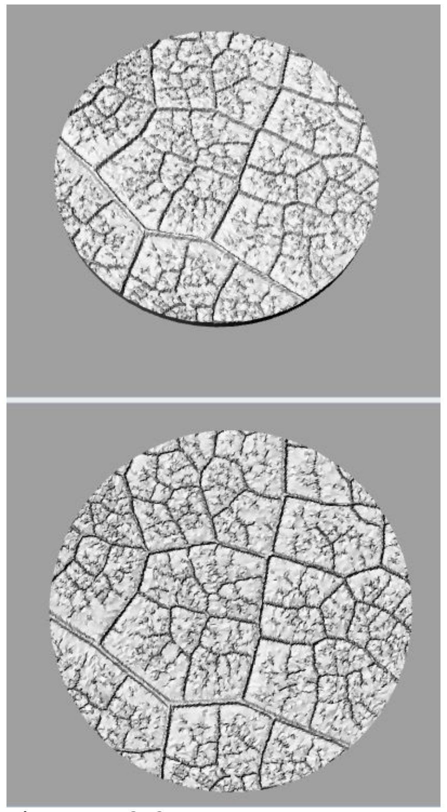


Figure 5.2-2 *Leaf sample model made using Rhinoceros 5*

Besides the nine samples a sheet with emotions was used (appendix O). On this sheet the participants high-lighted the emotions they felt during the texture exploration. The specific emotions were chosen because of there possible relevance for this material. The list was composed using the 700+ product emotions by Desmet (2018) as an inspiration.

Furthermore, the samples were covered with a black cover before the test started.

The participants were also given 9 numbers during the first round which they had to place next to the samples (figure 5.2-3).

Lastly a black foam mat was put underneath the nine samples. This soft surface protected the samples when the participants were moving them around (figure 5.2-4).

Apparatus

A camera with film function and microphone was used to record the test. Furthermore, Rhinoceros 5 was used to create the surface textures.

Procedure

The test setup can be seen in figure 5.2-5.

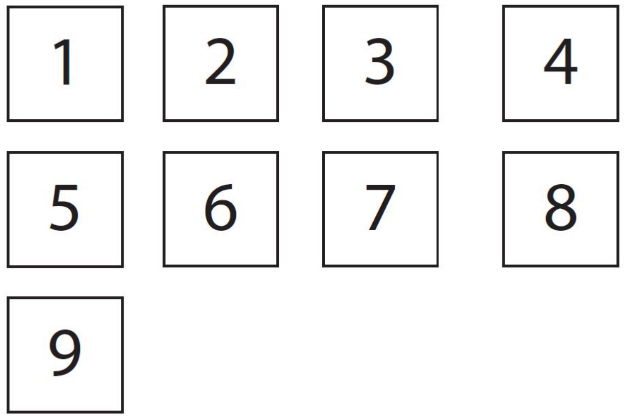


Figure 5.2-3 *9 numbers used for ranking during the test*

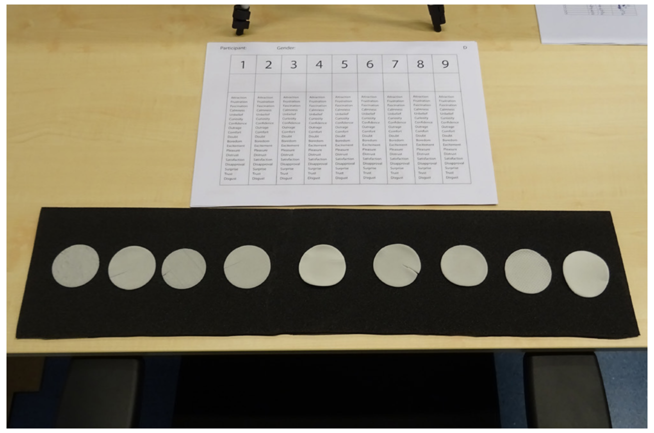


Figure 5.2-4 *Black foam mat to protect the samples*

Figure 5.2-5 *Test setup tactility test*

The purpose of this test was to measure the perceived transparency of each sample and the perceived visual and tactual pleasantness of the digitally manufactured textures, with or without external light source.
Since the visual pleasantness was also measured the participants were not blindfolded. Furthermore, one of the results from the focus group (chapter 3) was that, besides the roughness of the material, the very unpleasant user experience was caused by the incongruences between the visual and tactual stimulation. To be able to notice incongruence the participants have to tactually explore the samples, without a blindfold, after visually exploring them.
The test conductor lined up the nine samples in a random order every time. The samples were covered during the introduction. This introduction included information about the amount of rounds and what was expected from the participants when the cover got removed. During the introduction the participants were also asked to try to look past the unintended cracks and warping of the samples and if they could think out loud during the complete test.

The test was made up out of three rounds. In the first round the participants were asked to rank the samples from most pleasant to least pleasant based on visual stimulation only. The ranking was done by placing numbers 1 through 9 next to the samples.

During the second round the participants were asked to rank the samples based on visual and tactual stimulation. Since the participants were allowed to touch the samples during this round the ranking was done by moving the samples around and placing them on the mat from left to right. Left being most pleasant right being least pleasant. After placing the samples in order from most pleasant to least pleasant the participants were asked to mark the emotions they felt during the exploration. They could mark as many emotions as they wanted or even non if they did not feel any emotions. They were asked to think out loud while ranking and marking.

During the third round the participants were asked to rank the samples based on visual and tactual stimulation with an external light source, so by holding the sample into the light. After exploring the samples the participants were asked to rank the sample from most pleasant to least pleasant again by laying them on the mat from left to right. Left being most pleasant right being least pleasant. After ranking the samples from most pleasant to least pleasant the participants were asked to mark the emotions they felt during the exploration. They were again asked to think out loud while ranking and marking.

After finishing the 3 rounds the participants were given a snack as a thank you and some more information about the project was given.

How the participants interacted with the samples was based on the knowledge gathered from the touch research (Appendix L).

The participants were asked to actively explore the textures of the samples and rank them from most pleasant to least pleasant. The level of tactual sensitivity is dependant of the location of the stimulation and influences the perception of roughness and pleasantness. So, the body part that is used to explore the samples will influence the results. When actively exploring, people use specific movements to be able to specify the tactual properties of an object (Klatzky et al., 1985) (figure 5.2-6).

Textures and patterns are explored by lateral motion, meaning stroking the surface of the object. Stroking is necessary for the detection of fine surface textures (Hollins and Risner, 2000). However, coarser surface textures may already be explored through static touch (Lederman, 1981).

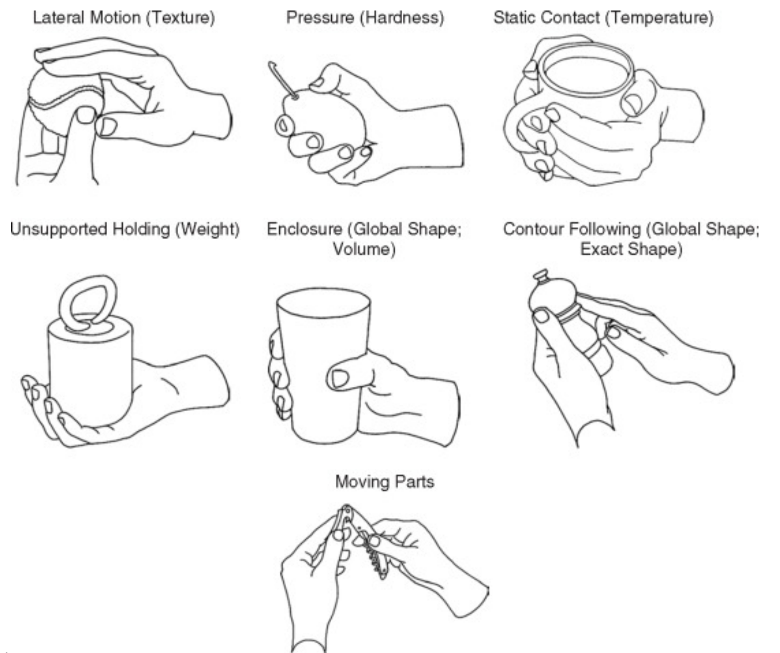
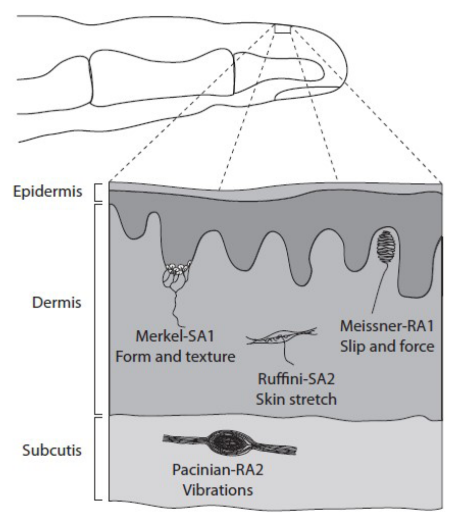


Figure 5.2-6 *Overview of exploratory movements that people use*

Reprinted from "Identifying objects by touch: An "expert system"", Klatzky et al., 1985, Perception & Psychophysics, 37(4), 299–302. Copyright 1985 by Psychonomic Society, Inc.

There are several reasons why people use this type of movement to explore textures. First of all, the glabrous skin (skin covering the palms of the hands and the soles of the feet) has a higher accuracy of touch, since it has a papillary structure. These are the ridges in the epidermal layer (figure 5.2-7) that form the palm and fingerprints. These ridges allow for the receptors to register lateral pressure and will offer more grip when holding and using an object (MacKenzie and Iberall, 1994).
The glabrous skin also contains rapidly adapting Meissner's corpuscles (figure 5.2-7). These corpuscles make it possible for a human to sense light touch and vibrations. So, they allow for the sensation of subtle tactual details, like texture differences (MacKenzie and Iberall, 1994).



SA **= slowly adapting**
= persistent (DC signal)

RA **= rapidly adapting**
= transient (AC signal)

1 **= small receptive field**
= high spatial resolution

2 **= large receptive field**
= low spatial resolution

Figure 5.2-7 *The human skin.*

Adapted from "PUUE lecture – Touch", Wijntjes, M., n.d., TU Delft.

The glabrous skin on the palms of the hands also has high sensitivity because of the size and the distribution of the receptors and the receptive fields (figure 5.2-8). In the human body the fingertips and the lips contain the most receptors per mm2 (Stevens, 1990). Furthermore, the receptive fields of the receptors in the upper skin layer are relatively small, being between 2-4mm. These fields also overlap creating a sensitive whole which is able to accurately communicate how and where the skin is stimulated exactly (Sekuler and Blake, 1994).

The last reason why the hands are most fit for actively exploring objects is because of the size of the receptive area in the somatosensory cortex. The Homunculus by Penfield (figure 5.2-9) visualises the human body based on the size of the receptive areas in the brain. As can be seen the lips and hands cover the largest area in the cortex, while the calves and the back cover small areas.

So, this is why the participants used their fingers to actively interact with the samples, since the lips and fingers are most sensitive to roughness (Stevens, 1990) and the skin type (Glabrous skin) on the palms of the hands is most fit for actively touching and exploring objects (Bolanowski, 2004).

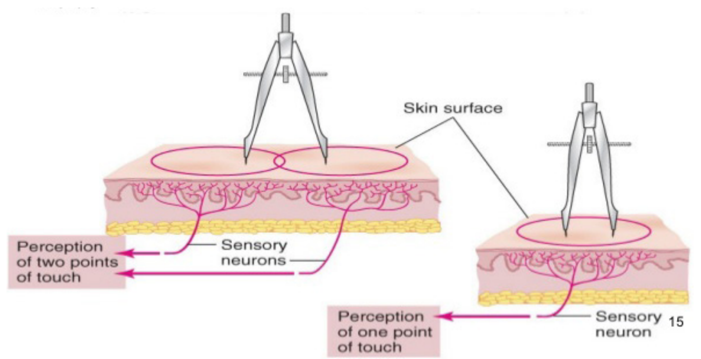


Figure 5.2-8 *Distribution of receptor fields.*

Adapted from "Sensory system", Rao, S., 2012, Dow International Medical College.

Measures

Ranking order

The data retrieved from this test were ranked orders. The participants were asked to rank 9 samples from most pleasant to least pleasant. So, the participants could rank from 1, being most pleasant, to 9 being, least pleasant and each number could only be chosen once.
Analysing the ranking order data was done using SPSS. The data within the three round was analysed to find the most pleasant sample within each round. Furthermore, the data between the three rounds was analysed to find the best method of interaction for each sample.

First of all, the mean ranking order of each sample, within the rounds and between the rounds, was calculated to get an indication of which sample scored the highest in pleasantness according to the 15 participants. As said these mean values give an indication but do not set the final ranking order since it is not sure if the values are significant. The test was executed with a specific group of 15 people resulting in a set of mean values but these values can change completely when executing the test with 15 different people. It has to be tested if the results are purely coincidental or if one sample is actually more pleasant than the other.

Figure 5.2-9 *Penfield's Homunculus.*

From "Homunculus". Retrieved from https://www.connectinside.nl/het-vijfde-lichaam-tempel-voor-de-zintuigen/homunculus/. Copyright 2019 by Connect Inside

Testing the significance was done using three different statistical tests.

The Friedman test was executed within rounds to analyse if there was any significant difference between the samples. When a significant difference is found an analysis can be done to find which samples actually differ from each other.

This can be done using a Wilcoxon signed rank test or a paired sample T-test. They have the same principle of comparing each pair to analyse if there is a significant difference between them, but the paired sample T-test has a higher statistical power than the Wilcoxon signed rank test. Meaning that the paired sample T-test is more likely to reject the null hypothesis when an alternative hypothesis is true.

For this research it was chosen to execute both the Wilcoxon signed rank test and the paired sample T-test. It is more likely that the data gathered during the test meet the assumptions of the Wilcoxon signed rank test since these are less strict. However, by also executing the paired sample T-test the results can be compared and understanding can be created about the analysed significance. When the data is not comparable it shows that the significance is not actually true but when they do compare it can be concluded that there is a real significant difference.

Emotions

Emotions will be mapped out in a visual when they were mentioned 5 or more times.

Results

All the results can be found in appendix P.

Round 1: Visual exploration

Temporary ranking order from most pleasant to least pleasant is (figure 5.2-10):

1. Wavy lines
2. Leather
3. Leaf
4. Wood
5. Straight lines
6. Moon surface
7. Untextured
8. Holes
9. Spikes

The Friedman test did not measure a significant difference between any of the samples. Meaning that the rank order is completely coincidental. To be sure that this is the case the Wilcoxon signed rank test and the paired sample T-test were executed.
These tests did measure significant differences between pairs.

3 significantly different pairs were found from the 36
Wavy lines was found significantly more pleasant than:

- Moon surface (p = 0.030)
- Untextured (p = 0.042)
- Spikes (p = 0.028)

But there were no significant differences found between 1 – 5 and 8 and 2 – 9. Meaning that any of the first 5 samples or sample 8 can be as visually pleasing as unpleasing (figure 5.2-11).

Round 1: Visual

	Mean	N	Std. Deviation
1.1 Sample inspired by wood	4,93	15	2,549
2.1 Sample inspired by leafs	4,20	15	2,957
3.1 Sample inspired by moon surface	5,67	15	2,664
4.1 Sample inspired by leather	4,13	15	1,995
5.1 Sample without texture	5,73	15	2,520
6.1 Sample with symmetrical lines	5,13	15	2,356
7.1 Sample with symmetrical wavy lines	3,60	15	2,261
8.1 Sample with symmetrical holes	5,73	15	3,105
9.1 Sample with symmetrical spikes	5,87	15	2,295

Figure 5.2-10 Mean ranking score of all textures

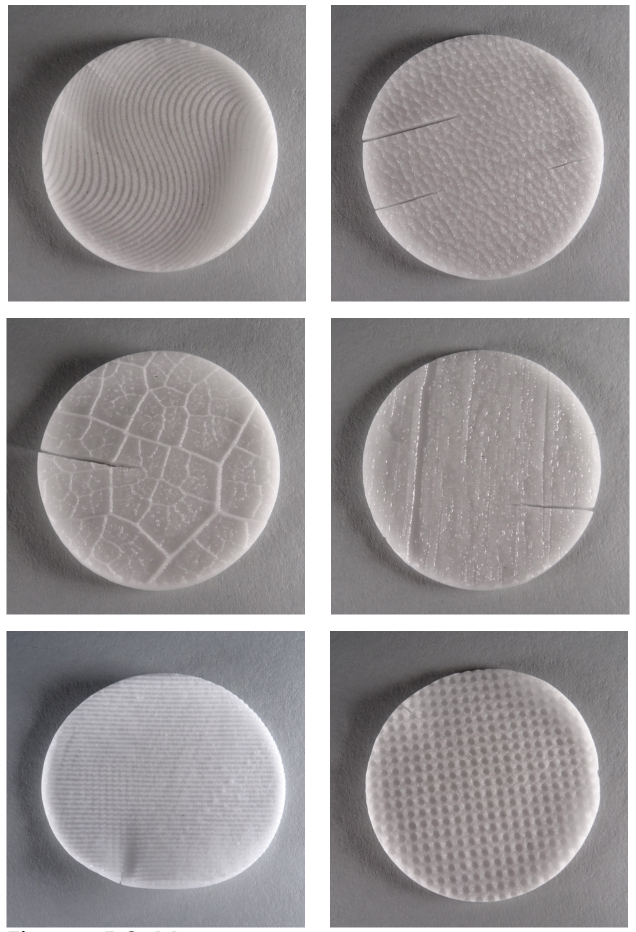


Figure 5.2-11 Visually pleasing textures

Round 2: Visual and tactual exploration

Temporary ranking order from most pleasant to least pleasant is (figure 5.2-12):

1. Wood
2. Moon surface
3. Wavy lines
4. Leather
5. Straight lines
6. Spikes
7. Leaf
8. Holes
9. Untextured

The Friedman test does measure a great significant difference between the 9 samples (p = 0.001).
The Wilcoxon signed rank test and the Paired sample T-test will clarify which sample are significantly different from one another.

