Development of Interface for Replaceable Toothbrush Head

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DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

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Abstract

This master thesis aims to explore the possibility of creating a toothbrush made from renewable raw materials by developing a toothbrush handle consisting of wood. The content in this master thesis covers a product development process of a toothbrush and has been executed in collaboration with TePe Munhygienprodukter AB, at Lund University. The majority of the process has involved concept development by manufacturing prototypes and testing them.

The main focus has been directed towards creating an interface that enables the toothbrush head in plastic to connect with the toothbrush handle in wood. Finding an appropriate wooden material for the toothbrush handle has also been a part of the project.

The concepts developed in this master thesis are a result from established customer needs that have been identified by observations and a questionnaire. The developed concepts were presented as CAD models and 3D printed parts. These were then further developed by continuous testing and refinement of the concepts.

The result of the master thesis was two different concept proposals for a toothbrush with a replaceable toothbrush head. This design allows the toothbrush head to be easily changed when considered worn out and the toothbrush handle is able to be reused. The final wooden material recommended for the toothbrush handle was beech.

Keywords: Product design, Concept development, Toothbrush head, Toothbrush handle, Wood, Interface, Injection moulding

Sammanfattning

Detta examensarbete undersöker möjligheten att skapa en tandborste gjord av förnyelsebara råvaror genom att utveckla ett tandborsthandtag bestående av trä. Arbetet täcker en produktutvecklingsprocess av en tandborste och har utförts i samarbete med TePe Munhygienprodukter AB, vid Lunds Universitet. Den största delen av processen har involverat konceptutveckling genom att tillverka prototyper och testa dessa.

Huvudsaklig fokus har legat på att skapa ett gränssnitt som gör det möjligt koppla samman ett tandborsthuvud i plast med ett tandborsthandtag i trä. Att hitta ett passande trämaterial för tandborsthandtaget har också varit en del av projektet.

Koncepten som framtagits i detta examensarbete är ett resultat av insamlade kundbehov som blivit identifierade via observationer och en enkät. De framtagna koncepten presenterades i form av CAD modeller samt 3D printade delar. Dessa utvecklades sedan vidare genom att systematiskt testa och förfina koncepten.

Resultatet av examensarbetet blev två olika konceptförslag på tandborstar med ett utbytbart tandborsthuvud. Designen tillåter tandborsthuvudet att enkelt bytas ut när det anses förbrukat och handtaget kan därmed återanvändas. Det slutgiltiga träslaget som rekommenderades var bok.

Nyckelord: Trä, Gränssnitt, Produktdesign, Konceptutveckling, Tandborsthuvud, Tandborsthandtag, Formsprutning

Acknowledgments

This master thesis has been performed at the division of Product Development within Mechanical Engineering with Industrial Design at Lund University. It is a project done in collaboration with TePe Munhygienprodukter AB.

Writing this master thesis has provided us with a lot of knowledge and has prepared us for our future as engineers. We are grateful to have been given this opportunity and would like to thank some people for making this journey possible.

A special thanks goes to our supervisor at TePe, Patrik Werius. He has always believed in us and given us the possibility to make this project something we feel proud of. Furthermore, we would like to express our gratitude to Jim Leveen and Alexander Dingizian, as well as many other colleagues at TePe, for their expertise.

We also appreciate all the support and feedback received from Katarina Elner-Haglund during this project. Her insights have been of high value for the result of this master thesis. Lastly, we would like to thank all the people from the workshop at Lund University for their help.

Lund, May 2020

Liridona Dervishi and Filippa Melin

Table of contents

List of acronyms and abbreviations

CAD	computer aided design
FDM	fused deposition modelling
HDPE	high density polyethylene
PA	polyamide
PE	polyethylene
PLA	polylactic acid
SLS	selective laser sintering
TePe	TePe Munhygienprodukter AB

1 Introduction

This section describes the background, the problem and the purpose which this master thesis aims to cover. A brief section about the company providing the idea for this master thesis is also included.

1.1 Background

99% of the compounds in plastics are derived from fossil fuels, which is the main contributor to the carbon dioxide emissions (Shield 2019). Aspiring to minimise these emissions, alternative raw materials can be used for production of plastic. Renewable raw materials are an excellent way of producing plastic without contributing with a direct increase of carbon dioxide emissions but instead recirculate the majority of it.

However, the process from the renewable raw material to the finished plastic material involves many steps. The raw material must be degraded into smaller elements before having the possibility to become plastic. Therefore, it is of interest to investigate if it is possible to eliminate these intermediate steps and thus go directly from the renewable raw material to the finished material used in products. Eliminating these steps might result in less emissions released to the atmosphere as the process is radically shortened and can therefore be a more environmentally friendly alternative to plastic made from renewable raw materials.

The idea behind this master thesis is to explore the possibility of using wooden material for a toothbrush by replacing some of the plastic parts. The company behind the proposal is TePe Munhygien AB (TePe). Looking back, their journey started with a wooden toothpick. Now, they are curious to know if a wooden toothbrush carries the same success for the future.

1.2 TePe Munhygienprodukter AB

TePe is a family owned company that was founded in 1965. Today they are a global trademark within oral health and their products are used daily by consumers and professionals in the dental care sector in more than 60 countries worldwide. Their well-known interdental brushes along with toothpicks and toothbrushes, see Figure 1 - Figure 3, are some examples from their product assortment.

Figure 1. Interdental toothbrushes.

Figure 2. Toothpicks.

Figure 3. Select toothbrush.

The headquarter of the company is located in Malmö, Sweden. All design, development and production are situated here which gives them control of a large part of the value chain. When developing their products, the company place great importance in collaborating with professionals from the dental care sector. The company also works continuously with becoming more sustainable and an example of this are solar cells on the roof of the building that generates electricity to power parts of their production. Their latest product release is a new toothbrush series called TePe GOOD. The plastic in these toothbrushes are made from sugar cane and castor oil which are renewable raw materials. By using these renewable raw materials, they manage to recirculate 95% of the carbon dioxide emissions during the lifecycle of the toothbrush handle (TePe Munhygienprodukter AB n.d.).

1.3 Problem Description

The purpose of this master thesis is to explore the possibility of creating a toothbrush with parts made of wood. Due to specific demands from TePe, the head of the toothbrush is determined to consist of plastic. In detail, the focus will therefore be directed towards creating a toothbrush handle in wood as well as designing an interface between the toothbrush head and the toothbrush handle, see Figure 4. The interface can be designed to either permanently attach the two materials together or to enable detachment.

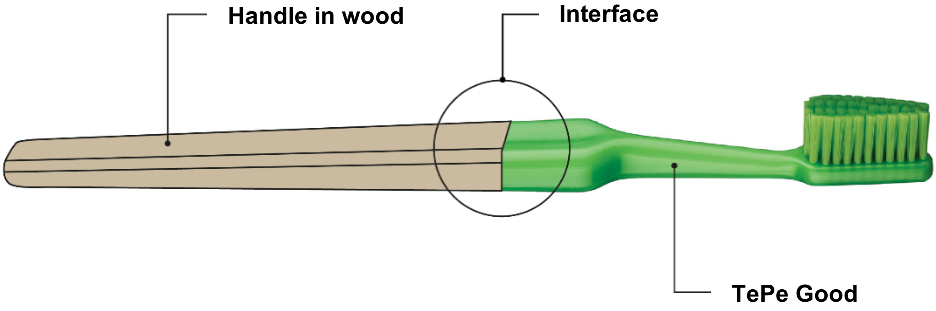


Figure 4. Illustration of the different parts of the toothbrush.

1.4 Goal

The goal is to present a prototype consisting of a toothbrush head made of plastic and a handle made of wood. A brief section about manufacturing methods for prototyping in wood and a proposal for production of the finished product is also to be provided.

1.5 Delimitations

A delimitation set in the beginning of the master thesis was that only Swedish wood was to be considered as a potential choice for the toothbrush handle which limited the selection of wood.

It was also decided that the toothbrush head would have the same design as the current Select model from TePe. The interface therefore had to be possible to integrate with the top of the Select models geometry.

No consideration will be taken to the packaging of the product, only development of the product itself will be performed.

Neither will this master thesis cover whether a toothbrush handle made from wood is more or less sustainable compared to a toothbrush made from plastic.

1.6 Definitions

Biodegradable
For something to be biodegradable it must be broken down by microorganisms in an environment with or without the presence of oxygen. Two necessary criteria for this procedure to occur are moisture and heat. The finished product is water, carbon dioxide and/or methane and biomass. (Elner-Haglund 2020)

Biomass
Biomass is a matter that originates from living plants (Nationalencyklopedin n.d.).

Compostable:
A biodegradable material is considered compostable when the degradation is finished within a specific time frame defined by the European standardisation EN 13432. Oxygen must be present and high requirements are set for the balance of moisture and heat. (Elner-Haglund 2020)

2 Material

In this section, the theory that laid the foundation for the following product development process is presented.

2.1 Plastic

Plastic, also called polymer, is a material made from several elements, such as carbon, hydrogen, oxygen, nitrogen, chlorine and sulphur. The carbon atom is linked to other carbon atoms as well as the earlier mentioned hydrogen, oxygen, nitrogen, chlorine and sulphur. This connection can result in chains of different lengths. When resulting in a specifically long one, the polymer becomes a thermoplastic which is a polymer characterised by its ability to be melt. A thermoplastic can be divided into identical sections. These sections repeat themselves and as a result, form a chain called polymer, see Figure 5. The atom group creating the repetitive structure are called monomers. A monomer can have various appearances and can contain only one carbon atom and two hydrogen atoms as it does for polyethylene (PE) or consist of as many as 38 or more atoms like for polyamides (PA). About 92 % of all plastics are thermoplastics. (American Chemistry Council 2005)

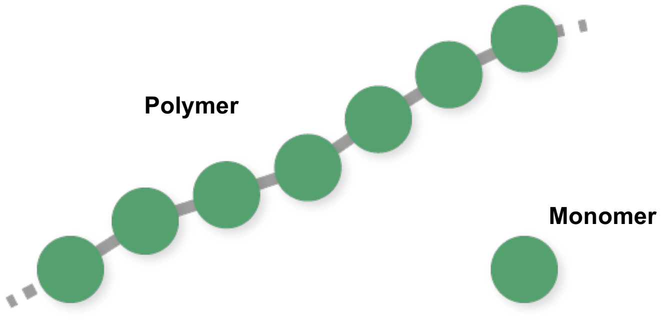


Figure 5. Monomer and polymer

Raw materials for the production of polymers can be obtained from petroleum and coal but also from renewable resources like cellulose. (American Chemistry Council 2005)

When commercially produced, the toothbrush head will be injection moulded in High Density Polyethylene (HDPE). During the initial development of the toothbrush however, it will not be possible to prototype in this material. This because of the lack of access to a cost-efficient and quick method of creating prototypes in PE. Therefore, prototypes in the beginning will be done in the materials polyamide (PA) and polylactic acid (PLA) as these plastics are well suited for 3D printing. All three materials are further described in chapter *2.1.2.1 PE*, *2.1.2.2 PA* and *2.1.2.3 PLA*.

Further, 3D printing is an easy process of creating prototypes and can be done using various methods. The two methods used for this project are Selective Laser Sintering (SLS) and Fused Deposition Modelling (FDM), further described in chapter *2.1.3 SLS* and *2.1.4 FDM*.