11 significantly different pairs were found from the 36
Wood was found significantly more pleasant than:

- Leather (p = 0.009)
- Straight lines (p = 0.046)
- Spikes (p = 0.012)
- Leaf (p = 0.008)
- Holes (p = 0.008)
- Untextured (p = 0.015)

Moon was found significantly more pleasant than:

- Leaf (p = 0.022)
- Holes (p = 0.049)

Wavy lines was found significantly more pleasant than:

- Holes (p = 0.024)
- Untextured (p = 0.009)

Straight lines were found significantly more pleasant than untextured (p = 0.045)

But there were no significant differences found between 1 – 3, 2 – 6 and 6 – 9. Meaning that any of the first 3 samples (wood, moon surface, wavy lines) can be as visually and tactually pleasing as unpleasing (figure 5.2-13).

Round 2: Visual + tactual

	Mean	N	Std. Deviation
1.2 Sample inspired by wood round 2	2,73	15	2,314
2.2 Sample inspired by leafs round 2	5,93	15	2,576
3.2 Sample inspired by moon surface round 2	3,87	15	2,748
4.2 Sample inspired by leather round 2	4,87	15	1,959
5.2 Sample without texture round 2	6,60	15	2,667
6.2 Sample with symmetrical lines round 2	5,27	15	2,685
7.2 Sample with symmetrical wavy lines round 2	3,93	15	2,154
8.2 Sample with symmetrical holes round 2	6,27	15	2,154
9.2 Sample with symmetrical spikes round 2	5,53	15	1,846

Figure 5.2-12 Mean ranking score of all textures

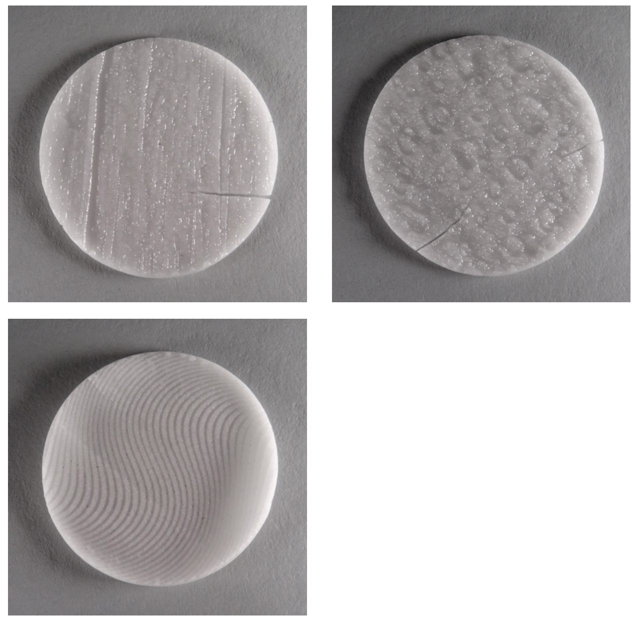


Figure 5.2-13 Visually and tactually pleasing textures

Round 3: Visual and tactual exploration with light

Temporary ranking order from most pleasant to least pleasant is (figure 5.2-14):

1. Wood
2. Leaf
3. Wavy lines
4. Moon surface
5. Leather
6. Straight lines
7. Untextured
8. Spikes
9. Holes

Friedman test does measure a great significant difference between the 9 samples (p = 0.000).
The Wilcoxon signed rank test and the Paired sample T-test will clarify which sample are significantly different from one another.

19 significantly different pairs were found from the 36
Wood was found significantly more pleasant than:

- Wavy lines (p = 0.022)
- Moon surface (p = 0.036)
- Leather (p = 0.003)
- Straight lines (p = 0.002)
- Untextured (p = 0.002)
- Spikes (p = 0.001)
- Holes (p = 0.001)

Leaf was found significantly more pleasant than:

- Untextured (p = 0.035)
- Spikes (p = 0.004)
- Holes (p = 0.003)

Wavy lines was found significantly more pleasant than:

- Straight lines (p = 0.003)
- Untextured (p = 0.003)
- Spikes (p = 0.003)
- Holes (p = 0.001)

Moon surface was found significantly more pleasant than:

- Untextured (p = 0.043)
- Spikes (p = 0.003)
- Holes (p = 0.005)

Leather was found significantly more pleasant than:

- Spikes (p = 0.005)
- Holes (p = 0.004)

But there were no significant differences found between 1 and 2, 2 – 5 and 6 – 9. Meaning that any of the first 2 samples (wood and leaf) can be as visually and tactually pleasing in the light as unpleasing (figure 5.2-15).

Round 3: Visual, tactual & light

	Mean	N	Std. Deviation
1.3 Sample inspired by wood round 3	2,27	15	1,280
2.3 Sample inspired by leafs round 3	3,73	15	2,463
3.3 Sample inspired by moon surface round 3	3,87	15	2,446
4.3 Sample inspired by leather round 3	4,73	15	1,944
5.3 Sample without texture round 3	6,53	15	2,615
6.3 Sample with symmetrical lines round 3	6,00	15	2,268
7.3 Sample with symmetrical wavy lines round 3	3,73	15	2,017
8.3 Sample with symmetrical holes round 3	7,27	15	1,710
9.3 Sample with symmetrical spikes round 3	6,87	15	1,457

Figure 5.2-14 Mean ranking score of all textures

Figure 5.2-15 Visually and tactually pleasing textures when held in the light

So, the sample which were the most pleasing per round were:
Visually the most pleasing

- Wavy lines
- Leather
- Leaf
- Wood
- Straight lines
- Holes

Visually and tactually the most pleasing

- Wood
- Moon surface
- Wavy lines

Visually and tactually the most pleasing in the light

- Wood
- Leaf

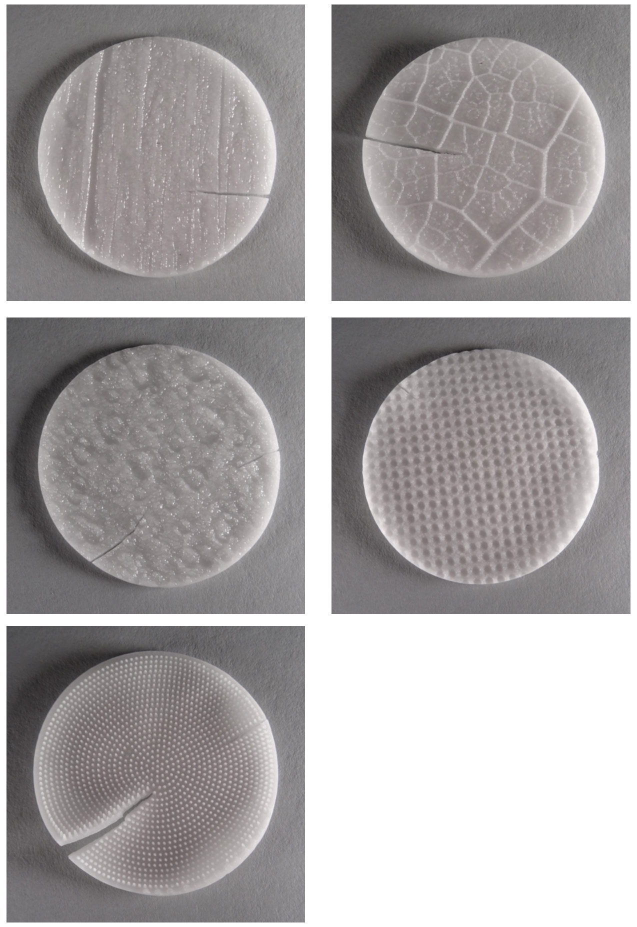


Figure 5.2-16 Textures which were experienced as more pleasant in specific rounds

Between rounds

Wood, Leaf, Moon surface, Holes and Spikes had significant differences between rounds (figure 5.2-16).

Wood was experienced as most pleasant when interacting

- Visually and tactually or (p = 0.031)
- Visually and tactually in the light (p = 0.003)
- Not only visually

Moon surface was experienced as most pleasant when interacting

- Visually and tactually or (p = 0.029)
- Visually and tactually in the light (p = 0.032)
- Not only visually

Leaf was experienced as most pleasant when interacting visually and tactually in the light not only visually and tactually (p = 0.002).

Spikes was experienced as most pleasant when interacting visually and tactually not visually and tactually in the light (p = 0.014).

Holes was experienced as most pleasant when interacting only visually not visually and tactually in the light (p = 0.024).

Emotions

The emotions mentioned during the test are visualised in figure 5.2-17 when they were mentioned at least 5 times.

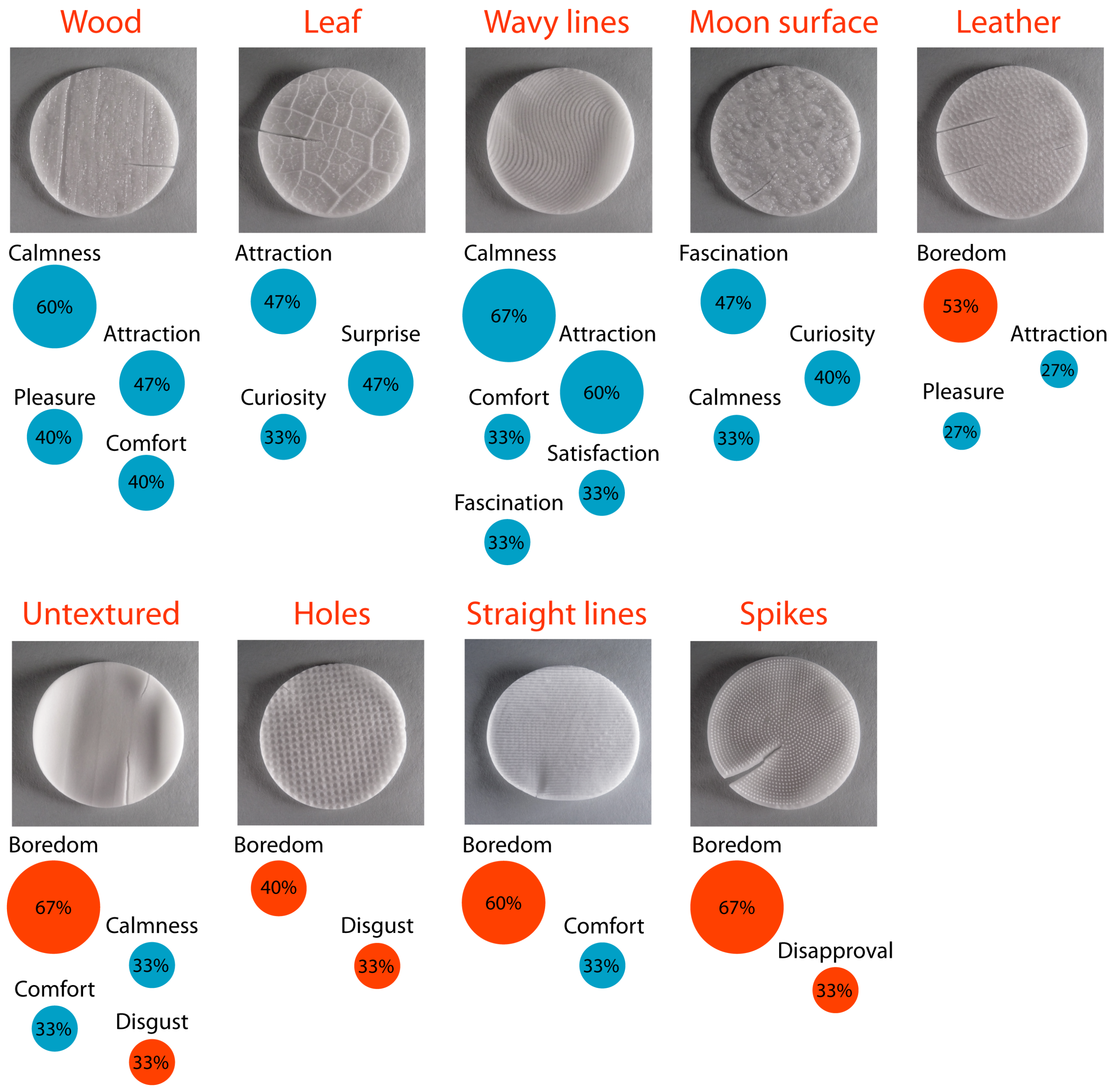


Figure 5.2-17 *Emotions felt per sample*

Discussion

Visual pleasantness

6 out of 9 sample were found to be as visually pleasant as unpleasant to each other. Meaning 6 of the 9 samples did not have a significant difference in visual pleasantness so they could all be implemented in an object that has a purely decorative function.

There were samples which were experienced as visually more pleasing than Moon surface, Untextured and Spikes. So, these three samples are preferably not used in an object with a purely decorative function.

Moon surface was found visually less pleasing because of the unrecognizability it brings. People could not identify what is was making other samples which were recognizable more appealing.

Untextured was found visually less pleasing because it was experienced as boring. Especially when put next to interestingly textured samples.

Spikes was experienced as visually less pleasant because people found it boring since they could expect what it would feel like when touching it. It was also found less pleasing because it looked like something that might hurt the user when they touch it. It did not appear to be a texture made for human interaction.

No difference between the other 6 samples was found because when ranking something on visual appearance it is mostly based on personal aesthetic preference and to be able to really measure a significant difference more participants should be put through the test.

Visual and tactual pleasantness

3 out of 9 samples were found to be as visually and tactually pleasing as unpleasing. Meaning 3 out of the 9 samples did not have a significant difference in visual and tactual pleasantness so they could all three be implemented in an interactive object.

There were samples which were experienced as visually and tactually more pleasing than Leather, Straight lines, Spikes, Leaf, Holes and Untextured. So, these 6 samples are preferably not used in an interactive object. The samples were mostly experienced as less pleasing because of sensory incongruence (Holes, Leaf, Untextured), negative associations (Straight lines, Holes) and a boring or less exciting tactual stimulation (Straight lines, Spikes, Leather, Untextured).

Wood, Moon surface and Wavy lines were found visually and tactually more pleasing because they felt smoother compared to the other samples and they also created an urge to explore.

Visual and tactual pleasantness when explored in the light

2 out 9 samples were found to be as visually and tactually pleasing as unpleasing when held in the light. Meaning 2 out of the 9 samples did not have a significant difference in visual and tactual pleasantness when exploring in the light, so they could all two be implemented in an interactive object which uses or contains light.

There were samples which were experienced as visually and tactually more pleasing when explored in the light than Leather, Moon surface, Straight lines, Wavy lines, Spikes, Holes, and Untextured. So, these 7 samples are preferably not used in an interactive object which uses or contains light. The samples were mostly experienced as less pleasing because they were experienced as boring or less exciting when held in the light.

Wood and Leaf were found visually and tactually more pleasing when held in the light because it would unveil the depth of the texture. Organic textures created in a computer modelling program have depth since they are made up out of tiny triangular surface which create dimension. Symmetrical or geometrical shapes are made up out of larger flat surfaces which do not create dimension and depth when held in the light being less exciting.

Pleasantness between rounds

5 samples required specific methods of interaction for them to be experienced as pleasant. Meaning some textures should be explored a certain way preferably to the other exploration method to create a positive experience.

When interacting with Wood it should be done visually and tactually. This can be in the light or without light as long as it is explored tactually as well. Only exploring it visually created calmness but the texture really distinguished itself from the others when it was explored tactually unveiling how pleasant the surface texture was compared to the other samples.

Moon surface should be explored visually and tactually. This can again be in the light or without light as long as it is explored tactually as well. Only exploring it visually created disbelief since it was an unrecognizable texture for many of the participants. Associations could be formed when the texture was touched making it more recognizable and less unsettling.

When interacting with Leaf it should be done visually and tactually in the light. The texture was not experienced as pleasant during the visual and tactual round but when exploring it in the light the overall pleasantness went up making it a more pleasant experience.

Spikes should be explored visually and tactually without light. For most participants the texture became more boring, however for some it created an unsettling sensation leading to them potentially feeling physically unwell.

Lastly Holes should be explored only visually. The texture was experienced as being tactually unpleasant and disgusting and adding a light source lowered the level disgust but the texture became very boring because of it.

Emotions

The organic textures mostly elicited positive emotions.

Wood and wavy lines mostly elicit calmness because of calming associations like the forest, waves and nature. They also elicit attractions because people like nature and it looks recognizable but also just different enough. The pleasure and comfort are felt because of the pleasant tactility of both samples.

Moon surface elicits fascination and curiosity because it was unclear what the texture was exactly. But when holding it in the light it became clear and started to look like something from outer space, which people find fascinating.

Leaf elicits attraction and surprise. This is because it is associated with nature or biological patterns which people find attracting. When holding it in the light the depth of the texture is shown and it becomes more clear that it is a leaf which elicits surprise.
Leather elicits boredom because people expected what they would experience when touching or holding in the light. It dose elicit attraction because of the association with leather. The leather sample also elicits pleasure because of the pleasant tactility and the association with leather.

The symmetrical textures elicited more negative emotions.

Untextured, Straight line, Holes and Spikes all elicit boredom. This was mainly because of the repetition and the recognizability of the samples. The samples were also not as tactually stimulating as others and nothing happened when holding the samples in the light.

Untextured and Straight lines elicit comfort and calmness because of the simplicity of the samples.

Holes and Untextured elicit disgust. This was because of the unpleasant roughness of the samples but also because they were associated with dirty makeup wipes or medical patches.

Lastly Spikes elicits disapproval. This was mainly because it was experienced as a texture that could potentially harm someone. So it was labelled as something that should not be implemented in consumer products since it cannot be trusted.

5.3 CONCLUSION

The purpose of this test was to research the effect of light and the manipulated surface textures on the perceived sensorial pleasantness of the material.

Hypothesis 1
It was expected that the sensorial incongruence of the material could be removed by adding surface textures. Since it would visually communicate the roughness and relief creating a more pleasant experience

It was found that the textures can remove the incongruence. However, some still had an incongruence so not all textures will. Most textures that had a sensorial incongruence were the ones that looked very textured but felt relatively smooth.

When implementing a texture that looks rough or textured it should also feel this way otherwise it is experienced as less tactually stimulating than expected creating an untrustworthy experience.

It was found that mostly the organically shaped samples with unstructured relief and displacements had removed sensory incongruence.

Hypothesis 2
It was expected that the surface texture of the material would be perceived as smoother when it creates slip. Meaning when the actual contact area is smaller because of the surface relief, resulting in a more pleasant experience.

It was found that textures can improve the tactual experience making it appear to be tactually smoother. This was done by creating slip as was clearly noticed when touching Spikes, Straight lines and Wavy lines.
However the tactual experience was not immediately perceived as more pleasant because of sensory incongruence. People expected more stimulation making the samples untrustworthy and boring.

So the perceived smoothness of a surface can be influenced by adding textures but this does not always create a positive or pleasant tactile experience.

People preferred rough looking and also slightly rough feeling over rough looking and smooth feeling.

Visually
Some design guides for visually pleasing textures have been set up based on the results of the research.

The textures should be at least somewhat recognizable. This is necessary for people to be able to create associations and understanding, otherwise it will result in an unsettling experience.

The textures should be relatively interesting. Meaning samples with a repetitive texture will be found boring when put next to samples with organic textures. However, repetitive textures can be very soothing and aesthetically pleasing when put in the right environment. So, how the texture is perceived will also depend on other textures in the same environment.

Lastly the textures should appear to be made for human interaction. Not like something that can possibly hurt someone

Visual and tactual
Some design guides for visually and tactually pleasing textures have been set up based on the results of the research.
The textures should not create sensorial incongruence since this will create a negative experience. So it should not look rough and feel smooth or look smooth and feel rough.

The textures should not elicit negative associations. Some of the samples were for example associated to dirty makeup wipes or medical patches creating an unsettling and negative experience.

When samples are textured they should be tactually stimulating and not boring or less exciting than expected.

Lastly more organic shapes with irregular displacements were perceived as tactually pleasing.

Visual and tactual with light
The textures should unveil depth and dimension, when incorporating light into the interaction. The organic textures had more depth so were perceived as more pleasing.

CHAPTER 6
PRODUCT CONCEPT

This chapter will describe the ideation process, the concepts that resulted from the ideation and the final concept.

6.1 IDEATION

A brainstorm session was conducted. During this session ideas were created which reflect the material experience vision.

The vision aims to create an experience which is tactually pleasing and has a hidden feature unveiled through the translucency of the material. The translucency will unveil de hidden feature so the brainstorm is based of developing ideas based on "Hidden features" and "Emphasizing translucency".

The brainstorm was divided into three rounds and conducted with 3 Integrated Product Design students and the author of this report (Integrated Product Design). During the first two rounds of the brainstorm the material was not jet given to participants. This allowed for the creation of ideas unrelated to the restrains and capabilities of the material. During the third round the participants were given the material before ideation but no explanation about the material was given.

The first round was a warm up round where knowledge was gathered on what people touch often and on what they would create using 3D printing and ceramics.
The questions for this round were:
- What would you create using 3D printing?
- What would you create with ceramics?
- What do you touch often in you daily life?

The second round of the brainstorm was based on the 6-3-5 brainstorming method. Meaning 6 people coming up with 3 ideas each in 5 minutes. However, the design challenges of this brainstorm were too complicated to be able to come up with 3 ideas in 5 minutes. So, the time was set to 9 minutes for 3 ideas. So, the brainstorm will be conducted with 4 people which will come up with 3 ideas each in 9 minutes making it the 4-3-9 method.

The design challenges of this round were:
- Create something that comes in contact with light and is made from a translucent and tactually pleasant material
- Create something that comes in contact with liquids and is made from a translucent and tactually pleasant material
- Create something that covers, shields or divides and is made from a translucent and tactually pleasant material
- Create something that has a hidden feature or message and is made from a translucent and tactually pleasant material

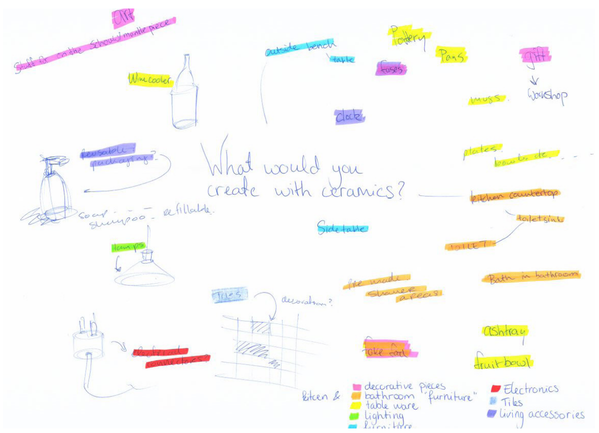
The participant were given a sample of the material for the third round of the brainstorm. The challenge for this round was to:
- Create something from this material

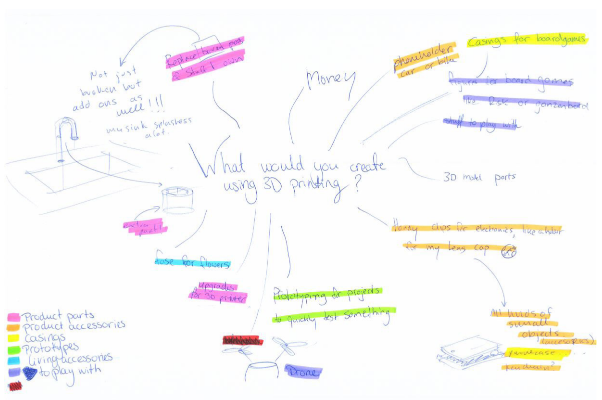
When all rounds were executed it was time for the participants to explain what they came up with. They would discuss the ideas and during this step the ideas could be further developed by adding on to them, combining them or altering them.

All results of the brainstorm can be found in appendix Q & R.

The object types which had overlap between the 3 questions from round 1 can be possible product fields to implement the material into. These objects types are (figure 6.1-1):
- Table ware
- Objects to play with / games
- Casings / electronics casings
- Product parts / handles for kitchen & bathroom furniture
- Product parts / controls and switches for lighting
- Lighting

Some interesting takeaways from the first round of the brainstorm are:
- When 3D printing people mostly print small functional parts or parts to play with which is logical because of the size constrains of the printers.
- Small parts made from ceramics are mostly product parts like handles and knobs and table ware like cups, saucers and bowls.





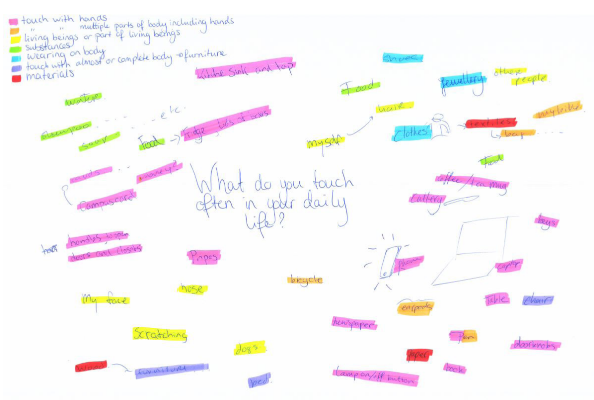
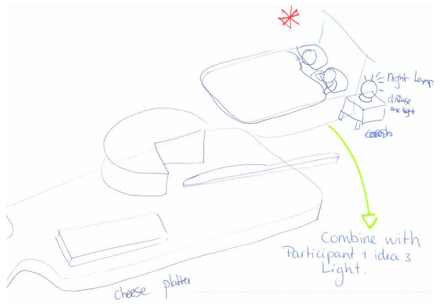
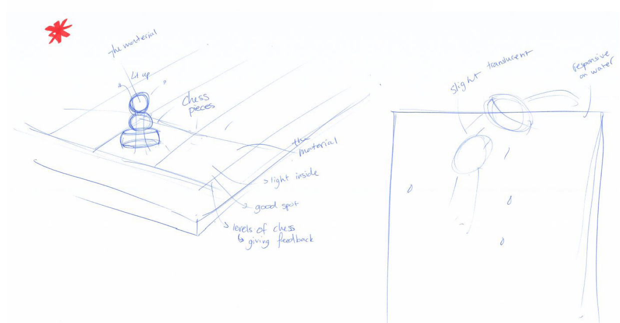


Figure 6.1-1 *Brainstorm results round 1*

At the end of round 2 the participants were asked to mark their preferred ideas. These preferred ideas led to some design directions which can inspire the conceptualisation process.
- Casings which cover your electronics so you will not look at them
- Products with hidden functional information only shown when activated
- A waterfall shower with lights and textured knobs
- Portable touch activated lamps
- Lit up bike handles

An interesting takeaway from the second round is:
- Preferred hidden features are functional information or messages with an emotional value.





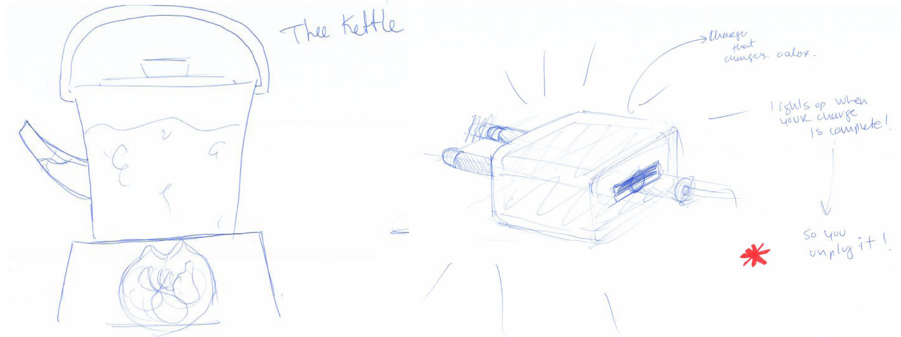


Figure 6.1-2 *Ideas created with the material in mind (round 3)*

During the last round the participants got 4 minutes to come up with as many ideas possible. They had to create a product with the Formlabs ceramic material. What the participants came up with was (figure 6.1-2):
- A chess game with chess pieces which light up when they are on the playing board. Two different colours of light to visualise the different players.
- A shower wall
- A side table lamp which is portable and touch activated
- Chopsticks
- A cheese platter
- Casing of a charger which lights up to communicate to the user when the device is charged

A takeaway from round three was that participants mostly redesigned known objects using this material and this was for several reasons:
- The material felt more luxurious compared to what the objects are made of currently
- The material diffused light in a nicer way compared to current materials
- The material was lighter than comparable materials (stone, marble, ceramics) and had a beautiful aesthetic, making the product-user interaction more comfortable
- The translucency of the material would make it possible to add extra functionalities like hidden lights

Some ideas were generated based on the takeaways and ideas of the brainstorm. These ideas can be found in appendix R.

6.2 DESIGN DIRECTIONS

The ideas generated after the brainstorm can be rewritten into design directions.

Design direction 1

Design direction 1 is to design an object which plays with the flow and movement of liquids (figure 6.2-1). These dynamic liquids will unveil the hidden feature, when using the object. The design direction is divided into different elements. Functional, performative and sensorial.

Functional

The function of the material is to provide information about the liquid. Being the amount, the flow, the colour, etc..
The hidden feature can be functional indicating, for example, the exact quantity of the liquid. But it can also be purely aesthetic.

Performative

This design direction encourages the user to move the object, moving the liquid around inside. The move should be functional as well as fun, making sure that the object is always moved instead of only ones or twice when it is still new.

Sensorial

The translucency of the material is emphasized by a liquid and the tactual pleasantness is created by implementing digitally modified surface textures.

Design direction 2

Design direction 2 is to design initially identical looking objects which become distinguishable when the hidden feature is unveiled (figure 6.2-2). The design direction is divided into different elements. Functional, performative and sensorial.

Functional

The function of the material is to communicate what the difference is between the initially identical looking object / parts. The difference between objects / parts is communicated by unveiling the hidden feature, making the hidden feature functional.

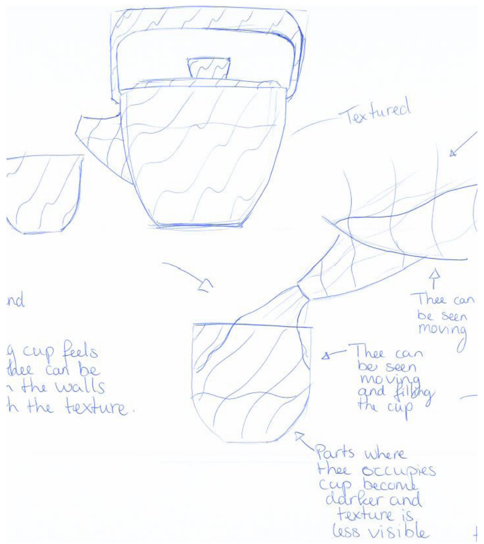


Figure 6.2-1 *Design direction 1*

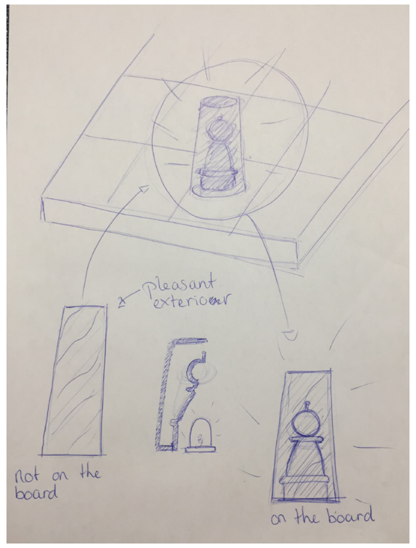


Figure 6.2-2 *Design direction 2*

Performative

The performative actions are dependent on how the translucency gets emphasized. So, can be:

- Moving object so liquid moves around
- Moving object so substance moves around
- Turning light on by moving, touching, stroking, pushing, etc.
- Moving object so it is hit by natural lighting
- Moving object so it will cover other objects

Sensorial

The translucency of the material can be emphasized in several different ways:

- By light
- By liquids
- By substances
- By covering something

The tactual pleasantness is created by implementing digitally modified surface textures.

Design direction 3

Design direction 3 is to design a daily used object with functional information, initially hidden and unveiled using light (figure 6.2-3). The functional information will be unveiled when the object is being used. The design direction is divided into different elements. Functional, performative and sensorial.

Functional

The function of the material is to provide information about for example, the product settings or product status. The product settings or product status are communicated by unveiling the hidden feature, making the hidden feature functional.