2.1.1 **Injection Moulding**

When injection moulding, melted plastic is fed into a mould until it solidifies, and then is ejected. It is done by feeding granular plastic from a hopper into a heating extruder. The plastic is pushed forward using a screw, resulting in the plastic being melted before injecting it into a cold mould with high pressure. The closed and cold mould solidifies the plastic until firm before opening and ejecting the finished plastic product, see Figure 6. (American Chemistry Council 2005)

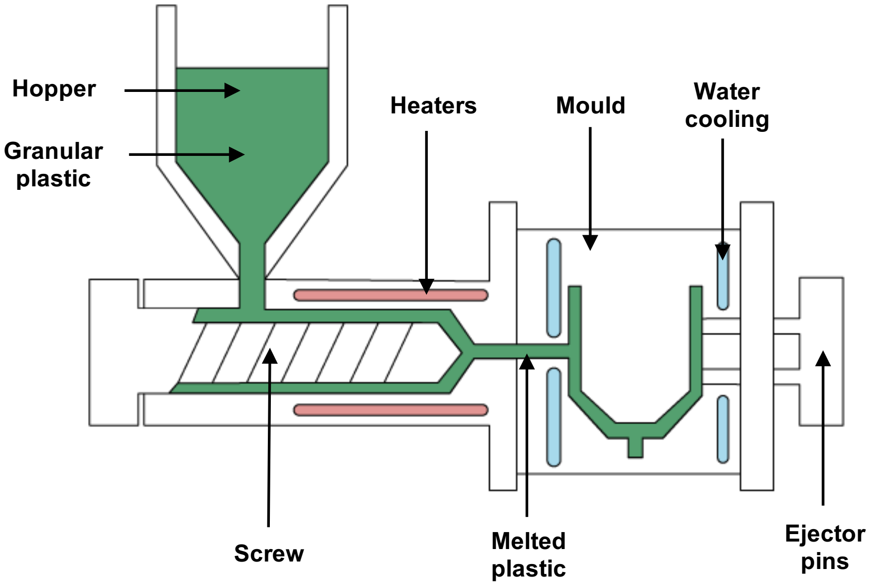


Figure 6. Illustration of injection moulding machine.

Using this process calls for careful consideration regarding the design of the object to ensure a smooth operation of how the product will be formed in the mould, the ejection from the mould and the structure of the final product. An important guideline is to have a design with a wall thickness as uniform as possible as it otherwise might result in uneven surfaces, in terms of sink marks. This due to the fact that thick walls cool slower than thin walls and therefore thick walls shrink more. Design features such as round corners wherever possible are also important, as well as having sides with an approximately 2 degrees draft for easy release of the object from the mould. (Engineers Edge 2020)

2.1.2 **Physical Properties**

There are mainly three plastics that have been of use for this product development project. These are PE that the final product will be made of, as well as PA and PLA that have been used as prototype materials during the development of concepts. See Table 1 for the physical properties of these three plastics.

Table 1. Physical properties of plastics.

	HDPE[1]	PA[2]	PLA[3]
Density [g/cm^3]	0.962	0.820-11.0	1.00-2.47
Tensile strength at Yield [MPa]	32	5.00-170	2.00-103
Shore D Hardness	64	40.0-88.0	59.0-77.0

[1] (Braskem, 2019)
[2] (MatWeb, n.d.)
[3] (MatWeb, n.d.)

2.1.2.1 PE

Each year 60 million tons of polyethylene are produced around the word, making it the most common plastic. PE has a low material price, barely absorbs moisture, has excellent wear resistance and is easy to colour. On the contrary it is not as stiff, is hard to lacquer and cannot manage temperatures above 80 ℃. (Bruder 2013)

2.1.2.2 PA

With regard to volume, PA is the most used construction plastic and is frequently used in the car industry. In high temperatures PA is stiff but becomes brittle as the temperature lowers. PA also tends to absorb moisture extracted from the air which affects the mechanical properties as well as the dimensions. (Bruder 2013)

2.1.2.3 PLA

PLA is produced by sugars found in sugar beets, potatoes, corns and wheat through fermentation. It is a plastic completely made from biobased raw materials and is compostable. PLA is water resistant but is not as resistant regarding heat and can withstand temperatures up to 55 ℃. (Bruder 2013)

2.1.3 **SLS**

SLS is a 3D printing method that sinters powder, using a laser, into a solid structure. It is done by spreading a thin layer of powder before letting the laser beam sinter the powder according to the objects cross section in that specific level. The build platform then drops by one level as a new layer of powder is spread on top. The process repeats itself until a solid object is complete. The powder surrounding the solid object that has not been sintered acts as support of the structure and can be reused for future printing after the object is removed, see Figure 7. (Formlabs n.d.)

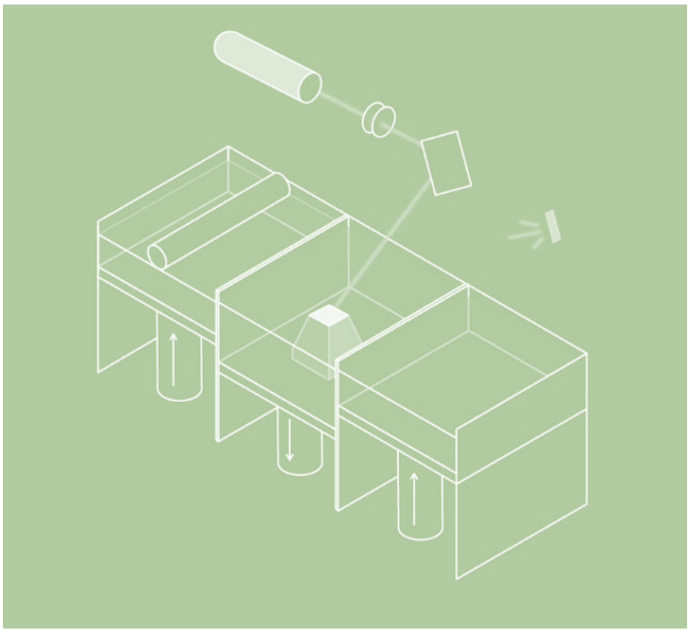


Figure 7. Illustration of the SLS method. (Formlabs n.d.)

2.1.4 **FDM**

Objects 3D printed using the FDM method are created by melted filament passing through a nozzle and building an object layer by layer. The filament thread is melted as it passes through the nozzle and then extruded on the build platform. Here the extruded material creates a cross section of one layer of the object before the build platform lowers a level making it possible for a new layer to be extruded above. This continues until completed. To support the object being 3D printed, support material is added around the body which is later removed when the print is ready, see Figure 8. (Live Science 2013)

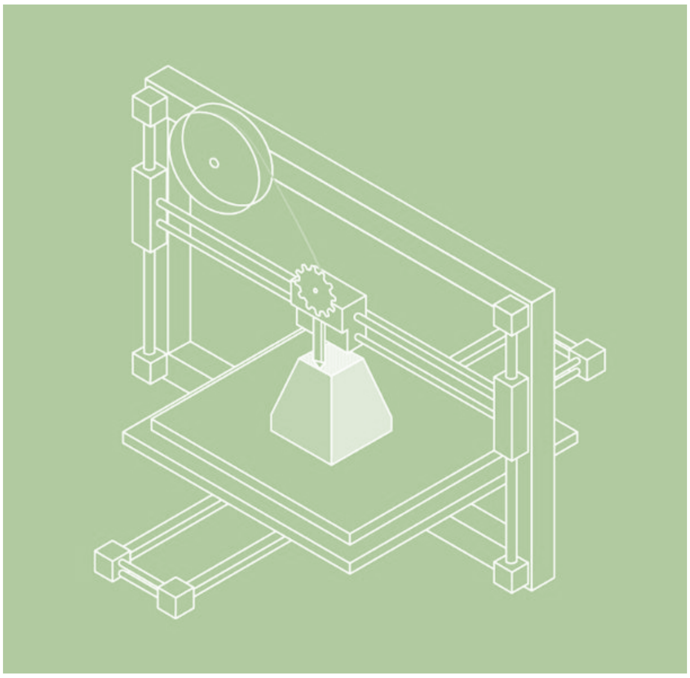


Figure 8. Illustration of the FDM method. (Formlabs n.d.)

2.2 Metal

Metals are substances that are characterised for conducting heat and electricity very well, for their ductility and malleability, and for being able to reflect light. Most metals have very high melting points and are hard as well as strong. (Good Science n.d.)

For this master thesis a threaded pin was created. It was 3D printed in aluminium. The aluminium pin was 3D printed using the Selective Laser Melting (SLM) method. Further facts about aluminium and SLM can be found in the text below.

2.2.1 **Aluminium**

After oxygen and silicon, aluminium is the most common element of the earth's crust. It has a low density and is very ductile making it perfect for production of different product shapes. It is used for everything from bicycle frames, to kitchen utensils. Aluminium is a metal that requires low maintenance as it forms a protective oxidation layer when reacting to the oxygen in the air and is one of the easiest materials to recycle. (Hydro n.d.)

2.2.2 **SLM**

The SLM method is very similar to the process in SLS, described in chapter *2.1.3 SLS*. Similarly to the SLS method, the process in SLM consists of a powder bed where a solid part is created by sintering/melting the powder one layer at a time using a high-energy power beam, see Figure 7 .The difference is found in the energy of the power beam, as it in the SLM method is much higher, making it popular when creating parts in metal. (Moritz, T and Maleksaeedi, S 2018)

2.3 Wood

Wood is a renewable raw material obtained when trees are felled. It has been used by mankind for thousands of years for fuel, as a construction material, for making tools and so on. Today, it still serves as a popular choice for our homes in the form of floor, doors, window frames, furniture and utensils to name a few.

Some of the desirable qualities for wood are its workability, high strength for its weight and aesthetic appeal. However, undesirable attributes like its ability to burn and decay are also present. Moreover, the properties of wood may vary not only between the different tree species but also within the same specie as well as within a single tree. Area of growth, part of the stem, time of the season when felled and individual characteristics of the tree are all factors that contribute to these variations. By understanding the structure and properties of wood, one is more likely to make better decisions when it comes to selecting type of wood for its intended purpose, regardless of the inherent variations that may exist. The following sections will therefore provide such knowledge. (Tsoumis 2019)

2.3.1 **Structure**

2.3.1.1 Macroscopic

The transverse section (cross section) of a tree trunk, see Figure 9, shows macroscopic parts of the structure for a tree. The following text describes the different parts in more detail. (Tsoumis 2019)

Outer bark
The outermost layer of the tree is called outer bark and it provides protection against dehydration and parasites as it encloses the whole stem of the tree. (Tsoumis 2019)

Inner bark

Beneath the outer bark is the inner bark which serves the purpose of transporting the nutrition (carbohydrates) down from the stem to the living cells in the tree branches, stem and root. (Tsoumis 2019)

Pitch

The pitch is placed at the centre of the transverse section and it is made of ground tissue and dead heartwood. (Tsoumis 2019)

Growth rings

The concentric layers formed around the pitch are called growth rings or annual rings. Normally, one ring is produced for each growth season in temperate regions, but false rings may also occur. The growth rings are visible due to differences between the earlywood and latewood, i.e. wood usually produced early in the season and later in the season. Commonly, the earlywood is known for its lower density and the latewood of its higher density. (Tsoumis 2019)

Heartwood

The darker zone called heartwood, consists of older layers that no longer take part in transporting or storing water and nutrients. The darker colour is not true for all tree species since the heartwood also can appear with the same colour as the surrounding sapwood. (Tsoumis 2019) The natural resistance to biological attack, such as wood decaying fungi or wood destroying insects, varies from poor to very good for heartwood (Swedish Wood n.d.).

Sapwood

The sapwood is composed of the newer growth rings and it participates in the life process of the tree by transporting and storing water as well as nutrients. (Tsoumis 2019) In comparison to heartwood, sapwood commonly have no resistance to biological attack (Swedish Wood n.d).