Performative

This design direction requires the user to touch, hold, move, stroke or push the object or parts of the object. By doing so the light inside is turned on unveiling the hidden feature.

Sensorial

The translucency of the material is emphasized by light and the tactual pleasantness is created by implementing digitally modified surface textures.

Together with the stakeholders design direction 2 was chosen. This direction was chosen because it was the most unique direction and it would give the opportunity to show, for example, multiple digitally modified surface textures or hidden features. Really showcasing the possibilities of the material in combination with the free form, high precision production method.

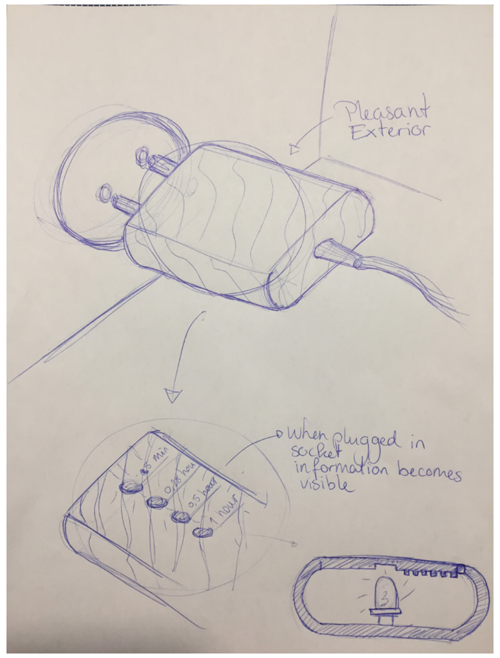


Figure 6.2-3 *Design direction 3*

6.3 CONCEPT DEVELOPMENT

The design direction chosen is translated into several concepts. The complete concept development can be found in appendix S.
The concepts had to meet the following design constraints, formulated based on the material characteristics, material experience vision and design direction.

- It is easily printable with the Formlabs SLA printers.
- The concept is a product set or a product made out of several pieces. These pieces will initially look identical.
- The pieces should need, invite, encourage touch
- The pieces should allow for holding and movement
- The human-product interaction is frequent and includes long contact between human and product, making a pleasant tactile stimulation more important.
- The pieces should have a function which emphasises translucency
- The pieces should include a hidden feature which becomes visible when translucency is emphasised
- The translucency is emphasized by a performative action taken by the user. These actions are tactual actions and can be moving, holding, touching, pushing, stroking, etc.
- The concept makes use of the full potential of the 3D printing technique in combination with the material.

The design constraints have to be followed. Unlike design constraints, wishes do not have to be followed. A brainstorm takeaway was formulated into a wish.

- The hidden feature is functional information or a message with emotional value.

The concept development started with a quick brainstorm on possible product sets and products made out of several pieces, visualised in figure 6.3-1 Not all product sets fulfilled the design constraints.
The ones that did were translated into product ideas visualised in appendix S.

Some ideas were more feasible to actually work, to be produced or were more interesting. To make sure that the ideas would actually work and could be produced all possible hidden structure types were listed in combination with how they can be unveiled, shown in figure 6.3-2.

The ideas that were not interesting or feasible were filtered out leaving 4 ideas further developed into concepts.

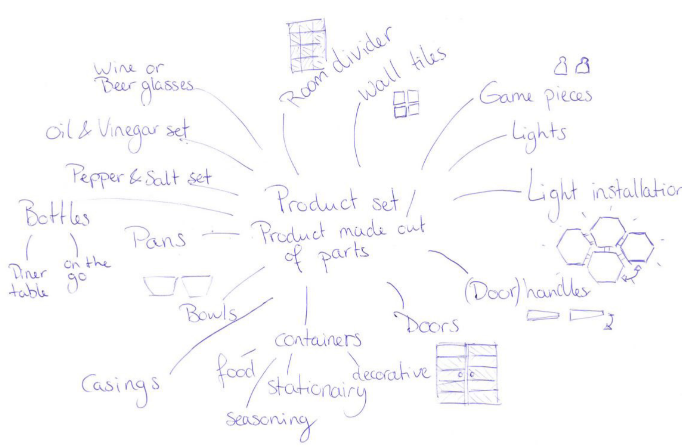


Figure 6.3-1 Products consisting out of multiple pieces

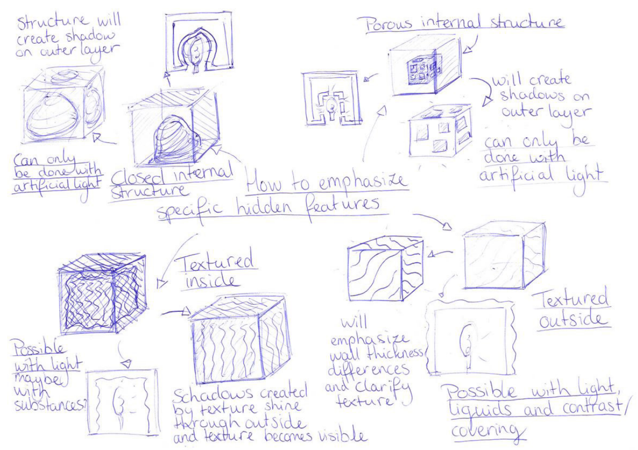


Figure 6.3-2 How to unveil specific hidden structures

6.4 CONCEPT 1: WALL LIGHT INSTALLATION

The wall light installation is a light installation made up out of different pieces connected to each other through magnets. Each component can be turned on and off separately. Some components have hidden features with emotional value and others hidden features which are aesthetic.

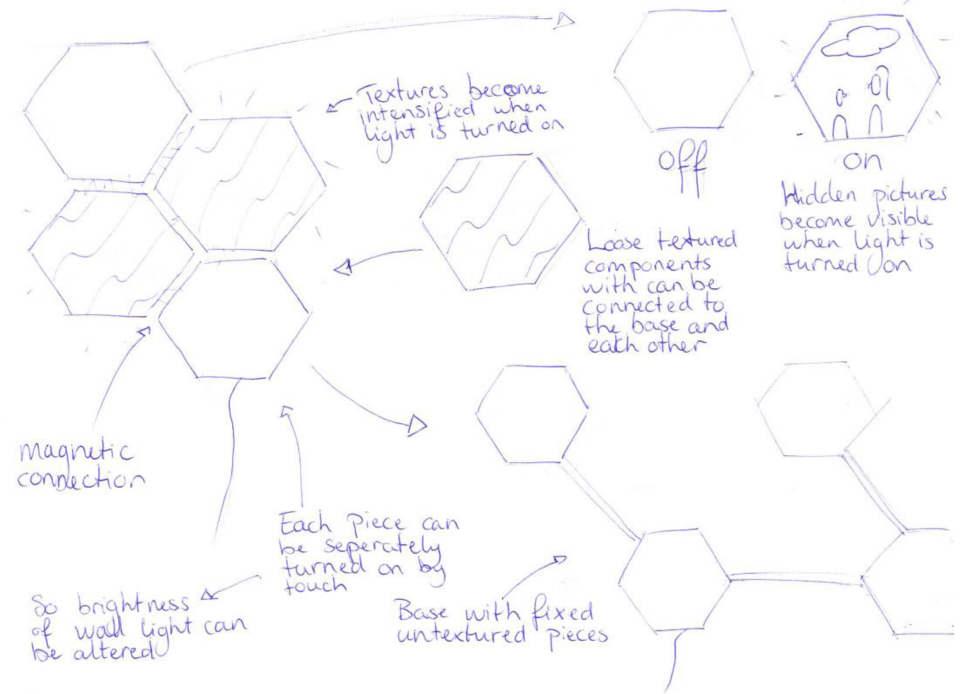
The wall light installation has a base with several fixed pieces. These pieces are untextured and cannot be moved. The light installation also consists of loose components which are pleasantly textured and can be moved around. The components can be connected to each other through a magnetic connection. The magnets get activated by placing the components next to each other.

This concept emphasizes the translucency of the material using light. The light source inside each separate component can be turned on and off. When turned on the translucency of the material is emphasized.

The hidden feature is unveiled when the lights are turned on. The untextured base components have engraved pictures on the inside, initially invisible. When the lights are turned on by touch the pictures become visible. Unveiling the hidden feature.
The digitally produced surface textures look quite calm and muted when the light is turned off but the textures become intensified when the light is turned on, showing every detail of the textures.

The brightness of the light installation can be altered and customised because each component can be turned on and off separately, by touch.

The movability of the separate components allows for light on location. Meaning rearranging the components in such a way that the component saturation is higher on one side than the other when more light is needed on that side.



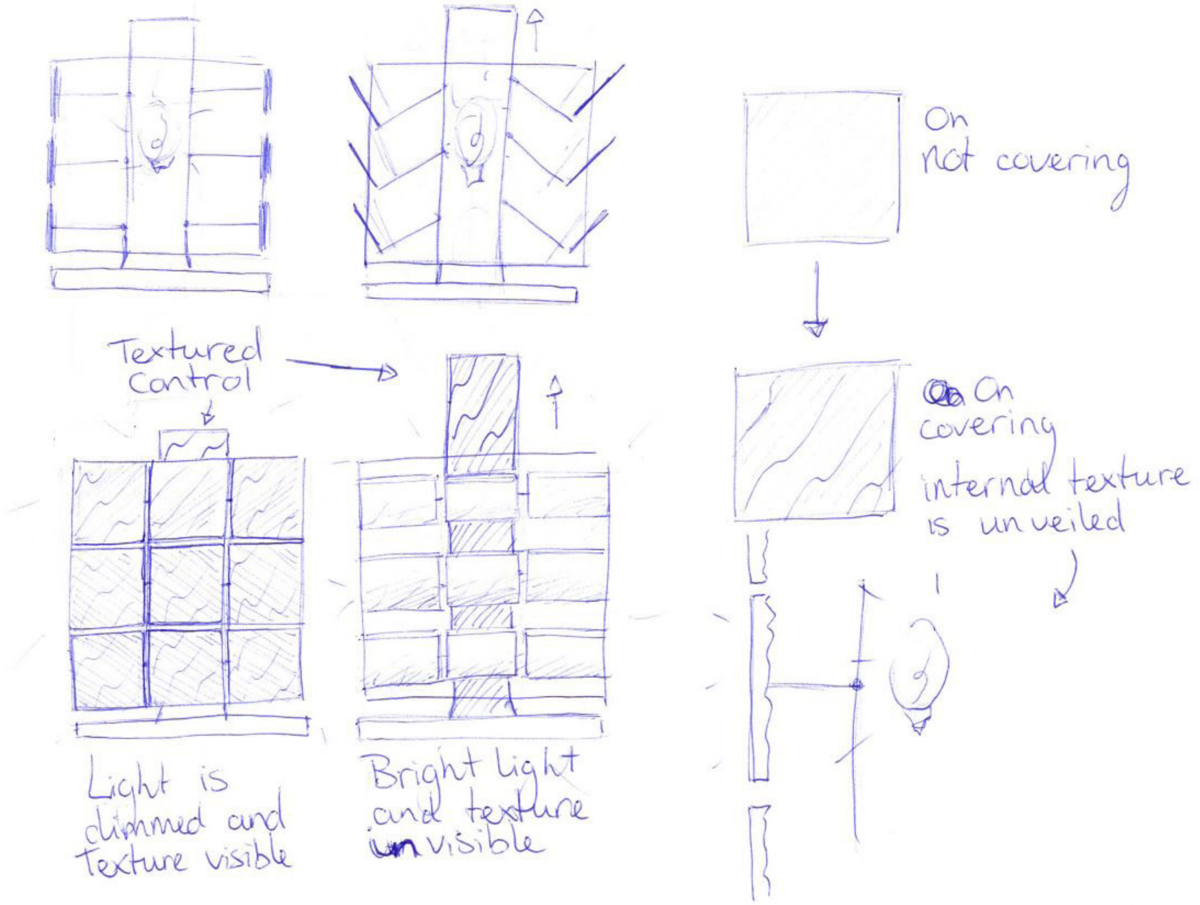
6.5 CONCEPT 2: TABLE LAMP

The table lamp is a lamp made up out of different pieces with a mechanism which allows for manual dimming by movement, could be through rotation, pulling, pushing, etc.. Some pieces have hidden features and others do not. The hidden features are aesthetic.

This concept emphasises the translucency of the material using light. The separate pieces can move, covering the light source or not. When covering the light source the translucency of the material is emphasized.

The hidden feature is unveiled when the pieces are covering the light source. Some of the pieces have a textured surface on the side phasing the light source. Slightly visible when the lamp is turned off but intensified when the light is turned on, showing every detail. Some pieces are untextured and the difference between the pieces becomes clear when the light is turned on.

The lamp is turned on by touching the pleasantly textured base. This base can be moved to activate the dimming mechanism. The lamp is dimmed by covering the light source with the individual pieces. The individual pieces are arranged in such a way that they open and close when the base is moved.



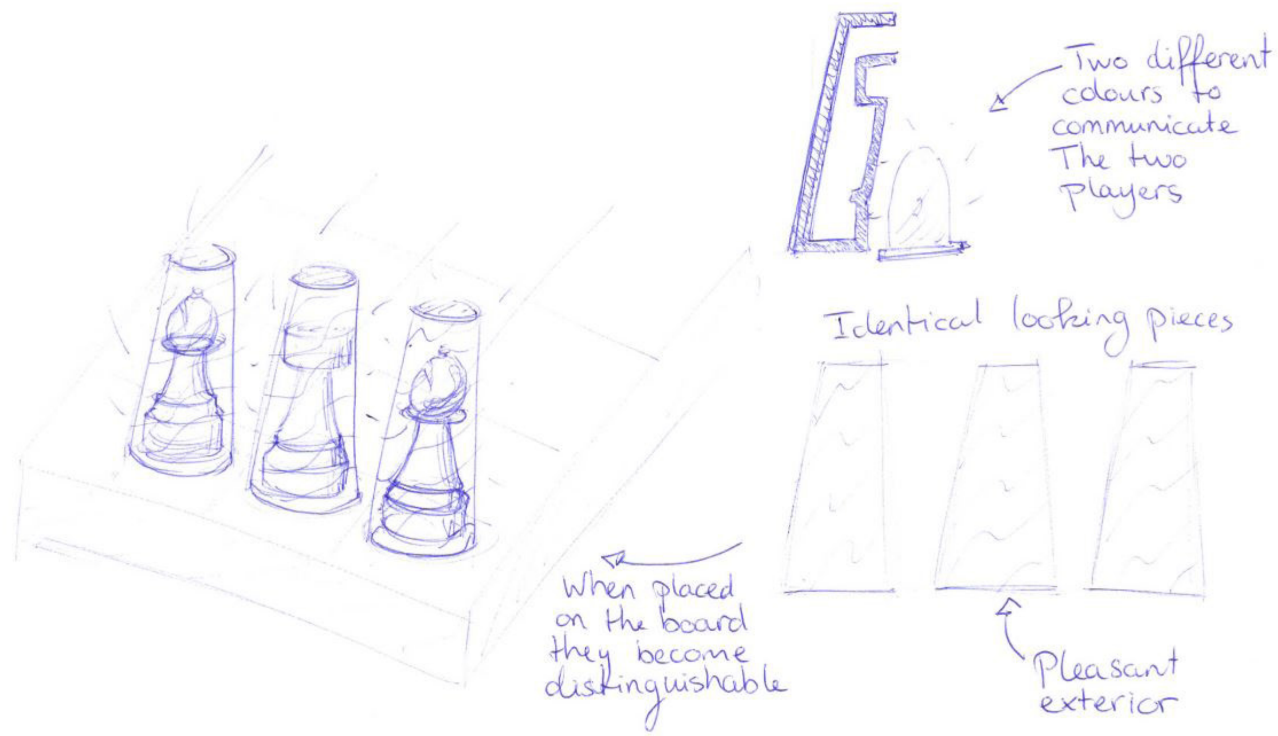
6.6 CONCEPT 3: CHESS PIECES

The chess pieces initially are identical. When playing chess and placing the pieces on the board the pieces can be distinguished because of LED's lighting up unveiling the hidden feature. The hidden feature is functional information.

This concept emphasises the translucency of the material using light. The chess pieces are hollow and contain LED's, invisible when the pieces are not placed on the board. When the pieces are placed on the chess board they are turned on, lighting up the pieces showcasing the translucency of the material. Two colours are used to communicate which pieces belong to which player.

The hidden feature is unveiled when the pieces are placed on the chess board. The pieces have a minimalistic design from the outside. However, each piece contains an internal structure which becomes visible when the LED's are lit. This internal structure indicates and clarifies what kind of piece it is.

Chess pieces are constantly touched and moved around, so the user is subject to a lot of tactual stimulation. So, the exterior of the pieces have digitally modified surface texture.