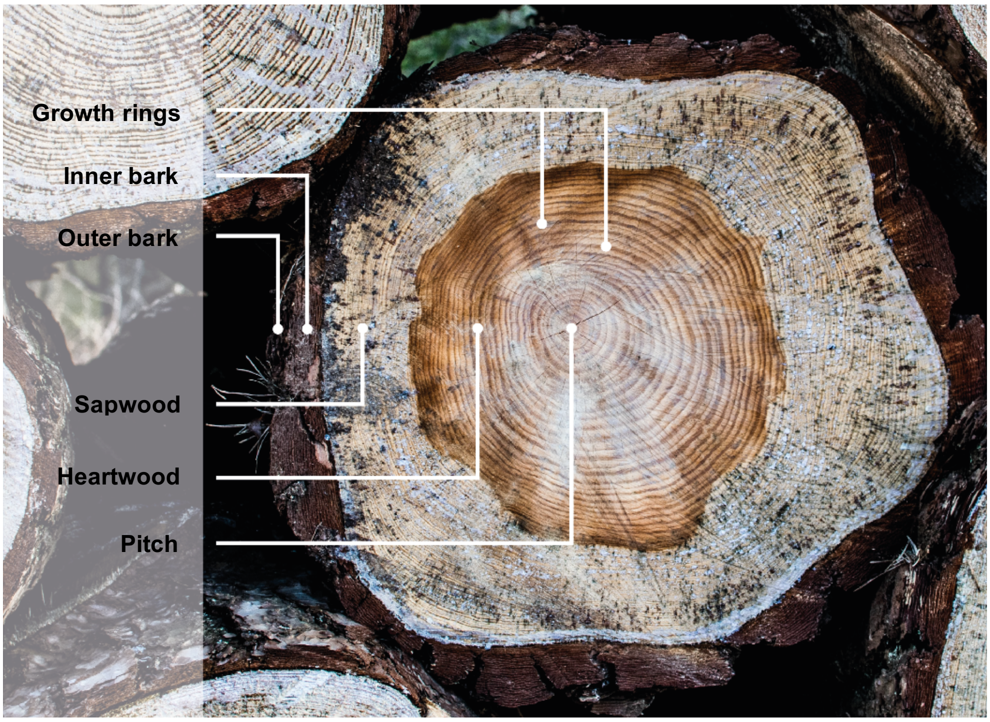


Figure 9. Macroscopic structure of a tree trunk.

2.3.1.2 Microscopic

The microstructure of wood consists of different types of cells. For coniferous trees, two kinds of cells exist, tracheids and parenchyma cells. Broad-leaved trees on the other hand has a more diverse structure consisting of vessel members, fibres and parenchyma.

Broad-leaved trees

What denotes broad-leaved trees are their vessels, which are not found in the coniferous trees. These vessels can often be distinguished with the bare eye as pores in the cross section of a tree and grooves in the tangential section, see Figure 10. According to the pores size and distribution, further categorisation is made among the broad-leaved trees into ring-porous (e.g. oak), semi-porous (e.g. walnut) and diffuse-porous (e.g. beech, birch). For ring-porous wood, the pores for earlywood are larger compared to those for latewood. Regarding diffuse-porous, the pores are generally distributed evenly and obtain about the same size. See Figure 11 for illustrations of microscopic examples for ring-porous, semi-porous and diffuse-porous. (Wolman n.d.)

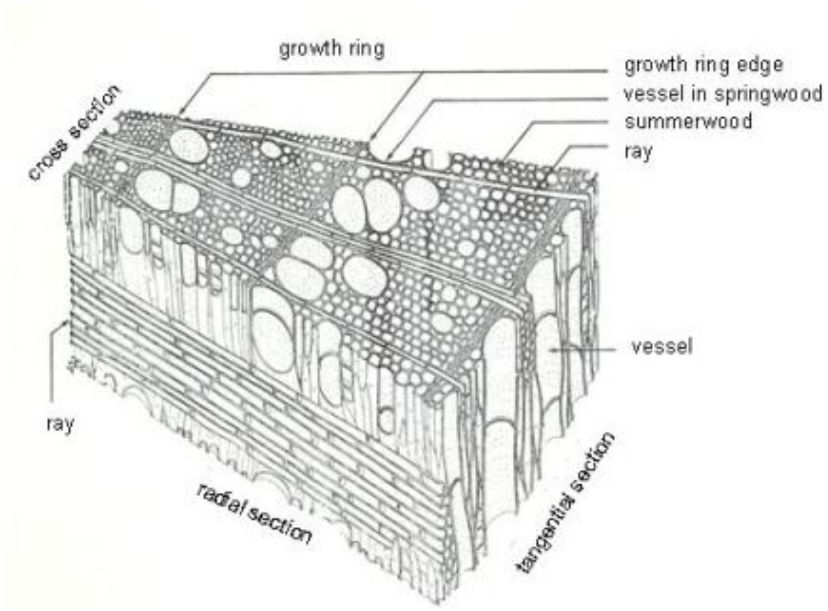


Figure 10. Part of the cross-section of a broad-leaved tree illustrating the microstructure. (Grosser n.d.)

Figure 11. Illustrations of microscopic structure for ring-porous (left), semi-porous (middle) and diffuse-porous (right). (Favorite 2012)

2.3.2 **Physical Properties**

Hygroscopicity

Hygroscopicity is a materials ability to obtain water by absorbing it while in contact or from the water molecules in the air. Wood always contains water as a result of its hygroscopicity, no matter if it is while being a living tree or after being cut. The absorption of water affects the properties of the wood. Most changes occur from absorption of the cell walls of the wood rather than from moisture contained in the cell cavities as this only adds weight. In addition to the weight, the water content in wood also affects the resistances to decay and insects, the processing process of the material, the thermal and acoustic properties as well as the dimensions. The severity of the changes depends on the moisture level in the wood. While the moisture level alters depending on the humidity in the air and the temperature. (Tsoumis 2019)

Anisotropy

Wood is an anisotropic material as it has different characteristics in different directions. In Figure 12, the fibre directions are explained relative to a cube, extracted from a log of wood. The cube is placed to have the fibre directions in longitudinal (L), tangential (T) and radial (R) direction. However, the differences between the tangential and the radial directions are frequently neglected and used as one. Therefore, the directions are often described as being in the fibre direction (longitudinal) or being perpendicular to it (tangential and radial). (Träguiden 2017)

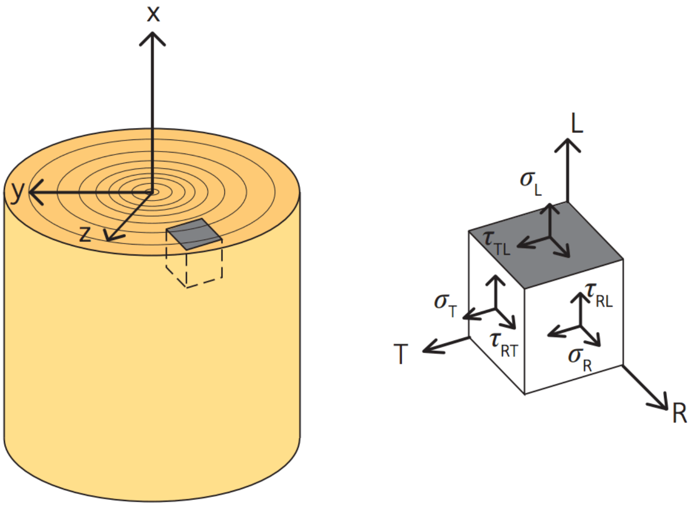


Figure 12. An illustration of the fibre directions relative to a cube. (Träguiden 2017)

The anisotropy of wood leads to the wood having different strengths in different directions. The tensile strength in the fibre direction is remarkably higher than in the perpendicular direction. Similarly, the compressive strength in the fibre direction again is higher than in the perpendicular, but not by as much. (Träguiden 2017)

Due to the woods anisotropic characteristics the swelling and shrinking also occurs differently in different directions. The biggest changes of dimensions happen in the direction perpendicular to the fibres and the smallest changes are in the direction along the fibres. (Tsoumis 2019)

Moisture regain

The amount of water existing in wood is expressed by the moisture regain. It is defined as the weight of the water in a moist material divided by the weight of the dehydrated material. This is then multiplied by 100 to get the percentage. See equation 1.1. (Swedish Wood n.d.)

$$\mu = \frac{weight\ when\ moist - weight\ when\ dehydrated}{weight\ when\ dehydrated} \cdot 100 \qquad (1)$$

Growing stock in Sweden
The percentages of growing stock in Sweden, see Table 2, represents the share of the total amount of productive woodland in Sweden for each tree (Skogskunskap 2016). Further, productive woodland means land used primarily for forestry (Sveriges lantbruksuniversitet 2020).

Density
The density for wood is measured in 0% moisture regain. This means that the density is measured for the dehydrated mass of the wood. There are different methods of measuring density and every method is equally valid if the same method is used when comparing different woods.

Shrinkage
The shrinkage for wood is measured from raw state to 0% moisture regain. Shrinkage can be measured from raw state to different moisture regains but as long as the shrinkage is measured to the same moisture regain, every method is valid.

Hardness
The hardness for wood is measured at 12% moisture regain along the surface using the test method Janka. The Janka test measures the force it takes to press a steel ball with a diameter of 11.28 mm into a wood until half the ball is pressed into the surface (Advantage Lumber n.d.).

Resistance
The resistance for rot and insects is measured by the standard SS-EN 350-2, rated according to:

1 - Very resistant
2 - Resistant
3 - Moderately resistant
4 - Barely resistant
5 - Not resistant

Table 2. Physical properties of wood.

	Beech	Birch	Oak	Pine
Growing stock in Sweden [%][1]	0.6	11.9	1.1	39.0
Density [kg/m3][2]	640-680	580-620	650-720	450-500
Shrinkage [%][2] - Radially - Tangentially	 4.4-5.9 10-11.8	 5.3 7.8	 4-5 7.8-10	 4 7.7
Hardness [Janka][2]	565-675	420	450	250
Resistance[3]	5	5	2	3-4

[1] (Skogskunskap 2016)
[2] Beech, Birch and Oak: (Träcentrum n.d.)
[2] Pine: (Boutelje and Rydell 1986)
[3] (Träguiden n.d.)

2.3.3 Tree Species

Beech
Most of the beech (fagus silvatica) found in Sweden grows in the south part. Its timber is often referred to as red beech and is known for both its toughness and hardness. The beech does not give off any fragrance or taste and neither does it absorb fat making it a good choice for products in contact with food. It is often felled at age 100-120. (SkogsSverige 2019)

- \+ Resistance against cracking or breaking under stress (toughness)
- \+ Resistance against scratching (hardness)
- \+ Tasteless
- − Low resistance against rot

Birch
The birch tree is Sweden's most common leaf tree and it is found all over the country in two different species, silver birch (betula pendula) and European white birch (betula pubescens). However, when it comes to the timber you do not make any difference between the species even if some variations may exist. Normally it is felled at age 40-60. Birch is also a common choice of material for furniture and floors due to its toughness and hardness. (SkogsSverige 2019)

- \+ Resistance against cracking or breaking under stress (toughness)
- \+ Resistance against scratching (hardness)
- − Low resistance against rot

Oak
There are two different species of oak trees in Sweden, common oak (quercus robur) and sessile oak (quercus petraea). Oak grows naturally in the south part of Sweden. The durability of the timber has made it an exceptional choice when making for instance furniture, stairs and doors but has also been used when making ships. The quality of the timber is highly influenced by the speed of growth. Heartwood of oak has the best resistance to rot compared to the native wood species. Timber that has grown faster has higher proportions of summer timber and is therefore much harder than slow grown oak. Oak trees can be very old and reach ages up to 1000 years but when timber is to be derived the tree is felled at age 120-150. (SkogsSverige 2019)

+ Resistance against cracking or breaking under stress (toughness)
+ Resistance against scratching (hardness)
+ High resistance against rot for heartwood
+ Impermeable to liquids
− Timber dries slowly with risk of cracking

Pine
Pine (pinus sylvestris) is a tree that can be found around all of Sweden. The pinewood is easy to process. The best parts of the timber are used to make furniture and constructions whereas the rest of the timber can be used to create craft paper. Normally the pine is felled at the age of 80-120. (SkogsSverige 2019)

+ Processing properties
+ Resistance against rot for core wood
− Low resistance against insect

2.3.4 Coating

If further durability regarding resistance against mould and expansion of the wood is wished upon one measure that can be taken is coating. This will minimise the risk of the wood absorbing water and therefore work against eliminating earlier mentioned problems. Requirements for a coating used in this project is that it must be food graded. Coatings recommended for these applications are linseed oil, tung oil, milk paint, carnauba wax or beeswax.

Linseed oil
Linseed oil is extracted from the ripe seeds of the flax plant and is one of the most commonly used finishing oils for furniture indoor as well as outdoor. It is an oil that is nontoxic if it is used in its pure state. But using pure linseed oil will also result in a drying time of about 3 days and tends to leave a sticky surface if coated to thick. (Ardec 2015)

Tung oil

Tung oil is made from the seed kernels from the tung tree and was used in China as a preservative for ships made from wood. As long as the surface finish is kept intact the coating results in wood very resistant to water but there is a risk of penetrating the thin surface and as a result, lowering this resistance. (Woodwork Details n.d.)

Milk paint

Milk paint is a mixture consisting of curdled milk, lime and earth pigment for colour. It is a paint often used for walls, furniture and wooden toys. To optimise the durability of this coating a few weeks of drying is recommended before exposed to wet environments. To create a further lasting coating the milk paint can be coated with linseed oil. (Real Milk Paint n.d.)

Carnauba Wax

Carnauba wax is a coating commonly used for wood but is also often used for pharmaceutical and food purposes as it is safe to digest. It is a plant-based wax, extracted from palm trees in Brazil. Out of all commercial waxes, carnauba wax is the hardest, it has a melting temperature of approximately 80 °C and is insoluble in water. (de Freitas et al. 2019)

Beeswax

Beeswax is often used as an ingredient in the waxing of floors. It is unlike the earlier mentioned waxes not plant based but extracted from the honeycomb walls created by the bees. Beeswax can be found in many parts of the world and may therefore alter in characteristics depending on its origin. The wax has a melting temperature of 60 °C and is insoluble in water. (Tsoumis 2019)

3 Methods

Information about the different methods that have been used during this master thesis are presented in the section below.

3.1 The Product Development Process

The product development process that has been used for this project is inspired by the process presented by Ulrich and Eppinger (2012), see Figure 13. According to the problem statement and the scope of the project, majority of the workload will be conducted in Phase 1 - Concept Development.

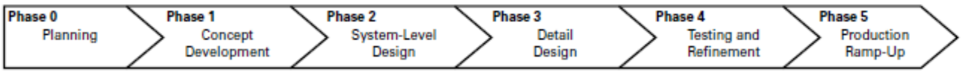


Figure 13. Product development process. (Ulrich and Eppinger 2012)

A more detailed plan of the concept development process can be seen in Figure 14. The concept developing process starts by identifying customer needs. The process of this stage is to result in a deeper understanding of the customers' needs by collecting needs statements and sorting them depending on their importance.

This process is followed by establishing the target specifications. The target specifications are concisely descriptions of the customer needs that has been reformulated into technical terms in cooperation with the product development team. The implementation from the customer needs results in detailed descriptions of the products purpose.

The next step is the concept generation phase and the goal is to produce concepts that fulfil the previously established customer needs. Usually 10 to 20 concepts are generated.

Following the generation of concepts is the concept selection where the most promising concept(s) are selected for further development. During this activity, iterations and refinements of already existing concepts are common but new ones may also arise.

Selected concepts are then tested to ensure that the customer needs are accomplished. Defects of the concepts may also be identified to improve future solutions.

After testing the selected concepts, the target specifications are finalised by deciding to commit to specific values.

The last step of the concept development process is to plan downstream development. (Ulrich and Eppinger 2012)

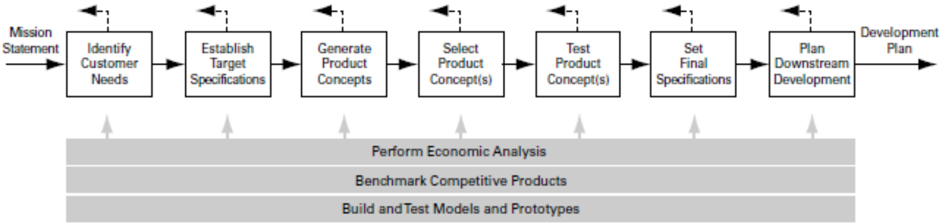


Figure 14. Concept development process. (Ulrich and Eppinger 2012)

3.2 Triangulation

Triangulation is a method used to collect data using two or more data gathering techniques. By practicing multiple data gathering techniques it enables the possibility to see a pattern and similarities conducted from different perspectives. It therefore eliminates the risk of the data gathering technique having as big of an impact on the result as it would have if only one technique was to be used. (Sharp, Rogers and Preece 2015)

3.3 Observation

Observation is a data gathering technique that is relevant to use in all the stages of the product development process. An observation done early in the process helps to collect information about the user's tasks, goals and contexts. Observations can be done in different ways. Either by direct observations of the activity or indirect by recordings and watched later. The observation can take place in different surroundings. It can either be in the field where the individuals are observed doing everyday things in natural settings or it can be done in a controlled environment where individuals are operating specific task that can take place in a usability laboratory. (Sharp, Rogers and Preece 2015)

By observing participants through videotaping both visual data and audio is gathered. Important to point out is that even if the observation is planed with consideration of making it comfortable for the participants, it can still have an impact on their behaviour since the situation could be considered intrusive. This is necessary to account when analysing the data. (Sharp, Rogers and Preece 2015)

3.4 Questionnaire

Questionnaires are a data gathering technique used for collecting demographic data and opinions of potential users. One advantage of using questionnaires as a data gathering technique is that it can be distributed easily and result in many participants. A questionnaire can have different types of formats, for example check boxes, ranges and Likert scales, these are considered to be closed-ended questions. Another alternative is to have open-ended questions where the participants instead can answer freely. (Sharp, Rogers & Preece 2015)

4 Concept Development

In this section, the process of the performed concept development phase is described. The activities that have been carried out are identification of customer needs, establishing target specification, generation and selection of concepts followed by iterations. Lastly, information about material selection and prototyping of the handle is provided.

4.1 Identifying Customer Needs

To identify the customer needs methodological triangulation was used. The two different methods chosen to gather data were observations and a questionnaire.

4.1.1 **Observation**

When conducting the observations an amount of 11 people was asked to brush their teeth while being recorded on film. Location, type of toothbrush and toothbrush model differed between the participants, for specified information see Table 3. The different types of locations were either in the field or in a controlled environment. When observations took place in the field, the participants were observed in natural setting at home. In the controlled environment, the participants were observed at school premises.

Out of 11 participants 2 used an electric toothbrush because they did not have a manual toothbrush in their possession and since the observation was made in the field with these participants no manual type could be distributed.

The toothbrush model for 3 out of 11 participants was also unknown, this since these observations were conducted in the field and therefore no model could be accurately confirmed through the recording. However, conclusion was drawn that the model of the electric toothbrushes did not serve any noticeable importance for the analysis of the observations, neither would the amount of one manual toothbrush with unknown model do.

Table 3. Detailed information about participant settings.

Participant no.	Location	Type of toothbrush	Toothbrush model
1	Field	Electric	Unknown
2	Field	Manual	Unknown
3	Controlled	Manual	TePe Select
4	Controlled	Manual	TePe Select
5	Controlled	Manual	TePe Select
6	Controlled	Manual	TePe Select
7	Controlled	Manual	TePe Select
8	Controlled	Manual	TePe Select
9	Controlled	Manual	TePe Select
10	Field	Manual	TePe Select
11	Field	Electric	Unknown

Before the analysis of the recorded videos were conducted a set of questions were established. The questions generated a systematic approach of observing the participants and made it easier to compare and find patterns. The questions were formulated as followed:

- What do the different hand grips look like?
- Where is the hand placed? Close or far from the bottom of the toothbrush?
- How is the time distributed between holding the toothbrush on the short side compared to the long side?

4.1.1.1 Result

The most common grips that were identified can be seen in Figure 15. These include whole hand grip, finger grip and high edge grip. All participants using a manual toothbrush used the high edge grip at some point while brushing. No participant had the same grip during the whole session but instead changed grip depending on what side of the mouth and teeth they were brushing on. 8 out of 11 participants placed their hand close to the bottom of the toothbrush. No significant pattern was recognised regarding gender and placement on the handle.

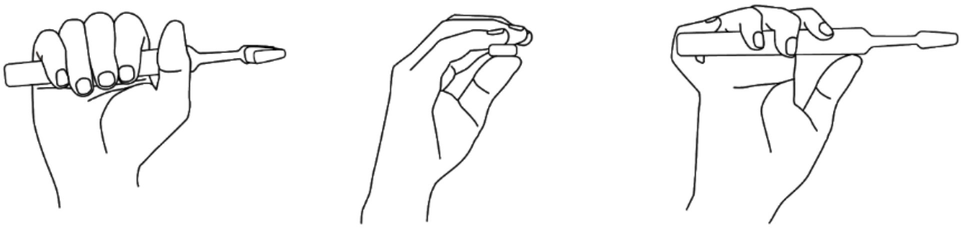


Figure 15. Most common grips. Whole hand grip to the left, finger grip in the middle and high edge grip to the right.

4.1.1.2 Reflection

The observations showed that people tend to change their grip very often during their toothbrushing. Even though there were 3 grips that occurred most frequently no one of the participants stuck to only one during the whole tooth brushing session. The design of the handle must therefore allow an easy change of grip and be designed for multiple ways to hold.

Observation is a good way of seeing how people operate the product but since the participants are aware of the observation taking place, it could have had an impact on their behaviour. As a result, they might not act as they normally would and therefore it is important to take the possible change of behaviour into consideration.

Some of the participants explained that they normally would be in front of a mirror when brushing their teeth while the rest ordinarily brush their teeth whilst doing other chores. Their normal environment was not simulated in the observation and the change of environment settings could therefore affect how they perform the task.

Out of the 11 participants 4 recorded themselves in the field when brushing their teeth instead of the recording taking place in a controlled environment. Since they were not aware of what was to be analysed in the videos the cameras were not placed in an angle that was optimal for the observation. Therefore, making it harder to analyse the grips in these recordings.

4.1.2 **Questionnaire**

The questionnaire was created to investigate the thoughts a potential user has regarding sustainability when choosing a toothbrush. The questionnaire consisted of 11 questions having the format of check boxes, ranges and Likert scales. It also included two open-ended questions. The open-ended questions were chosen to be placed at the end of the questionnaire since it might be fewer people willing to answer them. By placing these questions last the participants could choose not to answer while still contributing with data for the questions asked in advance.

Before the questionnaire was released, a pilot study was performed. A woman answered the questions and was timed without her knowledge to not affect her. After she was done feedback was given by her and the approximate time to finish the questionnaire was changed from 3 min to 5 min in the introduction. No further changes were done to the questionnaire as a result of the pilot test.

The questionnaire was first released internally at TePe until 32 answers were collected. This was done because it was believed that the people working with toothbrushes might have a different approach and knowledge regarding the design. Therefore, the answers from TePe employees might be interesting to compare to other people. Answers from other people were gathered by making a poster with a QR-code leading to the questionnaire and hanging it up in different locations at Lund University. Answers were also conducted by asking classmates, family and friends to answer the questionnaire.