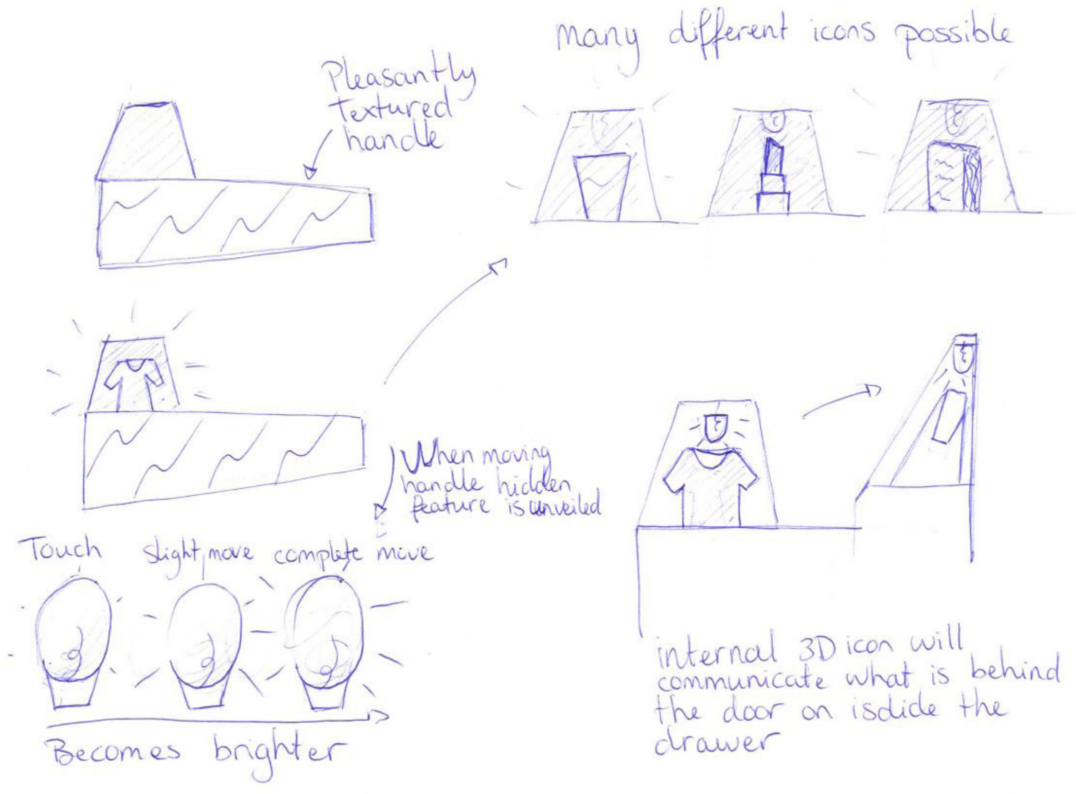
6.7 CONCEPT 4: DOOR OR DRAWER HANDLES

The door or drawer handles initially look identical and are made up out of a pleasantly textured handle and a small connection parts which contains the hidden feature. The hidden feature is hidden functional information.

The concept emphasises the translucency of the material using light. The connection part is partly hollow and contains LED's, invisible when the handle is not used. The LED's are turned on when the handle is touched or used, showcasing the translucency of the material.

The hidden feature is unveiled when the textured handle is touched, slightly moved or completely moved. The handle and connection part have a minimalistic design. However, the connection part contains an internal structure which becomes visible when the LED's are turned on. The hidden structure communicates what is behind the door on inside the drawer.

The LED's inside the connection part become brighter depending on the use, incrementally unveiling the hidden feature. When the handle is just touched the light source will shine barely unveiling the hidden feature slightly. This creates curiosity but it is also functional since it will already communicate what is inside the drawer or behind the door without having to move the handle at all. When the handle is moved slightly the LED's will become slightly brighter unveiling the hidden feature more. Lastly when the handle is completely moved the LED's will shine brightly unveiling the hidden feature completely.



6.8 DECISION MAKING

All concepts emphasize the translucency of the material, include tactile stimulation and have a hidden feature which can only be created using 3D printing, as was envisioned. However, some concepts are more fitting to the vision compared to others.

All concepts emphasize the translucency of the material, include tactile stimulation and have a hidden feature which can only be created using 3D printing, as was envisioned. However, some concepts are more fitting to the vision compared to others. How fitting they are is based on how many wishes they fulfil. The concept decision is made using the Weighed Decision Matrix. The scores given are from 1 to 4. The matrix is shown in figure 6.8-1.

The wish list for this design direction are:

1. All parts that are touched are tactually pleasing
2. The concept emphasizes the beauty of the digitally modified textures using light
3. The beauty of the digitally modified surface texture is still visible, when the hidden feature is unveiled
4. The concept encourages or requires intimate user-product contact
5. The hidden feature is functional information or a message with emotional value
6. The concept includes an exploring and playing aspect

The wishes are listed in order of importance.

Wishes		Concept 1		Concept 2		Concept 3		Concept 4	
#	Weight	S	V	S	V	S	V	S	V
1	0.25	2	0.50	4	1.00	4	1.00	4	1.00
2	0.20	4	0.80	4	0.80	3	0.60	2	0.40
3	0.20	4	0.80	4	0.80	2	0.40	3	0.60
4	0.15	3	0.45	4	0.60	2	0.30	3	0.45
5	0.10	4	0.40	1	0.10	4	0.40	4	0.40
6	0.10	3	0.30	4	0.40	3	0.30	2	0.20
Total	1.00		3.25		3.70		3.00		3.05

Figure 6.8-1 Weighed Decision Matrix

As can be seen the table lamp has the highest score. This is because the concept offers the possibility to show multiple textures because it is made out of different components. This is possible for most of the concepts accept the door or drawer handles.

Furthermore all parts which are touched have a pleasant tactility, unlike the wall light installation.
Furthermore all parts which are touched have a pleasant tactility, unlike the wall light installation.
Not all parts of the light installation have a textured exterior while all of them are still touched. This is because it was not possible to implement a texture on the components with the hidden feature. The hidden feature added was an engraved family picture on the inside of the components, since they are of emotional value. This hidden feature cannot be implemented when the component also has a textured exterior, since the images will merge and they will become unrecognizable. So, the components with the hidden feature had to be untextured. The problem is that they are touched to be able to turn them on so this is not ideal.

The textures implemented in the table lamp are beautifully emphasised when the lamp is used unlike the textures implemented in the door or drawer handles.
Here the textures can be emphasized but the users hand will cover most of the texture anyway making it impossible to emphasize the beauty during use.

Furthermore, the textures remain visible when the hidden feature is revealed since the textures are actually the hidden feature. The texture on the base also remains visible. This is not the case for the chess pieces, since the light is diffused by the internal structure. Light intensity or placing the LED's in between the internal and external layer might fix this but this is not certain.

The concept also requires intimate contact since the base has to be touched to turn on the light and the base is held and moved to dim the light. It is more intimate than the user-product contact of the other concepts, since two hands are used.

The hidden feature is not functional or of emotional value. This could be added by adding pictures, for example, but it was chosen to keep is aesthetic making the lamp a bit more calm.

Lastly the lamp includes an explorative feature. The separate pieces are dynamic and will play with the light. The textures on the inside of the pieces will translate differently depending on the position and angle of the pieces. So, the user can explore what the light does to the textures when moving the pieces.

6.9 FINAL CONCEPT

Design

The principle of dimming a light by covering it with separate components was inspired by a light installation shown in figure 6.9-1. This installation allows for touch and the interaction is actually functional since it is dimming the light or making it brighter.

Shape

The design of the lamp consists of a tactually pleasing base and several separate components which form the lamp shade. Images from some dynamic lamp designs were searched to get inspired (figures 6.9-2 - 6.9-6). These dynamic lamps all consist of a lamp shade made up out of multiple pieces which move.

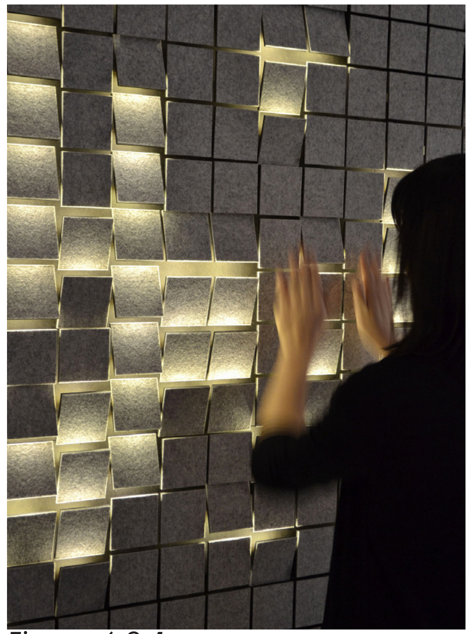


Figure 6.9-1 Interactive light installation
From FuoriSalone | Milano 2014. Retrieved from https://www.pinterest.se/pin/136937644900183270/?lp=true. Copyright 2014 by FuoriSalone

Figure 6.9-4 Penta lamp by Luca Casarotto

Figure 6.9-2 Moon Lamp by Verner Panton

Figure 6.9-3 honeycomb lamp
From Light of Inspiration : A Light Design That Was Inspired by Spain. Retrieved from http://www.tuvie.com/light-of-inspiration-a-light-design-that-was-inspired-by-spain/

Figure 6.9-5 Poul Henningsen's Artichoke Lamp

Figure 6.9-6 IKEA PS 2014 lamp

The lamp that was found most interesting was the pine cone looking lamp. Since, it would be relatively easy to produces the separate components. Furthermore, the amount of components allows for the implementation of the textures and the textures would be properly visible when the light is turned on, because they are not completely covering each other.
So, more pine cone looking lamps were searched to find table versions and a variety of component shapes. The lamps found are shown in figures 6.9-7 - 6.9-11.

The final component shape and lamp shade composition is based on the lamp shown in figure 6.9-10. This lamp has components which aren't curved which makes it a more geometric whole. It also creates bigger gaps between the separate components allowing for more light coming through and actually reaching the component at the top unlike the one shown in figure 6.9-9.

The lamp shown in figure 6.9-10 has 5 layers and each layer has 5 components coming to a total of 25 components. There is not enough time to produce this many components so the final table lamp will get 4 layers which each layer containing 4 components, coming to a total of 16 components.

Figure 6.9-10 Pinecone table lamp
From Flower lamp bed lamp Pinecone lamp by ArtLaserUA Retrieved from https://www.etsy.com/nl/listing/518448391/bloem-lamp-bed-lamp-pinecone-lamp?ref=landingpage_similar_listing_top-3 . Copyright 2019 by Etsy, Inc.

Figure 6.9-11 La Pigne by Woolights
From La Pigne | pine cone pendant light by Birch plywood. Retrieved from https://www.woolights.com/store/?product/page/3302/La+Pigne . Copyright 2017 by Woolights

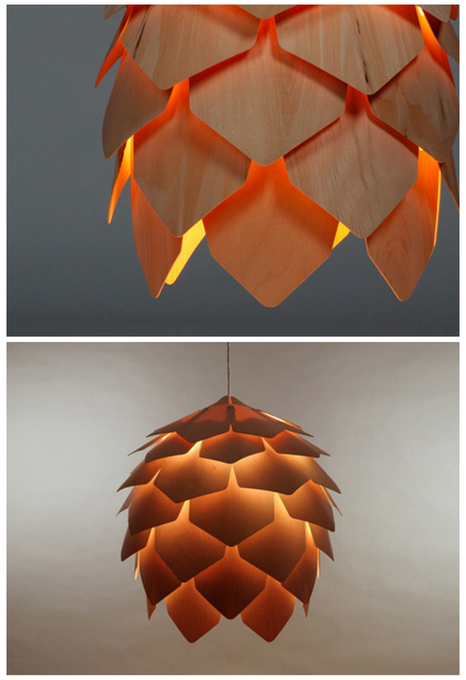


Figure 6.9-7 Pinecone lamp
From Pinecone lamp Retrieved from https://nl.pinterest.com/pin/512354895106296585/

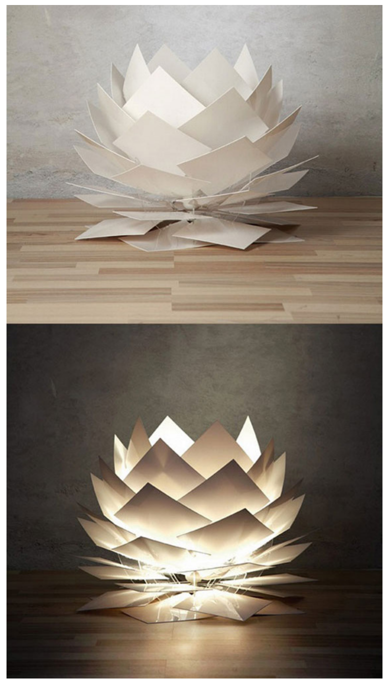


Figure 6.9-8 Pineapple Lamp by Frank Kerdil
From Pineapple Lamp by Danish designer Frank Kerdil. Retrieved from https://www.pinterest.it/pin/274227064787425224/?lp=true. Copyright 2016 by AJOUR & ITIDE

Figure 6.9-9 Vita Conia Mini Pendant Light
From Vita Conia Mini Pendant Light by Vita Lighting. Retrieved from https://www.amazon.com/Vita-Conia-Pendant-Light-White/dp/B011N1RDZY. Copyright 1996-2019 by Amazon.com, Inc. or its affiliates

The exact shape of each component was designed by making mock-ups of the components out of paper (figure 6.9-13). While making the mock-ups the size restrictions of the production process were kept in mind to assure that the components could actually be printed on a Formlabs printer. The components on each layer have a different shape. Making mock-ups out of paper created the possibility to actually see if different proportions and sizes worked together and allowed for fast alterations. Leading to the final 4 component types (figure 6.9-14).

The lamp has a mechanism which moves the components, opening and closing them. This mechanism should be connected to the components how this is done will be explained in the mechanism paragraph.

The shape of the base is dependant on the mechanism and the use. The components can be moved in several different ways. Most common movements are pushing, pulling, rotation, swinging and vibration. The lamp shade components could be opened and closed by pulling and pushing the base and this would most likely be done from the top, as is the case for the lamp shown in figure 6.9-12.

It does not have to be a very apparent button or control. It could also be a cord for example. To not disturb the design of the lamp this is actually preferred but it does mean that the user is actually only in contact with a very small part of the lamp not really being tactually stimulated. So, a different movement is preferred.

Figure 6.9-12 Bloom by Patrick Jouin
From Bloom Designed by Patrick Jouin. Retrieved from https://www.materialise.com/en/mgx/collection/bloom . Copyright 2019 by Materialise

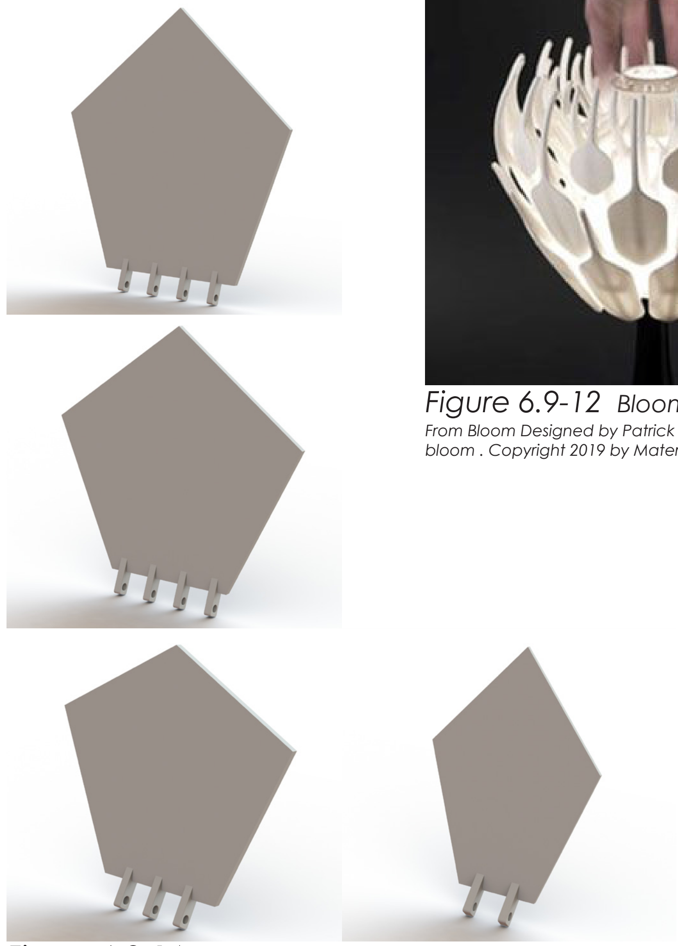


Figure 6.9-14 Final 4 component types (Leaves)

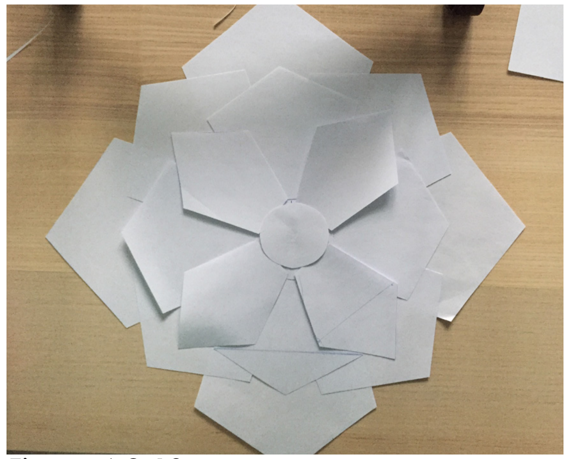


Figure 6.9-13 Lamp shade components mock-up

Rotation is better. When using rotation the control can be placed underneath the lamp shade. This way the lamp is balanced, design wise. Have a stable, bigger base and a small top. The shape of the base should be circular, since the base will be rotated. It can have some more geometric planes making it more into a polygon but the inner walls should be circular, it is not possible to rotate it otherwise. It was chosen to keep it simple and circular since the digitally modified surface texture will already make it interesting and busy enough. The base will be made out of several parts. The fixed base and the control which can be rotated. To assure that the lamp is not rotated as a whole. Only the control will have a digitally modified surface texture. The final design of the base is shown in figure 6.9-15.