4.1.2.1 Result

A total of 95 people answered the questionnaire. 49.5% of the people answering identified themselves as male and 50.5% as female. The age range of the participants can be seen in Figure 16. The distribution between the different ranges was approximately the same, the largest portion of participants had an age of 21-30 years old.

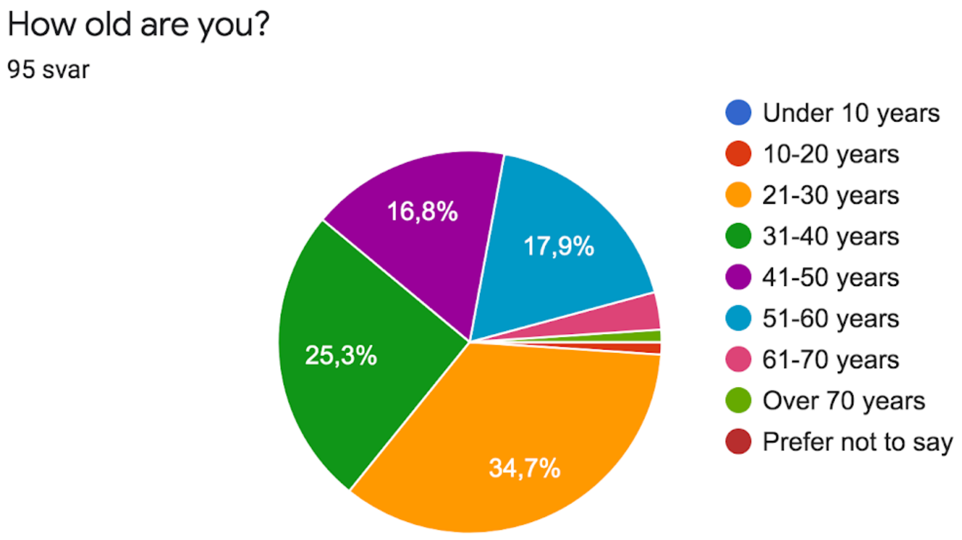


Figure 16. The age range of the participants of the survey.

The answers from the questionnaire showed that people were willing to pay everything between 21-40 SEK. The most distinctive range was the alternative with a price between 26-30 SEK.

Regarding the possibility to keep the toothbrush handle and only replace the worn-out toothbrush head with a new one, a clear majority of 85.3% appreciated this feature. People also agreed on that it was more beneficial for the environment to keep the toothbrush handle and only replace the head. When asked how long the participants are willing to keep the toothbrush handle the larger part of the participants, 35.8%, said 6 months to 1 year.

Most of the participants also agreed that it was important that the natural material is locally produced. However, the results also showed that many were neutral in their opinion.

As regard to the design 75.8 % of the answers were in favour of design alternative 2, see Figure 17.

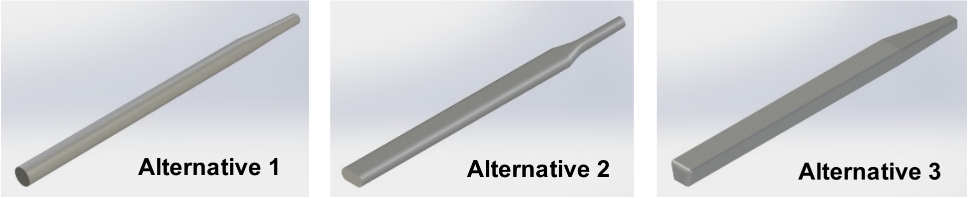


Figure 17. Design alternatives in the questionnaire.

The two most important aspects when choosing toothbrush were quality and environmental impact.

4.1.2.2 Reflection

The equal distribution of the respondents gender is seen as positive since it indicates that opinions from the entire target group has been equally gathered.

Important to point out is that a lot of people working at TePe, as well as some classmates, were aware of the project and its outcome before they filled out the questionnaire. This might have resulted in opinions being affected and answers being adjusted in the projects favour.

Even after the questionnaire was released for responses outside of TePe, people from the company could still fill out the questionnaire. This affects the comparison made between the results from the two different occasions when answers were extracted.

There were some distinctive changes in results between extraction one and extraction two where extraction one is answers collected only from TePe while extraction two is answers collected outside of the company as well. One of these changes was the age of the participants. When released outside of the company many participants had a younger age which resulted in an increase of the age range 21-30 years. What was noticed after the increase of younger participants was that the price one was willing to pay increased. Another thing that was observed was that the time you would consider using the same toothbrush handle also increased, people were now willing to use the same handle for over 2 years. However, the majority still preferred the alternative of keeping the toothbrush handle for 6 months to 1 year.

Results that remained the same from extraction one and extraction two were the possibility to keep the toothbrush handle while only exchanging the head, the design of the handle and the two most important aspects (quality and environmental impact) when choosing the toothbrush.

4.1.3 **Customer Needs**

The data gathered from the questionnaire was used as a base to establish the 46 customer needs that can be seen in Table 6.

Through a content analysis of the responses from the open-ended questions in the questionnaire, a structured approach of creating the customer needs list was obtained. The content analysis was performed by interpreting the statement from customer and was followed by phrasing a theme that covered the essence of what the customer was expressing. When a similar statement was encountered it became included in an existing theme and the occurrence was counted.

The first open-ended question had 71 responses and resulted in 11 themes that can be seen in Table 4. The second open-ended question had 57 responses and resulted in 8 themes that can be seen in Table 5. The sum of the counted occurrences does not match the amount of responses since a statement sometimes could include several different opinions resulting in an increase of occurrences in multiple themes.

Some themes were more vaguely expressed than others because they consisted of many different statements. The themes brush head and clean teeth are two examples of this. The theme brush head covered aspects such as filament softness, tapered brush head, length of the toothbrush neck and other statements in relation to the brush head. “Soft filaments and small brush head” is an example of how a statement that was put in the theme brush head could look like.

Table 4. Themes created from open-ended question 1.

What do you appreciate the most about your toothbrush?	**Counted occurrence**
Brush head	26
Clean teeth	20
Functionality	18
Quality	17
Ergonomics	6
Design (Aesthetic)	5
Sustainable	4
Feeling	4
Electrical	2
Simplicity	2
Price	1
Sum of occurrences:	105

Table 5. Themes created from open-ended question 2.

Is there something you would like to change about your toothbrush?	**Counted occurrence**
Sustainable	21
No	13
Durability	9
Design (Aesthetic)	7
Replaceable head	5
Ergonomics	5
Maintenance	2
Functionality	2
Brush head	1
Sum of occurrences:	65

The content analysis made it possible to organize large amount of data effectively and gave a good overview of all the responses. It also created knowledge about the attributes that were mentioned more frequently. All individual statements within the different themes were once again interpreted and rewritten as a customer need one by one. Moreover, this task was performed individually to create opportunities for different interpretations.

To ensure consistency in the phrasing of the customer needs among all members, Ulrich and Eppinger (2012) states five guidelines that were applied in the process. These were:

- Express the need in terms of what the product has to do, not in terms of how it might do it.

- Express the need as specifically as the raw data.
- Use positive, not negative, phrasing.
- Express the need as an attribute of the product.
- Avoid the word must and should.

After individually exploring possible customer needs for all the different statements, a discussion followed to compile the customer needs list. By dividing all statements into themes and exploring customer needs within these themes a structure was built among the customer needs from the beginning. However, the structure could be further developed since some themes were to general, such as the theme "Functionality". To improve the structure, a customer need which generalised the needs within a group was chosen as label for that group. The final customer needs list can be seen in Table 6. The bold text represents the label of the group.

The customer needs were also given a weight factor based on both intuition from the group members and with regards to the frequency that it had been mentioned from the content analysis. The customer needs were given a weight factor on a scale from 1-5 on how desirable they were. The meaning of the numbers is explained as followed:

1. This feature is **undesirable**. A product with this feature is not to be considered.
2. This feature is **not important** but having it would not matter for the user.
3. This feature is **not necessary** but would be a good attribute for the user.
4. This feature is **highly desirable** but a product without it would still be an option.
5. This feature is **critical**. A product without this feature is not to be considered.

Table 6. Customer needs list.

No.	Customer Need	Imp.
1	**The toothbrush is sustainable**	**5**
2	The toothbrush minimises the usage of petroleum resources	**4**
3	The toothbrush contains as little plastic as possible	**4**
4	The toothbrush has reduced environmental footprint compared to a plastic one	**5**
5	The toothbrush is made of environmentally sustainable materials	**5**
6	The toothbrush is biodegradable	**4**
7	The toothbrush handle is made out of locally produced natural material	**4**
8	The toothbrush has as little material as possible	**2**
9	**The toothbrush is durable**	**4**
10	The toothbrush can last for an eternity	**1**
11	The toothbrush has good quality	**5**
12	The toothbrush lasts longer so that the time between having to buy a new one is increased	**3**

13	**The toothbrush handle is ergonomic**	**4**
14	The toothbrush handle is comfortable to hold	**4**
15	The toothbrush has a good grip	**4**
16	**The toothbrush has a replaceable head**	**5**
17	The toothbrush can be used with different heads, i.e. normal one, small one etc.	**3**
18	**The toothbrush has an aesthetically pleasing design**	**4**
19	The toothbrush has a modern design	**3**
20	The toothbrush provides more design options, i.e. ability to personalise the design of the toothbrush	**3**
21	The toothbrush is simple	**3**
22	The toothbrush looks recognisable	**2**
23	**The toothbrush is made by a company with good strategies and efforts**	**3**
24	The toothbrush is made in good working conditions	**4**
25	**The toothbrush is easy to find**	**2**
26	The toothbrush has a bright colour	**2**
27	**The toothbrush feels smooth in the mouth**	**5**
28	The toothbrush connection point is outside of the mouth	**4**
29	The toothbrush leaves a good feeling in the gums	**4**
30	The toothbrush leaves a good feeling on the teeth	**4**
31	The toothbrush has rounded filaments	**5**
32	The toothbrush has soft filaments	**4**
33	**The toothbrush is easy to clean**	**4**
34	The toothbrush feels fresh	**4**
35	**The toothbrush cleans properly**	**5**
36	The toothbrush is effective	**4**
37	**The toothbrush has a good reach**	**4**
38	The toothbrush has a long neck	**3**
39	The toothbrush has a small brush head	**3**
40	**The toothbrush is easy to use**	**4**
41	The toothbrush indicates when the replaceable toothbrush head needs to be replaced	**3**
42	The toothbrush has an indicator on the handle that indicates when too much force is applied	**3**
43	**The toothbrush is affordable**	**4**
44	**The toothbrush offers possibility to put your name on it**	**3**
45	**The toothbrush can be found in the local grocery store**	**4**
46	**The toothbrush has a tongue scrape**	**3**

4.2 Target Specification

After analysing the results from the questionnaire and establishing the customer needs it became clear that a replaceable head was desirable among most of the users and therefor it was chosen as a must have feature when establishing the target specification. Since designing the head of the toothbrush was not a part of this project, all customer needs related to the design of the head were not taken into consideration when establishing the target specifications. When establishing the target specifications, metrics were formed from the customer needs. These metrics were given an importance rate. Since one metric can be constructed out of multiple customer needs the importance rate was given by choosing the highest importance rate from the customer needs that were used to construct the specific metric. The metrics that were formed from only one customer need got the same importance rate as that need. The target specifications can be seen in Table 7.

Table 7. Target specification list.

Metric no.	Need no.	Metric	Imp.	Unit
1	43	Unit manufacturing cost	**4**	SEK
2	2,3	Total mass of plastic	**4**	kg
3	33,40	Time to assemble/disassemble	**4**	s
4	37,38	Length of toothbrush neck	**4**	mm
5	9,11,12	Number of uses before failure	**5**	No.
6	9,11,16	Number of assembles/disassembles before failure	**5**	No.
7	14,27,34	Surface finish	**5**	Ra
8	41	Wear indicator	**3**	Visual
9	1,4,5,7	Locally produced material for the handle	**5**	km
10	6	Biodegradation of the handle	**4**	Months
11	13,14,15,28	Comfortable to use	**4**	Subj.
12	24	Produced with fair working conditions	**4**	Subj.
13	18,19,21,22	Good design	**4**	Subj.
14	9,11,34	Mould resistance	**5**	Days
15	9,11	Shrinkage of the handle	**5**	%
16	9,11	Janka hardness	**5**	N
17	9,11	Modulus of rupture	**5**	MPa
18	9,11	Modulus of elasticity	**5**	MPa

4.3 Concept Generation

The concept generation began by studying the customer needs and target specifications established earlier in the concept development phase. A five-step method, see Figure 18, presented by Ulrich and Eppinger (2012) was used to structure the concept generation phase. The result given from this phase was a set of product concepts.

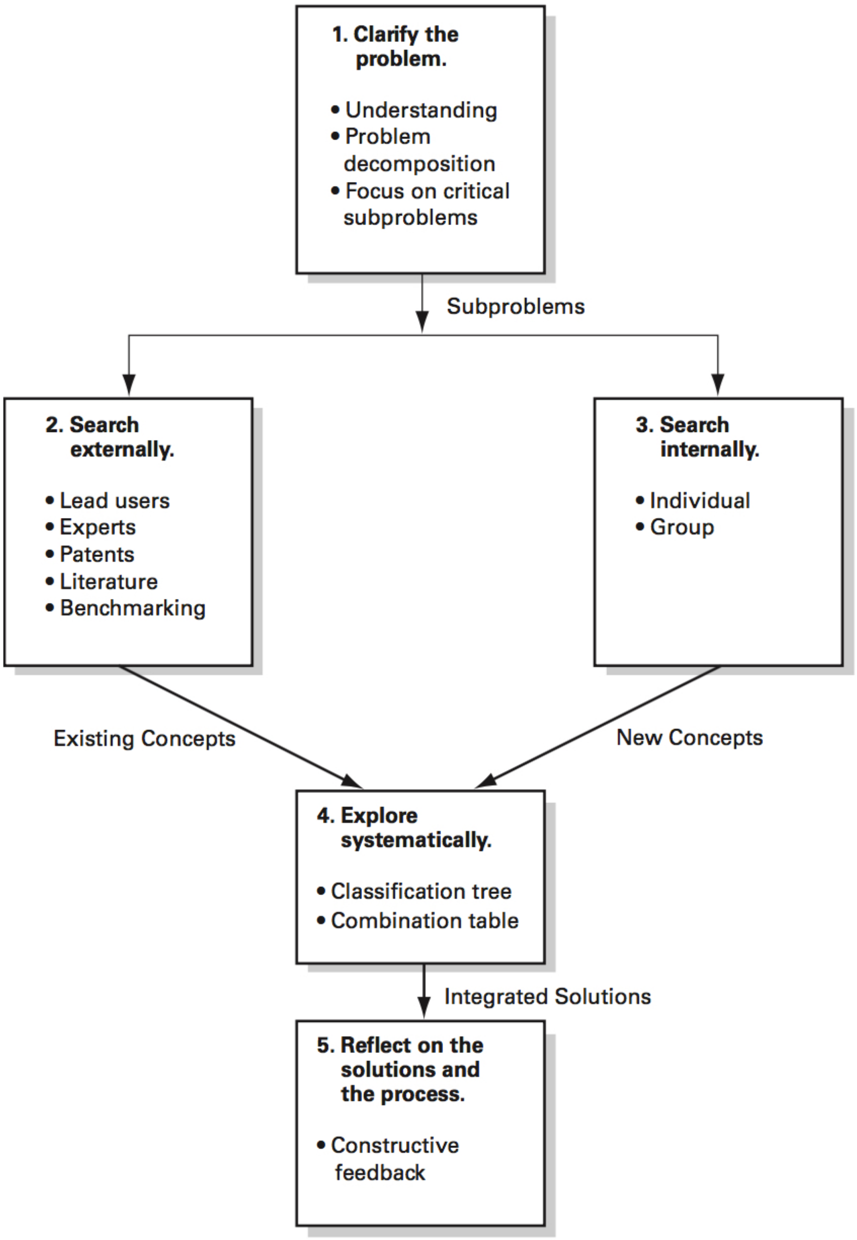


Figure 18. The Five-Step Method. (Ulrich and Eppinger 2012)

4.3.1 **Clarify the Problem**

To clarify the problem a decomposition by key customer needs (Ulrich and Eppinger 2012) were performed to divide the problem into simpler subproblems. Key customer needs that were chosen by the group were the following:

- The toothbrush is sustainable
- The toothbrush handle is ergonomic
- The toothbrush has a replaceable head
- The toothbrush is mould resistant

4.3.2 **Search Externally**

External search for the interface was done by benchmarking, searching for existing patents and talking to a designer.

When benchmarking related products, toothbrushes in bamboo with replaceable heads in bamboo were found. These toothbrushes had very simple solutions for the interface between the handle and the head. The solution was to simply have a plug. A toothbrush from Ecoboom was found which had the hole in the handle and the shaft on the head as seen in Figure 19, but the opposite solution also occurred for other brands, i.e. hole in the head and shaft on the handle.

Figure 19. A toothbrush from Ecoboom with an interface completely made of bamboo. The interface consists of having the hole in the handle and the shaft in the head. (Amazon n.d.)

Other solutions found when benchmarking was toothbrushes where the interface consisted of both plastic and metal. This design is frequently used for electrical toothbrushes. In Figure 20, a toothbrush from Oral B can be seen having the same solution. However, introducing another material besides plastic and wood was not seen as beneficial due to the complication of sorting the materials after use. It was therefore concluded to not be an option.

Figure 20. An electric toothbrush from Oral B with an interface created of both plastic and metal.

The most common solution found for products with wooden handles and replaceable plastic heads was to have a plastic mid part permanently attached to the handle. In Figure 21 a dish sponge from Full Circle having this design can be seen. The mid part in plastic acts as a link between the wooden handle and the removable plastic head. Therefore, the interface making the attachment and removal of the head was created between the two plastic parts. Since these kinds of interfaces are easily created in plastic a solution like this can be favourable for the project. But having two different materials permanently attached to each other, again is not beneficial due to problems when sorting the materials after worn out product.

Figure 21. A dish sponge from Full Circle with a handle in wood, a replaceable head in plastic and a permanently attached midpart in plastic. (Ecostainable n.d.)

No toothbrushes were found with a toothbrush head in plastic connecting to a handle in wood. The lack of solutions like this indicates that there is a research gap currently existing on the market.

Regarding the design of the toothbrush, a designer of multiple toothbrushes was consulted. At this point a lot of focus of the project had been put on making the toothbrush design as ergonomic as possible. However, the designer pointed out that a toothbrush session lasts for approximately 2 minutes which makes the ergonomics of it less important than previously anticipated. A more relevant aspect to focus on would therefore be the toothbrush's producibility.

4.3.3 **Search Internally**

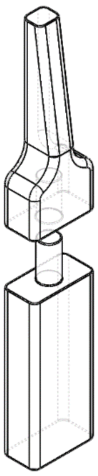
The internal search began by brainstorming ideas about the subproblems defined when clarifying the problem. This task was performed both individually and in cooperation. According to Ulrich and Eppinger (2012), using this strategy may result in the arise of more concepts and a broader spectrum of solutions are made possible. Concepts were produced by sketching as well as making models in clay. Since the design of the handle and the design of the interface are dependent on each other a decision was made to primarily only focus on the configuration of the interface. Because the interface includes more complex parts it is considered better if the interface put limitations on the design of the handle than the opposite.

4.3.4 **Explore Systematically**

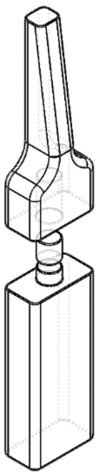
Systematic exploration is intended to organise and evaluate the ideas and concepts developed. To get an overview of what concepts had been created during the project a poster was made, see Figure 22. On this poster all the generated ideas regarding the interface, the handle and solutions to counteract moulding were attached as well as collected material from the benchmarking. These were then grouped in categories with similar solutions and each concept good enough to continue developing was given a name as a letter from A-R.

Figure 22. Poster of all generated ideas and inspiration from benchmarking.

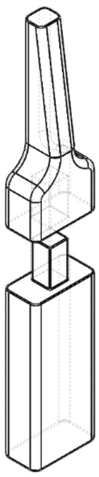
The next stage was to make the technical solutions to the ideas on the poster. This was done by creating 3D-models in CAD using the program SolidWorks. In this process, some concepts were eliminated. This happened to concept N and I due to the lack of ideas for technical solutions. In the same process a new idea arose, and concept S was added. The concepts are seen in Figure 23 below.



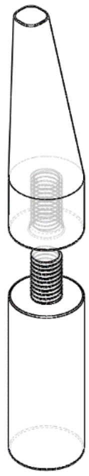
Concept A



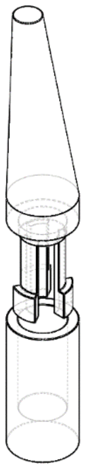
Concept B



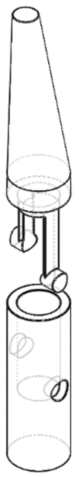
Concept C



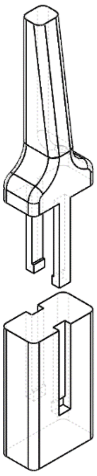
Concept D



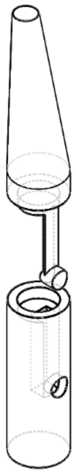
Concept E



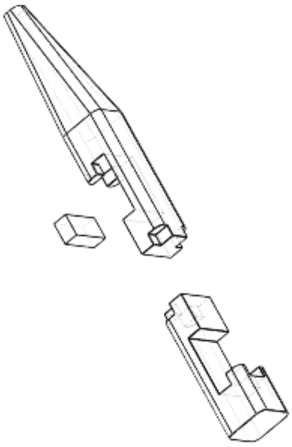
Concept F



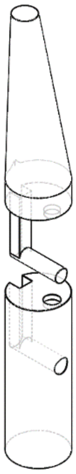
Concept G



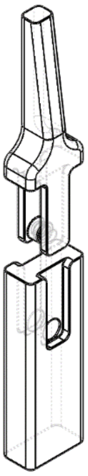
Concept H



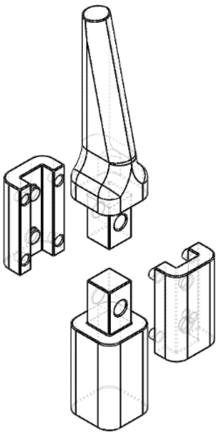
Concept J



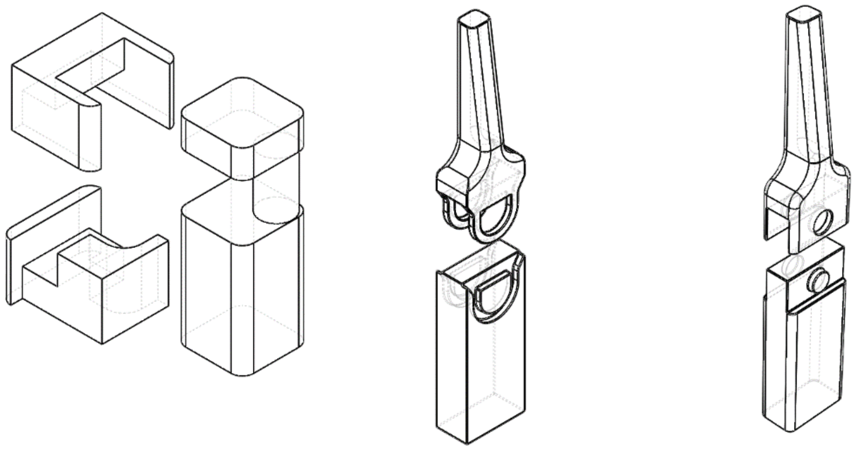
Concept K



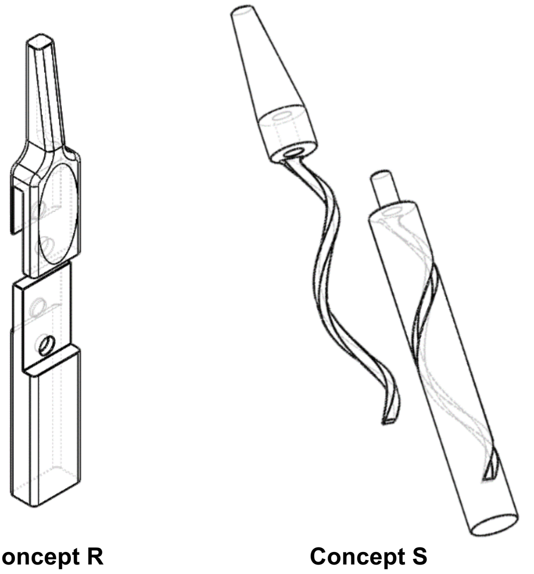
Concept L



Concept M



Concept O **Concept P** **Concept Q**



Concept R **Concept S**

Figure 23. Pictures of the 3D-models made in CAD.