Figure 6.9-15 Design of the lamp base

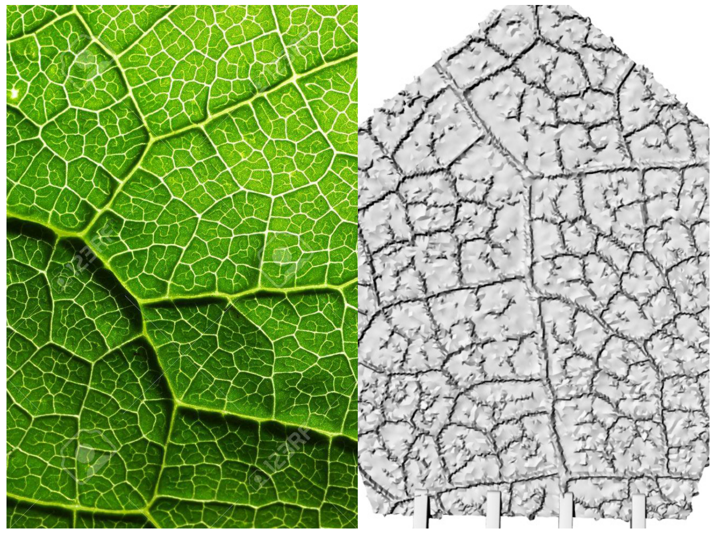


Figure 6.9-18 Leaf texture

Textures

The base and the lamp shade components of the lamp will be textured.

Not all lamp shade components will have a textured surface on the side facing the light source. Some will stay untextured. The difference between components is not visible when the light is turned off since the outside of each component is untextured and looks identical (figure 6.9-16). The difference is only unveiled when the lamp is turned on (figure 6.9-17). Two components on the first and second layers are textured and 4 components on the third and fourth layer are textured.

The texture chosen for the lamp shade components is a leaf texture (figure 6.9-18). This is chosen because it will fit the design of the lamp and also because it was concluded from the pleasant tactility research (chapter 5) that this texture was not perceived as tactually pleasing but definitely as visually pleasing when held in the light. The texture also elicited attraction and surprise. It is positive to use a texture which is attractive because it will encourage people to play with the lamp and explore how light effects the textures.

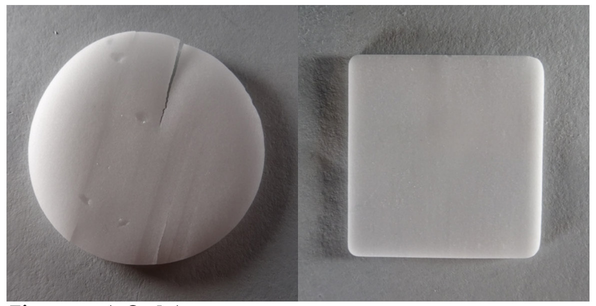


Figure 6.9-16 Components will initially both look smooth and untextured

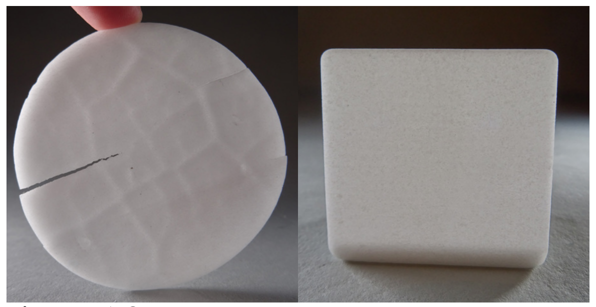


Figure 6.9-17 Texture is unveiled when light is turned on

The texture chosen for the base is the wood texture (figure 6.9-19). This texture makes the base look like the stem of the plant. The wood texture was chosen because it was concluded from the pleasant tactility research that this texture was found visually and tactually pleasing used with and without light. The wood texture elicits calmness and pleasantness. Meaning that the lamp will be a calming and aesthetically pleasing decorative piece but also a pleasant and calming product to use.

Mechanism

The lamp shade components will be moved by rotating the base. The components can be moved in several ways. It was chosen to move them in a way that they open an close like a lotus since this fits with the design (figure 6.9-20).

Figure 6.9-19 Wood texture

The mechanism should be mechanic since it is too time consuming and challenging to make an electrically powered mechanism. There are several mechanical mechanisms possible. Most are gear or collar mechanisms. Making a mechanism with gears will be to time consuming and is not possible within the available time. Using a collar mechanism is easier to produce but not desirable because the collars will always be visible and will be connected to the inside or outside of the lamp shade components possibly disturbing the light effects (figure 6.9-21).

Figure 6.9-20 Lotus flower opening

From Lotus flower begins to bloom at the Kenilworth Aquatic Gardens in Washington, DC. Photo by Tim Brown. Retrieved from https://www.flickr.com/photos/lip-photo-archive/27722827601/

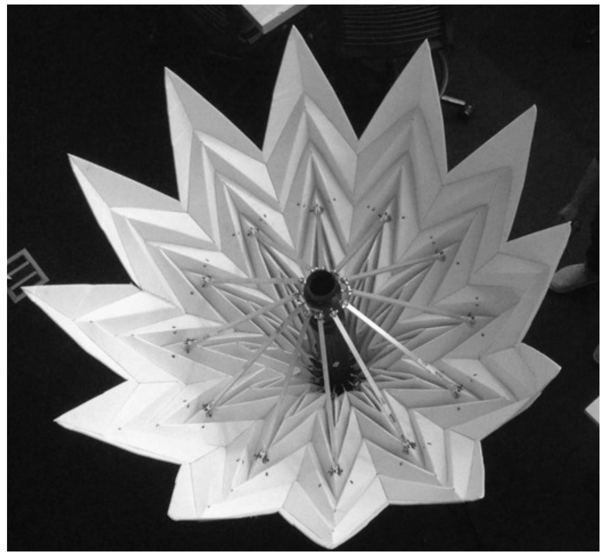


Figure 6.9-21 Mechanism with visible collars

From Botanical Engineering – Blumen Lumen. How to plant a giant, interactive flower garden in the middle of the Nevada desert by Joerg Student. Retrieved from https://labs.ideo.com/2014/07/10/botanical-engineering/

Another mechanism was found. The mechanism shown in figure 6.9-22. A profile with height variations will be rotated and the Y shaped profile will follow these height variations, going up and down. This linear movement created by the mechanism will push the lamp shade components up and down (figure 6.9-23).

The mechanism found was powered by a motor so it had constant movement and force driving it. The mechanism will not be constantly rotating inside this lamp. The base will be rotated to set the height of the lamp shade components and they should be able to stay at this set height. However, the lamp shade components will apply force onto the Y profile and this can lead to the profile sliding back down the ring causing the lamp shade components to drop rapidly hitting each other and the base, maybe even breaking as a result.

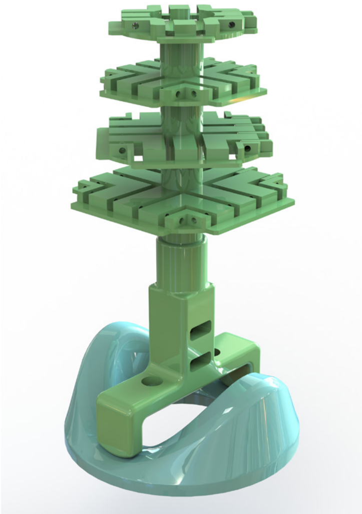


Figure 6.9-22 *Mechanism*

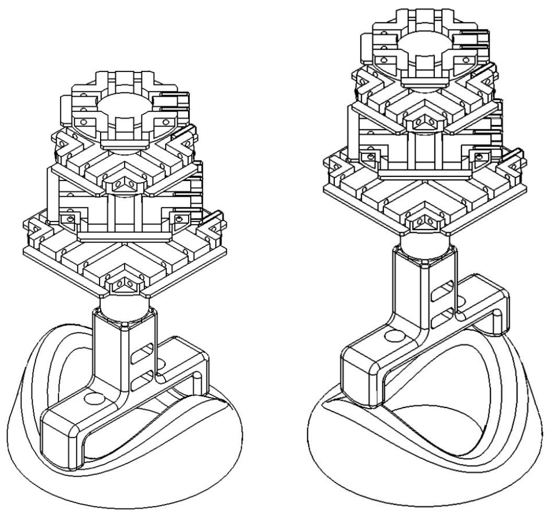


Figure 6.9-23 *Mechanism movement*

Friction is created to prevent this from happening. The mechanism is placed inside a container (yellow) and this container is placed inside another container (orange) holding the base of the lamp (figure 6.9-24). 4 small walls (orange) will be placed around the mechanism container (yellow) which will create slight friction (figure 6.9-25). Extra friction can always be created during assembly by adding small pieces of rubber for example.

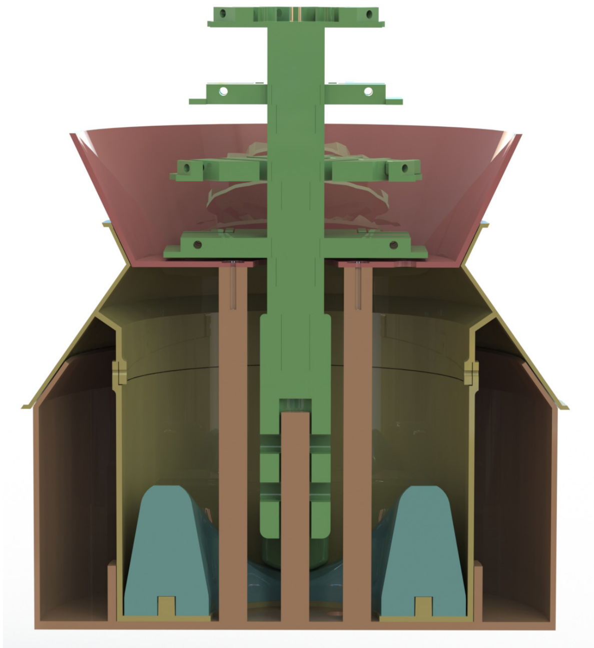


Figure 6.9-24 *Section view of mechanism and base components*

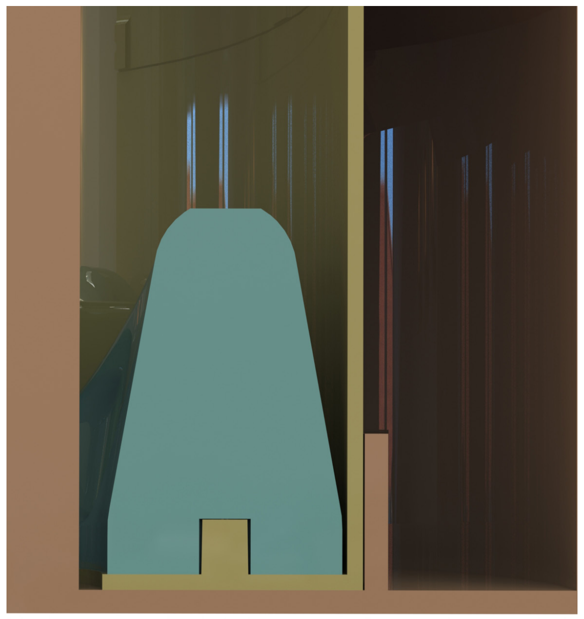


Figure 6.9-25 *Wall creating friction*

The components are opened and closed because of the base. They would just move up and down without opening or closing if there was no base. The walls of the base form a barrier, pushing up the lowest component layer, which in turn push up the layer above and so on, until all components are pushed up (figure 6.9-26). So, the lamp shade components are moved because of conflicting walls.

The complete assembly of the mechanism (green), lamp shade components (white) and base (yellow) is visualised in figure 6.9-27.

The lamp shade components will scrape past the walls of the base and past the walls of the other components (figure 6.9-28). So, they are subject to slight impact and wear during the move. It was tested that the material has relatively high impact strength and Formlabs states that the material is wear resistant so this should not be a problem. It will however, create an unpleasant sound of nails scratching a chalk board. So, it is necessary that the upper edge of the base and the outer points of the lamp shade components are covered. Most likely with a soft touch material like a smooth rubber. To prevent this from happening.

The final product will have a different mechanism which opens and closes the lamp shade components. It will probably work electronically allowing for the lamp to be smaller. So, the final design will be as showed in figure 6.9-29.

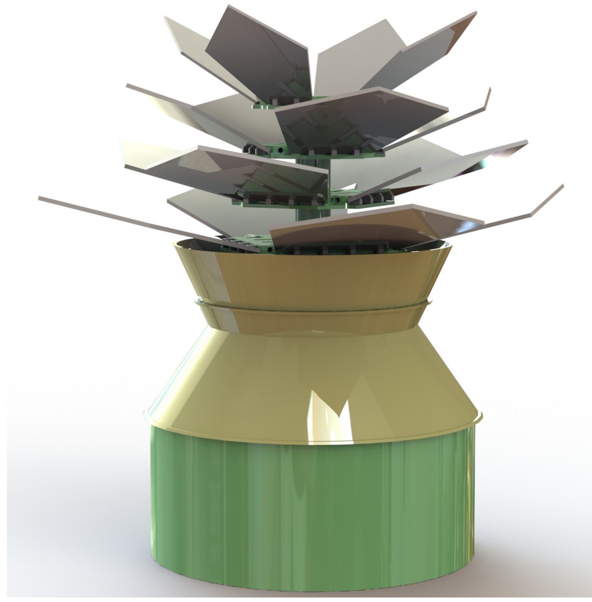


Figure 6.9-27 *Complete assembly: green is mechanism; yellow is base; white are lamp shade components*

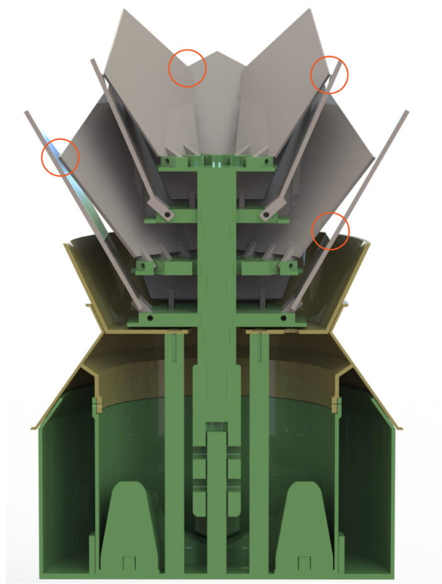


Figure 6.9-26 *Base and components pushing each other up*

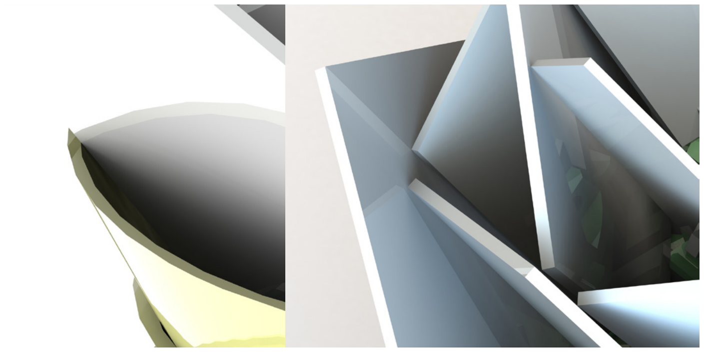


Figure 6.9-28 *Lamp shade components scraping past base and each other*

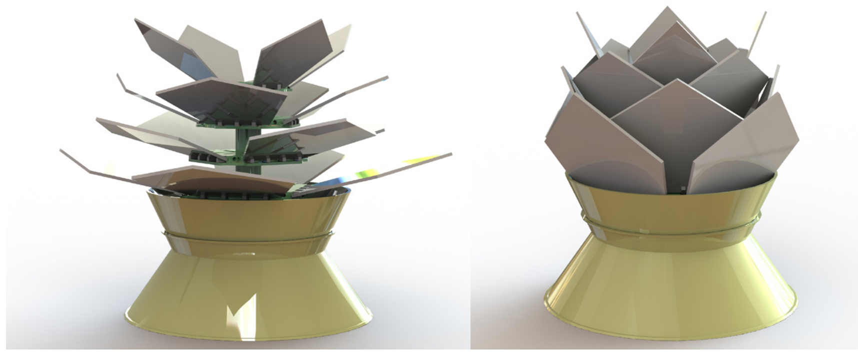


Figure 6.9-29 *Actual design, when smaller mechanism is incorporated*

Dimensions

The lamp opened with the mechanism base is 309,50 x 305,70mm (figure 6.9-30)
The lamp closed with the mechanism base is 193,90 x 295,50 mm (figure 6.9-31)
The lamp opened without the mechanism base is 309,50 x 225,90mm (figure 6.9-32)
The lamp closed with the mechanism base is 193,90 x 216,35mm (figure 6.9-33)