When all concepts were modelled in CAD, they were 3D printed. Taking into account that a total of 17 concepts were modelled, it was considered most time efficient to print them all in one session and therefore the SLS method was used. The physical prototypes in the material PA were believed to give a more evident representation of the concepts compared to only evaluating them in CAD, see Figure 24 for result.

Figure 24. Picture of the 3D printed models in PA using the SLS method.

4.4 Concept Selection

The first concept selection was done by using a scoring matrix. When using a scoring matrix, the team rates all concepts against predefined criteria. The criteria are also given a weight factor depending on their importance for the product (Ulrich and Eppinger 2012). The scoring matrix was chosen because it was believed that this method would result in an equal and foremost detailed review of all the concepts. Discussion and evaluation of the concepts were done in collaboration with the product development team at TePe.

The predefined criteria that were established to evaluate the concepts against were the following:

- Ease of assembly
- Interface robustness
- Ability to keep fresh
- Ease of manufacture
- Design (Aesthetic)

The criteria were formulated regarding knowledge gained from customer needs and they were meant to cover the most important needs identified. The last criteria, Design (Aesthetic), was not a part of the scoring matrix due to the probability of basing it on personal liking and therefore making it difficult to give an objective rating like the other criteria. However, the design criteria still had an impact on the evaluation and selection of the concepts since opinions from the product development department at TePe were gathered during the process. The opinions about the design were later taken into consideration separately from the result of the scoring matrix.

To rate the concepts against the criteria a Likert scale from 1-5 for each criterion was established. The meaning of the different ratings was defined as followed:

1. The concept is **very unsatisfying**.
2. The concept is **unsatisfying.**
3. The concept is **neutral.**
4. The concept is **satisfying.**
5. The concept is **very satisfying.**

To clarify the meaning of each rating a specific explanation connected to each criterion was also formulated. For example, if a concept was given rate 1 for the criterion ease of manufacture, the full meaning of this rating was: The concept is **very unsatisfying**. All manufacturing steps of the design requires manual processing. Will probably have a long cycle time. For full description of all ratings to each criterion, see appendix C.

After clarifying all ratings for each criterion, the weight factors were established. The weight factor sets the influence of the rating on the criteria. Calculation of the weighted score is accomplished by multiplying the rating with the weight factor proportion.

It was decided that interface robustness had the highest importance of all criteria because it was thought to have the highest impact on the user experience. This criterion was therefore given the highest weight factor. The second highest weight factor was given to the criteria ease of manufacture followed by ease of assembly and lastly ability to keep fresh. The choice of the order was built on the prediction that if the design were to be too complicated to manufacture it might become too costly and not beneficial for either the company or the customer. If the product were to end here, the criteria ease of assembly and ability to keep fresh would not matter because the customer would not buy the product in the first hand. The criteria ability to keep fresh was placed last with a similar reasoning as mentioned above, if not able to assemble the product, the customer would not be able to use the toothbrush, hence the criteria ability to keep fresh would not matter. For an example of the structure of the scoring matrix, see Table 8.

4.4.1 **Evaluation**

After establishing the structure of the scoring matrix, discussion and evaluation with the product development team at TePe began. To properly describe all the concepts both pictures and 3D printed prototypes were used. The concepts were presented one at a time and this was then followed by a discussion that ended with a joint decision from the team about the chosen rating for each criterion. Notes were taken parallel to the discussion in order to remember the argument for the given rate. Lastly, comments about the design from an aesthetic point of view were asked for and documented. See appendix D for complete documentation of notes. After going through all the concepts, the ratings were added in the scoring matrix and the weighted score was calculated. By summarising all the weighted scores for each concept, the total score was computed. The highest score among all the concepts were then given rank 1, the second highest rank 2, and so forth. The scoring matrices with complete data can be seen in Table 8 - Table 13.

Table 8. Complete scoring matrix for concept A-C.

		Concept					
		A		B		C	
Selection Criteria	**Weight**	**Rate**	**W. Score**	**Rate**	**W. Score**	**Rate**	**W. Score**
Ease of assembly	20%	3	0.6	3	0.6	4	0.8
Interface robustness	35%	3	1.05	3	1.05	3	1.05
Ability to keep fresh	15%	3	0.45	3	0.45	2	0.3
Ease of manufacture	30%	5	1.5	4	1.2	3	0.9
	Total		3.6		3.3		3.05
	Rank		1		2		3
	Continue?		No		No		No

Table 9. Complete scoring matrix for concept D-F.

		Concept					
		D		E		F	
Selection Criteria	**Weight**	**Rate**	**W. Score**	**Rate**	**W. Score**	**Rate**	**W. Score**
Ease of assembly	20%	4	0.8	4	0.8	2	0.4
Interface robustness	35%	3	1.05	3	1.05	2	0.7
Ability to keep fresh	15%	4	0.6	2	0.3	2	0.3
Ease of manufacture	30%	2	0.6	3	0.9	3	0.9
	Total		3.05		3.05		2.3
	Rank		3		3		9
	Continue?		Combine		No		Yes

Table 10. Complete scoring matrix for concept G-J.

		Concept					
		G		H		J	
Selection Criteria	**Weight**	**Rate**	**W. Score**	**Rate**	**W. Score**	**Rate**	**W. Score**
Ease of assembly	20%	3	0.6	4	0.8	2	0.4
Interface robustness	35%	1	0.35	2	0.7	2	0.7
Ability to keep fresh	15%	2	0.3	2	0.3	3	0.45
Ease of manufacture	30%	3	0.9	3	0.9	3	0.9
	Total		2.15		2.7		2.45
	Rank		10		5		6
	Continue?		No		Yes		No

Table 11. Complete scoring matrix for concept K-M.

		Concept					
		K		L		M	
Selection Criteria	**Weight**	**Rate**	**W. Score**	**Rate**	**W. Score**	**Rate**	**W. Score**
Ease of assembly	20%	4	0.8	2	0.4	1	0.2
Interface robustness	35%	1	0.35	2	0.7	2	0.7
Ability to keep fresh	15%	2	0.3	2	0.3	2	0.3
Ease of manufacture	30%	3	0.9	1	0.3	4	1.2
	Total		2.35		1.7		2.4
	Rank		8		12		7
	Continue?		No		No		No

Table 12. Complete scoring matrix for concept O-Q.

		Concept					
		O		P		Q	
Selection Criteria	**Weight**	**Rate**	**W. Score**	**Rate**	**W. Score**	**Rate**	**W. Score**
Ease of assembly	20%	1	0.2	4	0.8	4	0.8
Interface robustness	35%	1	0.35	2	0.7	2	0.7
Ability to keep fresh	15%	2	0.3	3	0.45	3	0.45
Ease of manufacture	30%	1	0.3	3	0.9	3	0.9
	Total		1.15		2.85		2.85
	Rank		13		4		4
	Continue?		No		Combine		No

Table 13. Complete scoring matrix for concept R-S.

		Concept					
		R		S		-	
Selection Criteria	**Weight**	**Rate**	**W. Score**	**Rate**	**W. Score**	**Rate**	**W. Score**
Ease of assembly	20%	4	0.8	3	0.6	-	-
Interface robustness	35%	2	0.7	1	0.35	-	-
Ability to keep fresh	15%	2	0.3	2	0.3	-	-
Ease of manufacture	30%	3	0.9	2	0.6	-	-
	Total		2.7		1.85		-
	Rank		5		11		-
	Continue?		No		No		-

The box from the scoring matrix stating the question “Continue?” was the last one to be filled in. The possible answers for this question were “yes”, “no” or “combine”. If the answer was “combine” it implied that the concept would be further developed but in combination with another concept. Both the rank of the concept and the notes taken during the evaluation at TePe were taken into consideration when deciding to continue, not continue or combine the concept. However, the discussion held during the evaluation has had a greater impact when selecting concepts rather than the individual ranks of them. This due to the fact that the ratings given were considered inconsistent with the opinions stated during the discussion. In Table 14, the concept with the highest rank to the lowest rank can be seen in descending order. Information about the continued development can also be observed.

Table 14. List of all concepts in descending order according to rank.

Rank	**Concept Name**	**Continue?**
1	A	No
2	B	No
3	C	No
3	D	Combine with P
3	E	No
4	P	Combine with D
4	Q	No
5	H	Yes
5	R	No
6	J	No
7	M	No
8	K	No
9	F	Yes
10	G	No
11	S	No
12	L	No
13	O	No

The result from Table 14 shows that even though a high rank was obtained it did not automatically mean that the concept moved on for further development. Among other, this was the case for concept A, concept B, concept C and concept E. All had high ranks but were determined not to be continued. The reason for not moving forward with concept A, concept B and concept C was that the function of the interface was considered too unstable. Regarding concept A and concept B, they were dismissed due to their tendency of rotation when exposed to rotational force. Even though an O-ring had been introduced in concept B to eliminate this problem, it was still not considered as a good enough solution. As for concept C, tendency of rotation was not a problem but instead it had no stability in the pull-direction since nothing hindered detachment except good tolerance between male and female part of the interface. This was also the case for concept A and concept B. Like concept A and concept B, concept E also tended to rotate. Additionally, the function for concept E was built on the requirement of the material being able to regain its form after being bent. According to TePe, this was something that the material PE, intended to be used for the final product, lacked. Looking at production, the injection moulding of concept E would also require core pull due to asymmetry with three legs and the negative space behind the legs.

Concept Q and concept R are also examples of high ranked concepts that did not move on for continued development. The reason was that concept Q and concept R was perceived as less promising than concept P who had the same rank or better. All concepts also resembled one another which called for the decision to only continue with concept P.

Other disregarded concepts despite a better rank compared to concept F that moved on for further development, was concept M and concept J. The reason for this was that both concepts had too many parts which was believed to have a negative impact regarding user friendliness and assembly in production. It was therefore concluded that their rate should have been lower than the one given during evaluation since the negative impact of several parts was not fairly reflected.

Lastly, concept K was decided not to be continued. With reference to concept E, concept K again had a function that was built on the materials ability to regain its former shape after being bent and therefore was not considered a suitable option.

As shown in Table 14, concept H and concept F went on for further development individually and concept D was combined with concept P.