As mentioned before the actually lamp will be smaller. This is possible because of the smaller mechanism and actually also necessary to be able to produce the base of the lamp. The size restrictions of the printer are 14 x 15mm so the base cannot be bigger than this.
The actually dimensions of the lamp will be:
The lamp opened is 201,18mm x 146,85mm
The lamp closed is 126,05mm x 140,65mm

Figure 6.9-30 Opened with mechanism base

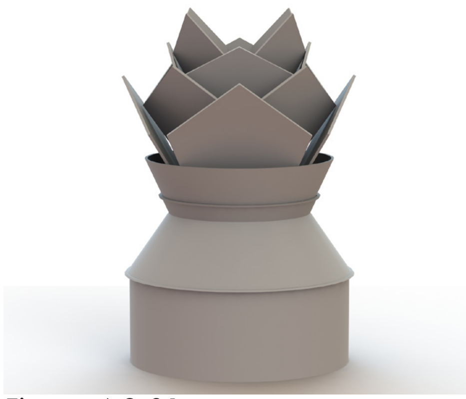


Figure 6.9-31 Closed with mechanism base

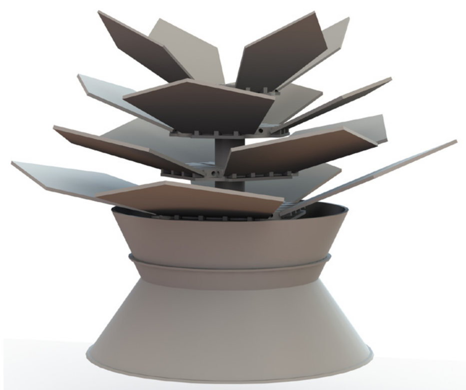


Figure 6.9-32 Opened without mechanism base

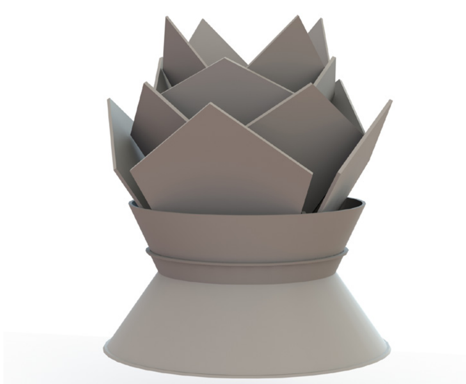
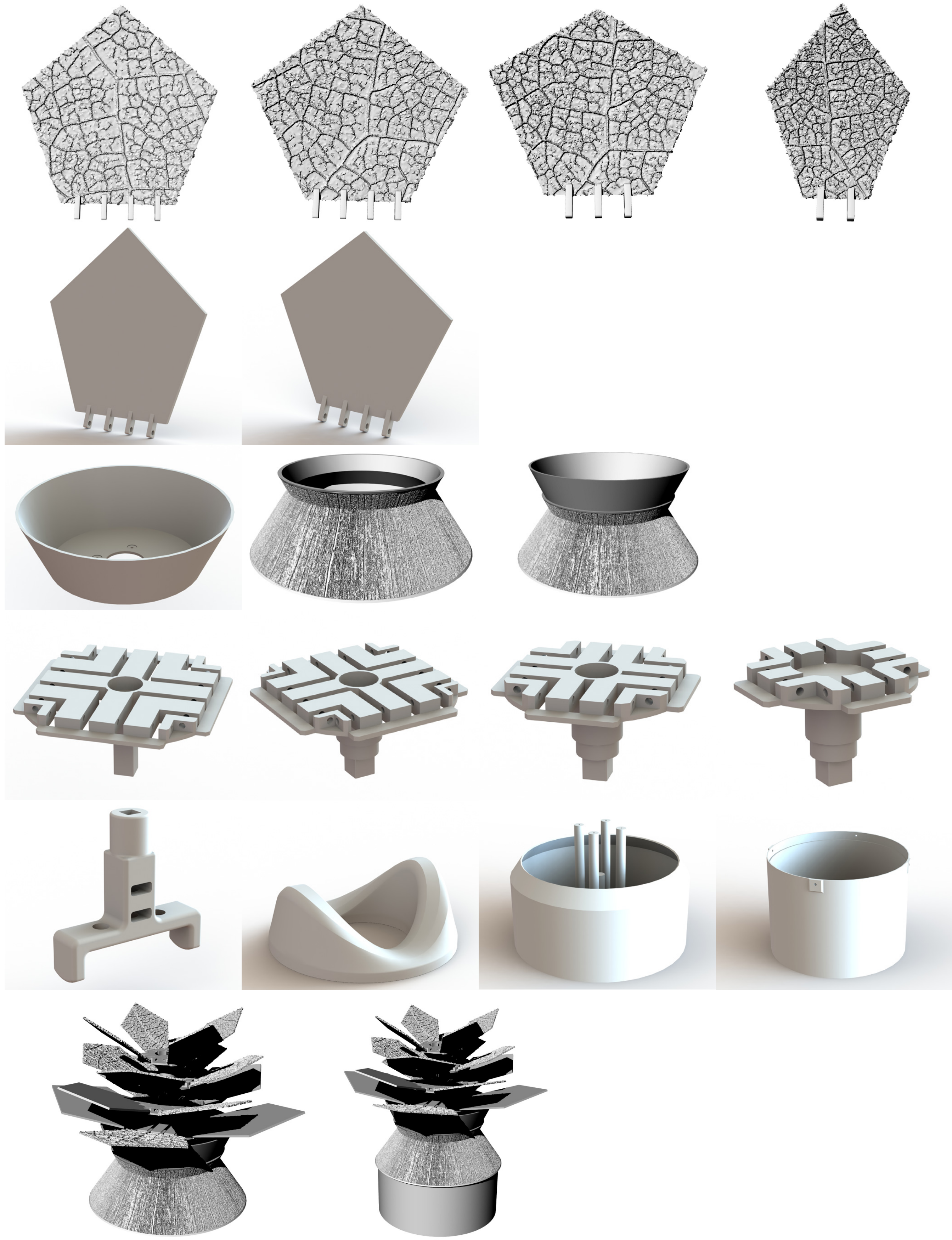


Figure 6.9-33 Closed without mechanism base

Parts

The final design and all the separate parts are shown below.



Use

The table lamp will be touch activated by touching the digitally modified surface texture on the base. Several LED's are turned on which will emphasize the translucency of the Formlabs ceramic material. The lamp can be manually dimmed. This is done by rotating the base of the lamp (figure 6.9-34). When rotating the base the separate components will move, opening up or closing (figure 6.9-35).

The textures on the inside of the components will become completely visible when the light is turned on and the components are closed (figure 6.9-36).

The base is also made from the Formlabs ceramic material, so when the lamp is turned on it will become slightly translucent because of some rays of light hitting it.

How the light hits the texture has effect on how emphasized it becomes. The light will create shadows making the texture visible (figure 6.9-37). When rotating the base the components will move changing their orientation relative to the LED's. This in turn will influence how the light hits the textured surface of the components influencing how intensely the textures are shown. The user can play and experiment with this by rotating the base.

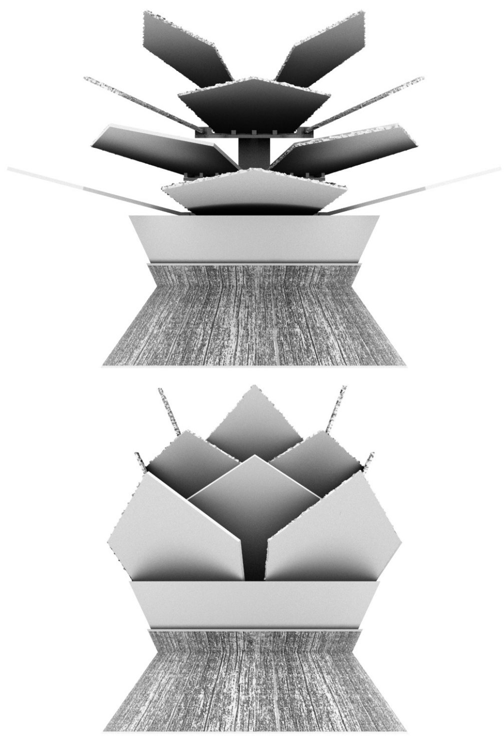


Figure 6.9-35 Open and closed state of the lamp

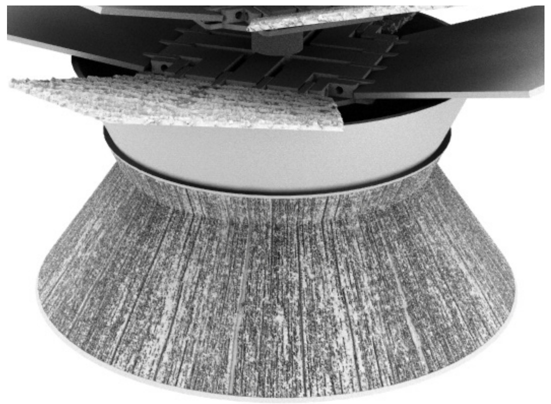


Figure 6.9-34 Base which can rotate to open and close the lamp shade

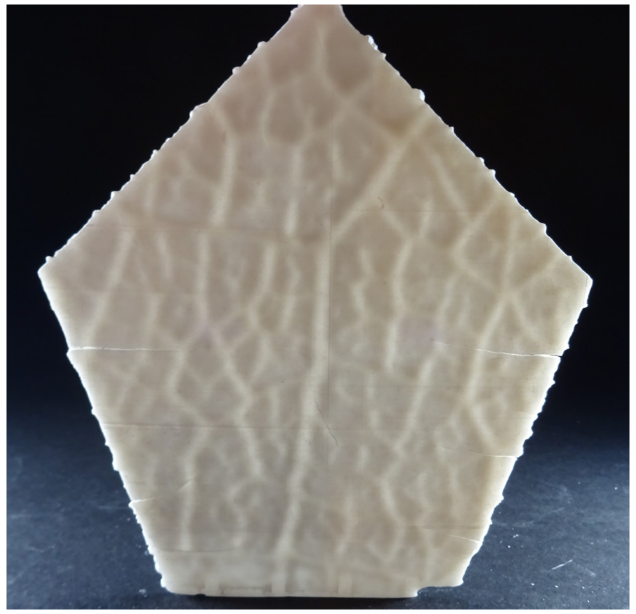


Figure 6.9-37 Light will create shadows unveiling the textures on the inside

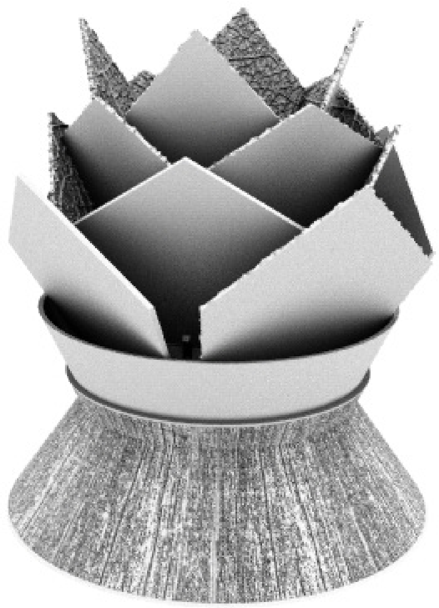


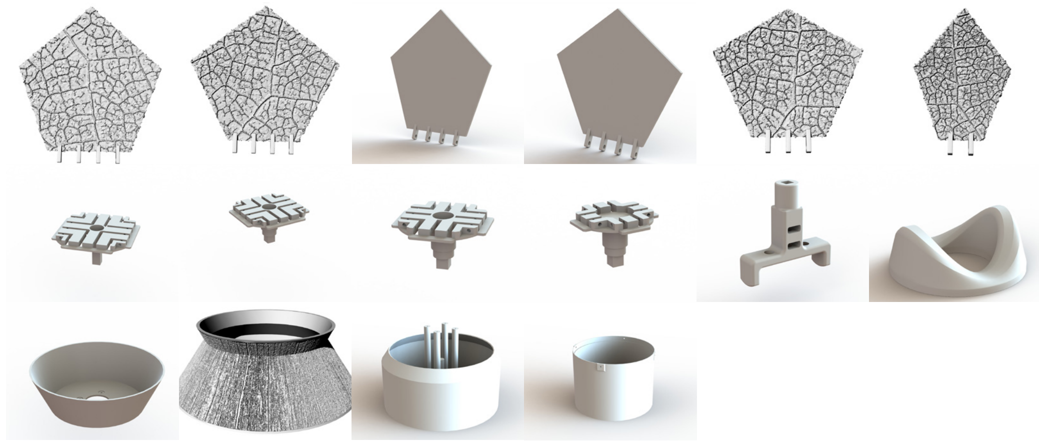
Figure 6.9-36 Closed state which allows for textures to become visible

Prototyping plan

The parts mentioned before have to be made. Some will be made with the Form 2 and other with the Ultimaker. A wooden presentation box will also be made which will cover the black mechanism base. This way it is showed what the lamp looks like with a smaller mechanism inside the base instead of this bulky mechanism.
All mechanism parts will be made using the Ultimaker, because this goes faster and they do not have to be made from the ceramic material.
Most of the lamp shade components will be made using the Form 2 since these have to be made from the ceramic material to be able to showcase the translucency of the material and the effect of the textures. The base is to big to produce using the Form 2 because of the large mechanism inside. So unfortunately the base has to be printed using the Ultimakers. If time permits a base sample can be printed using the Form 2 to show the texture and the size it will be.

The complete prototyping process is visualised in in this paragraph.

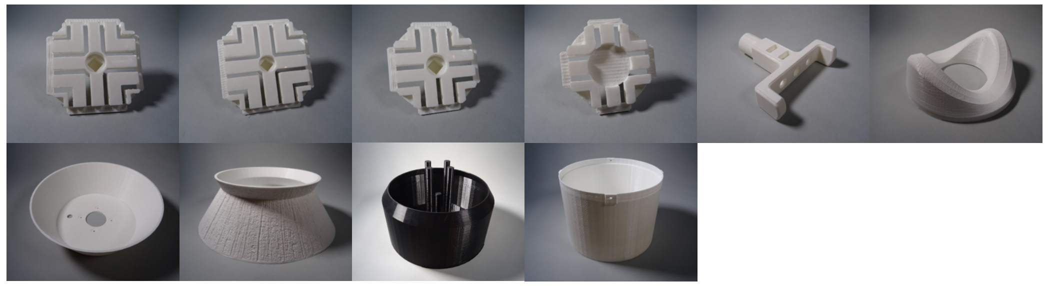
Modelling parts



16 parts to be modelled

Modelling time:
1 week

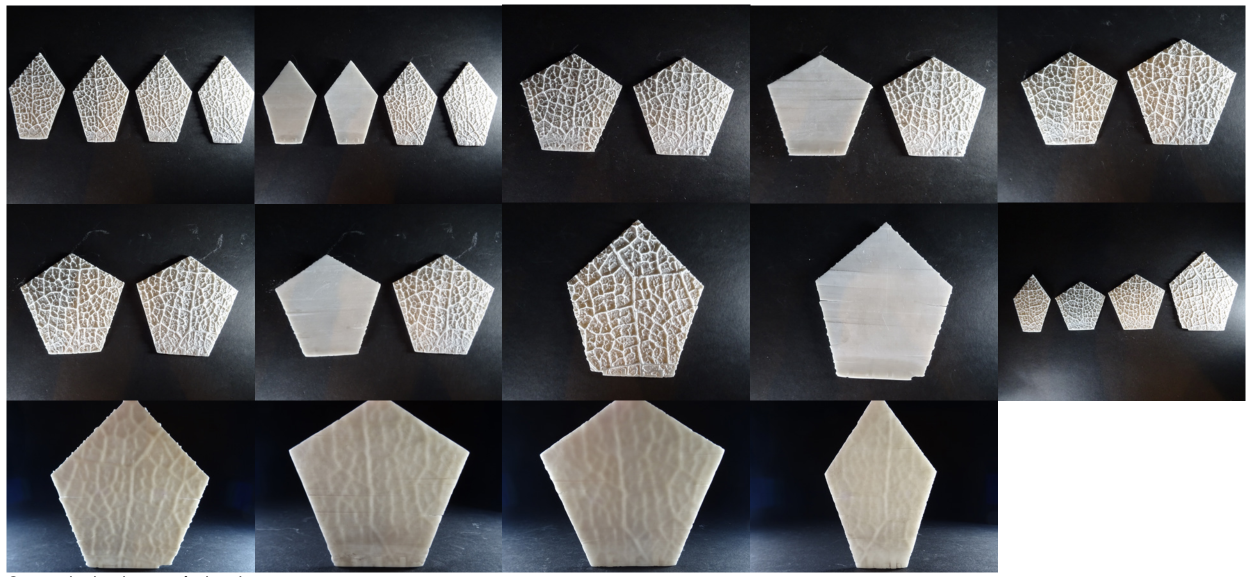
Printing parts Ultimaker



10 parts to be printed

Printing time:
1 week

Printing parts Form 2



9 parts to be printed

Printing time:
1 week

Firing

All 9 parts printed with Form 2

Firing time:
3 days

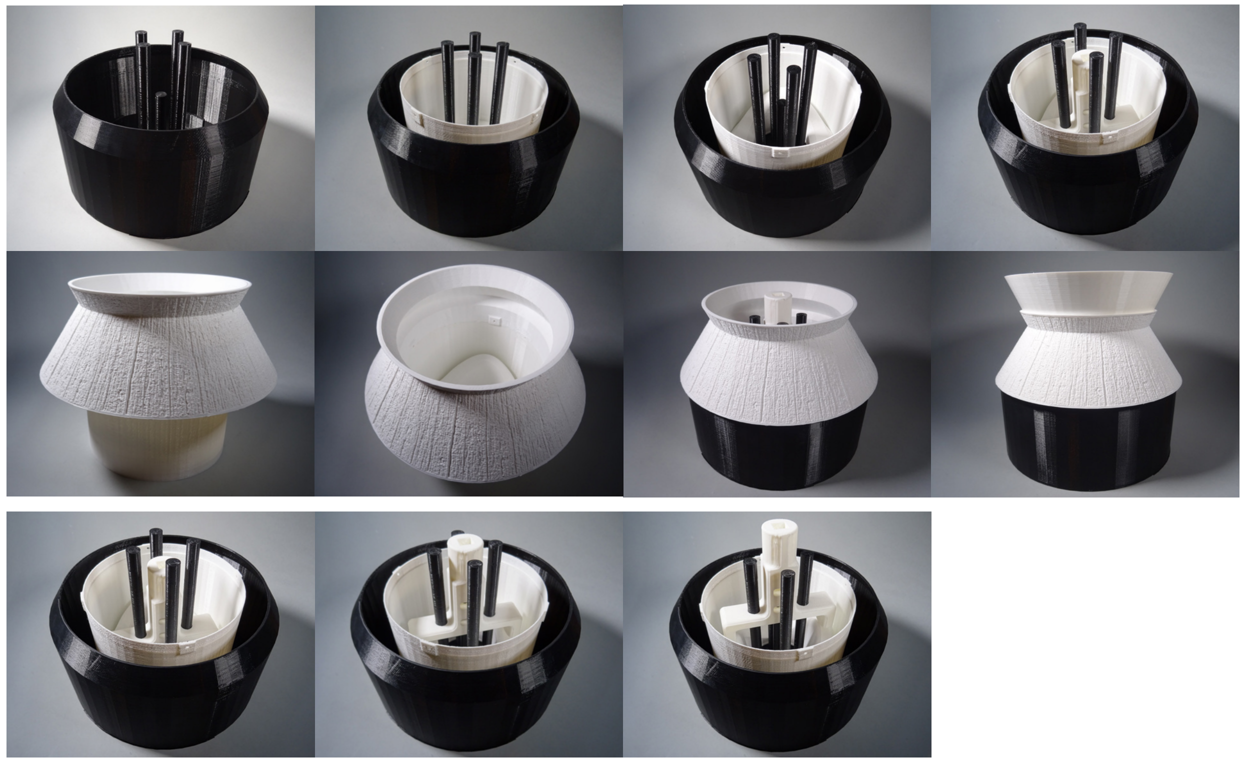
Samples were ruined because kiln was turned on following a different firing schedule (by someone else) with my samples inside, burning them.

Oven also broke because of this.

Not possible to fire lamp shade components anymore and not enough time to fix the oven.

So have to communicate the effects with the small samples from chapter 5.

Assembly



Complete assembly will be done after this report has been delivered

Assembly time:
3 days

Presentation box

A wooden presentation box will be made which will cover up the black mechanism base showcasing what the lamp would look like with a smaller mechanism.

If time allows it

It would be nice to have replacing lamp shade samples, since the original ones got ruined.

These could be made from plastic using the ultimaker of the Form 2.

With these replacing lamp shade samples the working prototype can still showcase the functionalities and use. And the light effects can be communicated using the samples used at chapter 5.

Slots can be incorporated in the presentation box for the small samples.
Light will be placed inside the presentation box to showcase the translucency of the material.

The lights inside the presentation box will turn on when the lamp is turned on unveiling the texture.

CHAPTER 7
CONCLUSION AND DISCUSSION

This chapter includes the thesis conclusion and discussions. The process, material and design will be evaluated on and recommendations for future research are listed. Lastly there will be reflected on the personal process and experience during this project.

7.1 CONCLUSION

The Formlabs ceramic resin is a 3D printable ceramic material which uses photopolymerization to solidify the resin into objects. The material requires extra steps and experimenting and is now mostly used in educational and researching environments, because of the challenges it brings. These challenges mainly occur because not enough is known about the material and the way of use. However, the Formlabs material has a great potential of being more user friendly and easier to use than other 3D printable ceramic materials. This is because the material is made for the specific 3D printer allowing them to work together perfectly, increasing the ease of use and success rate.

By following the Material Driven Design method (MDD) (Karana et al., 2015), understanding could be created about the material characteristics and experiences. Furthermore, the challenges the material brings were tackled, and the user friendliness of the material in combination with the production process was experienced. This was done in collaboration with the Materials Experience Lab of Industrial Design Engineering at the University of Technology in Delft.

The material was tinkered with to create understanding about the material characteristics and the behaviour of the material under specific pre-set conditions. The tinkering process was based on the information provided by Formlabs. Some interesting directions came forth out of the tinkering phase.

It is possible to create controlled cracks in the walls of objects. Resin will build up and settle when pausing the printer, creating prominent lines which will crack when fired.
Another interesting opportunity is the possibility to produce hidden Internal structures which play with the translucency of the material. This is possible because of the high precision 3D printing technique used.
Lastly digitally modified surface textures can be created which alter the tactual experience of the material. The high precision of the 3D printing technique offers the opportunity to mimic any know and recognisable texture as well as new and unique textures.

User studies concluded that the material was perceived as rough and tactually offensive but as pure, inviting and aesthetically pleasing because of the mat white colour, translucency and lack of impurities, creating a sensorial incongruence.

The translucency of the material and the possibility of digitally modified surface textures were further explored during this project. It was concluded from user studies that people experienced textures inspired by nature as more tactually pleasing. Furthermore, the translucency of the material allows for light to add depth to the more dimensional textures making the experience even more pleasing.

An envisioned material experience was formulated by combining the findings and insights from the tinkering process and user studies and an ideation session was held in order to materialise and realise this envisioned experience. This ideation resulted in a design direction. The goal was to design a product set or a product made up out of different components, which initially look identical but become distinguishable when a hidden feature is unveiled, by emphasizing the material's translucency.

The final product concept came to be a interactive table lamp which encourages people to explore the effects of light on the material. The lamps has digitally modified surface textures which remove the original tactile offensiveness, creating a pleasant tactile experience. It is also made up out of different components which look identical until the lamp is turned on, unveiling hidden textures.
The product concept beautifully showcases the limitlessness and uniqueness of this particular material in combination with the high precision manufacturing process.
The project acts as a starting point for further research on this material in combination with the production process and should inspire people to also thinker, explore and play with this material.

7.2 DESIGN EVALUATION

The prototyped base and mechanism and the texture samples made for the tactility test (chapter 5) were evaluated, since the final samples were ruined and no new ones could be made. The final prototype still has to be assembled with newly produced texture samples, now made from plastic using a faster printing technique. So for now only the parts can be evaluated not the final working prototype. Further evaluation should be made when the working model is assembled and can showcase use and the functionality of the product concept.

Vision

Maintaining inviting aesthetic of material

The material was experienced as inviting because of the mat white colour and the pureness of the material. The goal was to maintain this meaning and experience while altering the surface texture of the material.

The lamp shade components have a modified surface texture on the inside which is not immediately visible only when turning on the light or when the lamp is completely open. The outside of the components is untextured, so, at least when the light is turned off or closed, these parts will create the same experience and meaning as the raw unaltered material.

The lamp shade components will change visually when the lamp is turned on. Unveiling the hidden surface texture. This texture was chosen based on a tactility research executed during this project. This specific texture was experienced as visually attractive and surprising especially when held in the light. So, using it implemented in a lamp shade which is exposed to light will evoke these pleasant meanings and experiences.

The base has a modified surface texture. This texture was chosen based on the same tactility research. This specific texture was experienced as visually calming and pleasant so it will also evoke a positive meaning and experience.

Digitally modified surface textures

The surface texture of the original material had to be altered when wanting to implement the material in an interactive consumer product. The tactile experience can be altered by digitally modifying the surface textures, using computer modelling software. The interactive table lamp has digitally modified surface textures and these specific textures were chosen because they were experienced as tactually pleasant. So, in theory the offensive tactility of the material has been removed by using these textures, but this should of course be validated though another user test using the final prototype.

Unique material and production process combination

The benchmark highlighted that it was important to showcase that producing translucent ceramics with a high precision additive manufacturing process for relative low costs is unique. Emphasizing the uniqueness can be done in several ways as mentioned in this project. But it can only be done by first of all emphasizing the translucency of the material.

The translucency of the material is emphasized in the product concept using light. Furthermore, the lamp is dynamic which allows for exploration. Meaning the user can move the lamp shade components and observe what the effect is of the light on the components and the surface textures, when set to different angles and orientations. Creating understanding about how to emphasize translucency.

The interactive table lamp showcases the uniqueness of the material in combination with the production process because of the high precision digitally modified surface textured which could never be made using traditional porcelain and traditional production methods. Furthermore, the surface textures are multidimensional and this really intensifies when the samples are held in the light because of the high translucency of the material. The multidimensional aspect of the textures would not be as apparent when it would have been an opaque material.

Demand for tactile stimulation

Lastly a trend was found stating that there is a demand for tactile stimulation in daily used object. The interactive table lamp requires touch to work so this perfectly fits the trend.

Project brief

Understanding has been created about the material making it now possible to successfully produce intricate high precision objects. The material has been implemented into an interactive table lamp which showcases the material potential and emphasizes the role of the material in daily used consumer products.

User friendly

Working with the material and the 3D printer was experienced as challenging in the beginning but in the end it was possible to print high precision objects with intricate textures. The full potential of the printer could be used as if it was a standard polymer material by following some basic do's and don't so the experience was perceived as user friendly.

Limitations

Only one light design iteration was made. The light and the orientation of the lamp shade components can be iterated on and optimized to create the optimal experience. This was not possible within the given time, so It should be tested and researched further to optimize the design

7.3 RECOMMENDATIONS

The material could not be explored completely during the given time period of this project. Some insights found during this project could not be pursued but would make nice future studies, so a list of recommendations was set up.

Validation

The prototype, was scaled up because of the mechanism used. Because of this the base is bigger and to big to produce using the Form 2 3D printers. Product concepts should always be validated but this is not possible with the current prototype since not all parts are made from the Formlabs material. the prototype now shows the use and function of the product concept but does not give a valid representation of the tactile experience. So, in the future the prototype should be made using a smaller mechanism to be able to make all the parts using the Formlabs material and to be able to validate the concept.

Technical characteristics

Some technical characteristics of the material were explored and researched. However, Formlabs has stated that the material has even more technical characteristics beside the ones that were explored during this project. These could not be confirmed and researched within the given time of the project so they could be researched in future studies.

Tinker with kiln settings

It was planned to explore the effect of different kiln settings on the surface texture of the material. However, the kiln broke down during these tests and it was not possible to further explore. It is still interesting to research how glass like the material can actually become so the effect of varying kiln setting can be research in future studies.

Researching pure resin

The exact ratio of the components inside the resin is not known. So, the decision was made to not tinkering with the pure resin. Of course this can be done in future studies to maybe optimise the resin itself. To be able to do this more knowledge has to be gathered on the chemistry behind the resin and is could maybe be a collaboration with Formlabs.

Post-processing

Post processes, like glazing, were left out of scope for this research, since this would have been a research on it own. Normally post processes are executed to influence the visual and tactual experience of the material however, this research has proven that the visual and tactual experience of the material can be positively influenced using digital modification. This project does bring the opportunity to start researching and understanding the glazing process, now that understanding has been created about the material characteristics and the production process. And when wanting to implement this material in a food save application glazing should be researched, so this can be interesting for future research.

Hidden internal structures
It was chosen to not further research hidden internal structures which are unveiled by the translucency of the material. This is however still a very interesting subject and more research could be done on varieties of hidden internal structures and how to unveil them. So, might be nice to do more research on this topic.

Fully master the firing process
Lastly more research can be done on the firing process. It is challenging and samples were subject to cracking, deformation and warping. The sample quality became better over time because of the gained knowledge and experience but the last samples fired were still not flawless. Furthermore, there are some firing techniques like how to fire hollow structures or how to fire parts with an overhang and this has not been researched during this project. So this can be the focus for a different research.

7.4 REFLECTION

Tinkering
In the beginning too much focus was put on executing technical tests and making samples for these tests that not enough time was put into tinkering to find experiential characteristic. Because of this the less time was left for broad and focussed tinkering and when following this methodology again I have learned to definitely execute technical tests but to leave enough time for the experiential tinkering.

Slow process
Working with the Formlabs ceramic material is a slow process. It takes at least a week to make a small batch of samples and the process became even longer several times because of faulty machinery. The oven broke down several times including two weeks for my final presentation making it impossible for me to finalise my prototype with the actual Formlabs material.

This slow process does not allow for fast alteration during the tinkering process, which means that when printing it should be well thought out.

I have learned that the kiln used is not made for the temperatures required for this material, so it is better to use a kiln which easily reaches 1300 °C instead of one that just or barely reaches it.

The slow process needed some getting used to but I got used to it and was able to plan everything properly.

Prototype
It is very unfortunate that my final samples got ruined by a non-cautious person two weeks before my presentation. They were burned in the oven which simultaneously broke the oven so no new samples could be made.

Because of this my prototype is now more functional and it explains the use but it will not showcase how the light will play with the textures on each individual piece. A small presentation slot will be placed beside the prototype where the material sample will be showcased. The samples will also be lit to give an idea on what the lamp would look like.

The prototype is not assembled yet so I do not know for sure that it will look good with the presentation board but at least it is a solution to an unfortunate situation.
The prototype will also still show the design of the lamp and I am pleasantly surprised that I was able to make a prototype since I did not expect that I would have the time.

Methodology

The MDD method was a completely new methodology for me. I noticed that it was a bit challenging for me to get explorative in the beginning especially because I was a bit put off by the duration of the production process. It made me overthink some things while I should have just started exploring despite the long production process. The user studies luckily really helped for getting inspiration and new tinkering direction and this got me started.

I experienced the process as being very thorough and complete. It includes a lot of user studies and material research which made the documentation very time consuming but the research very well substantiated. I underestimated the necessary documentation time a bit even though I already mapped out a lot of weeks for documentation. Resulting in me making longer hours than I wanted to. But eventually managed to document everything with a delay of a day.

I learned to be a bit more free because of this method. The research is of course scientific and everything should be documented but I liked that a big part of the method is to just play and experience the material. It is well thought out playing but still playing. It offered the opportunity to not be super analytical all the time but to sometimes just experience and afterwards reflect.

In the beginning it was challenging for me to logically combine all the information gathered from the different tests executed. You generate an overflow of information and one really needs to take the time to reflect on what has happened and on what has been found and the opportunities it can bring. In the beginning I was going to fast and did not take enough time to reflect but I became better at it over time and I think everything came together nicely in the end.

I am over all happy with the result from this project and I am amazed about the amount of work I have accomplished in half a year.

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