4.5 The First Iteration

4.5.1 **Concept Generation**

Within the first iteration many improvements of each concept occurred. All concepts were modelled in SolidWorks and 3D printed using the FDM method as it was an accessible printing method in no need of management from a third part and therefore resulted in quick prototypes. The material used for the printed prototypes was PLA, which differs in properties in comparison to the PE material meant to be used for the final product. PLA is of stiffer characteristics but when searched for a material more resembling to PE, not many options were suitable. This due to long delivery time if ordered as well as the more challenging process of printing in a softer material. As a result, PLA was selected as the building material with the solution of always taking the different material behaviour in consideration when designing.

During the iterations both parts of the interface were 3D printed. As for the concepts where a prototype of a wooden handle was possible to produce, it was performed after all the concepts were set.

After the first evaluation with TePe there were specifically three concepts that were believed to have potential when further developed. As a result of this, they were chosen to be refined in the first iteration. These three concepts were concept D, concept F and concept H. See Figure 25.

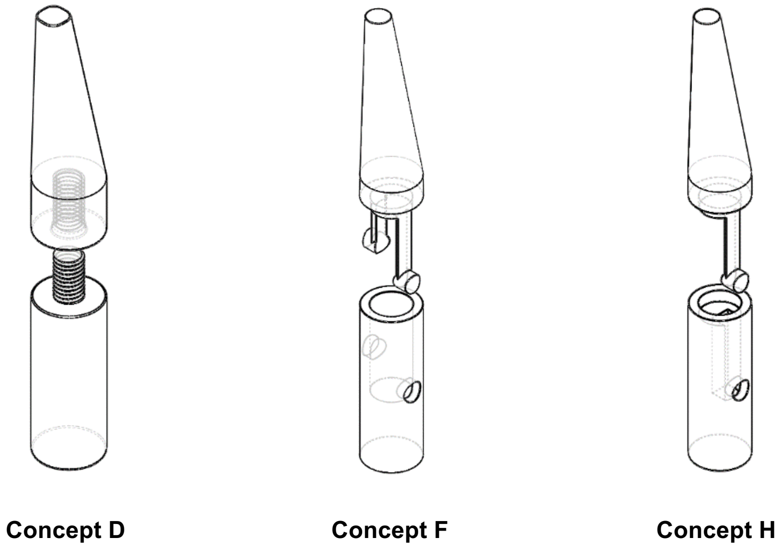


Figure 25. Concepts chosen to be refined in the first iteration.

The design of concept D enabled a sturdy construction but in order to assemble the parts, a long time was to be invested in the operation. Hence, the thread had to be redesigned. By making the pitch larger the time taken to assemble was drastically shortened. The new design of elongating the pitch was also needed to make the threading possible in wood as it allowed a larger amount of wood to exist between the threads and therefore not be as likely to break when manufactured.

Before the final design for concept D was set, many variations of the design was developed and tested. One idea was to combine concept D with concept P in order to have a locking method in the thread that would indicate the sealed interface with a click. This was done by adding a bump to the thread and having an inverted counterpart in the handle that allowed a space for the bump to secure against. See Figure 26 displaying the solution for iteration 1.1 of concept D. Different sizes and designs of the bump were tried out but none gave the result sought for and the idea was therefore dismissed.

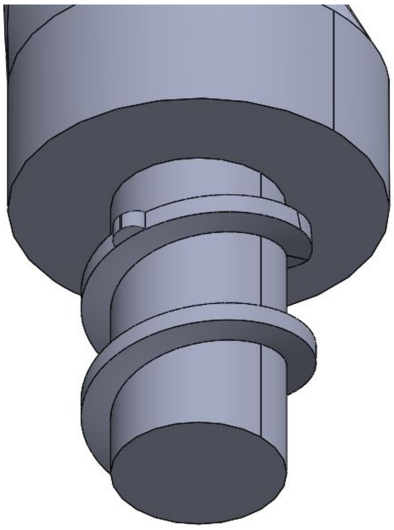


Figure 26. Iteration 1.1 of concept D displaying the solution of having a bump on the thread, locking the head to the handle.

Another solution of improving the sealing of the thread was to use an O-ring. At first this was done simply by moving the thread downwards and allowing space for an O-ring to exist in the slot between the flat surface of the head and the thread, see Figure 27 for iteration 1.2 for concept D. The O-ring contributed to an increased sealing but since no geometry for the O-ring to secure against existed, the result was an unsteady construction as the O-ring could move.

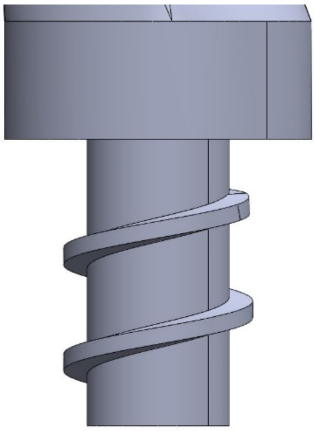


Figure 27. Iteration 1.2 of concept D displaying the solution of moving the thread downwards, enabling space for an O-ring.

By making an attachment for the O-ring and securing it in the vertical direction this problem was disposed of. The final design of concept D was a thread with an increased pitch and a space for an O-ring to be attached, see iteration 1.3 of concept D in Figure 28. The development of concept D can be seen in Figure 29.

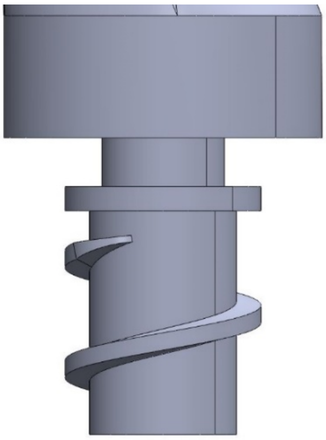


Figure 28. Iteration 1.3 of concept D displaying the solution of introducing an attachment for the O-ring.

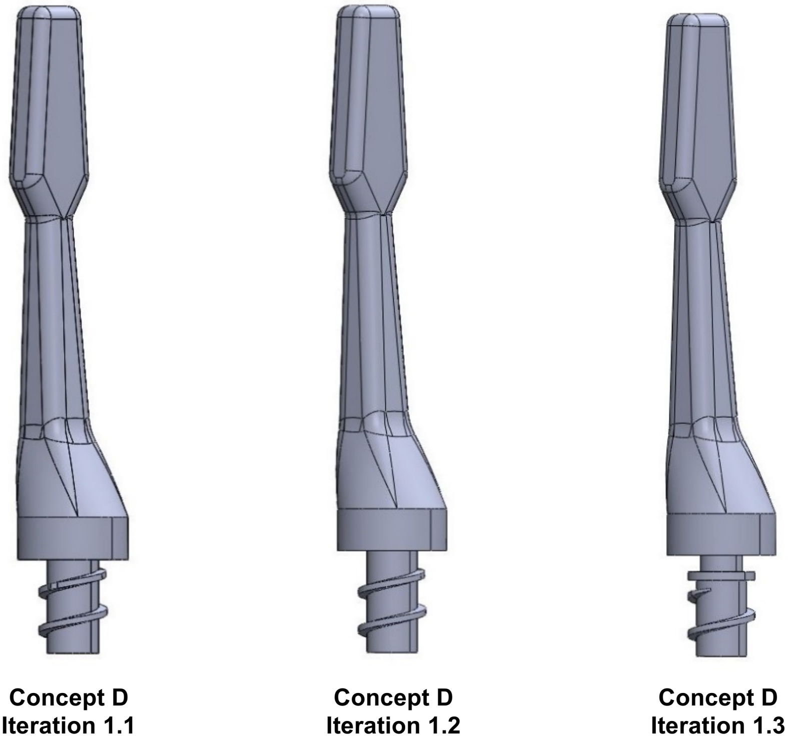


Figure 29. The three stages of development of concept D.

As for concept F and concept H they had a common denominator, they were simply too weak. For this reason, both had to be made thicker to assure sturdiness in the design. Prior to the changes of iteration 1, concept F had two legs placed in different heights, enabling them to be pushed in the handle one at a time. As the legs had different heights allowing them to be pushed into the handle one at a time, the limited space in handle was not as critical. When redesigning the concept, a symmetrical design was desired. The symmetric design would enable the user to mount the toothbrush head to the handle in two directions instead of one which would increase the tolerance for error. Therefore, the legs were changed to equal lengths. To increase the sturdiness of the interface the design of the legs was also changed and made thicker. See concept F, iteration 1.1 in Figure 30. The thickness of the legs was chosen so the legs would still be able to be compressed to a diameter smaller than the hole in the handle. To enable an easier release for the head, a radius was introduced to the extrusion on the legs, see concept F, iteration 1.2 in Figure 30.

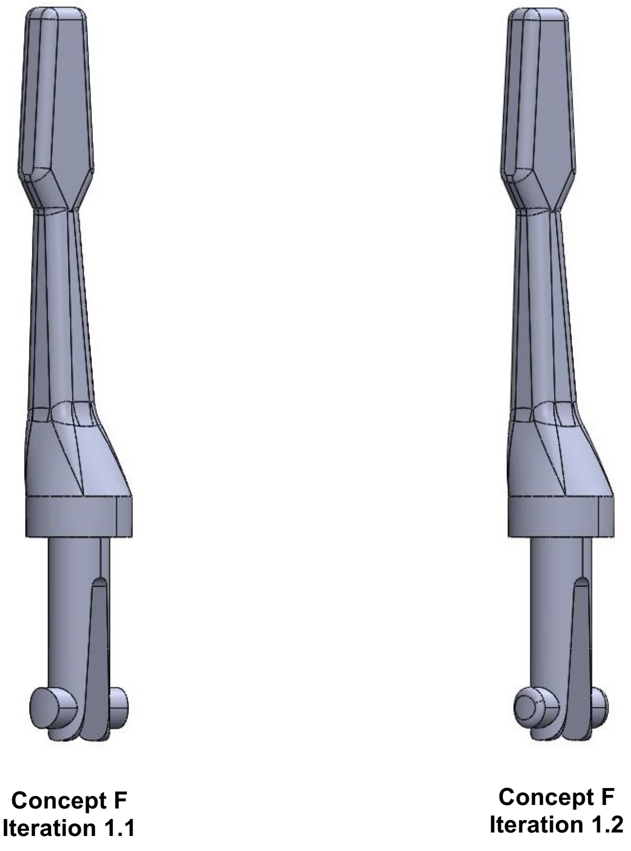


Figure 30. The two stages of development of concept F.

The only changes made between the first iteration and the second is the radius on the extrusion, see Figure 31.

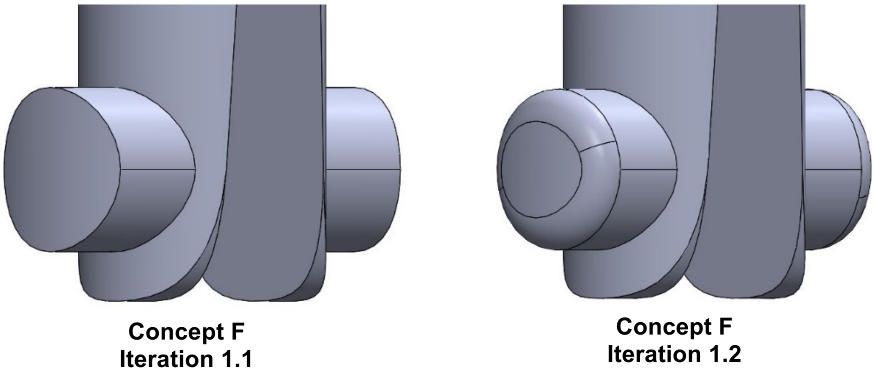


Figure 31. Detailed picture of the differences between iteration 1.1 and 1.2 of concept F

Concept H was in many ways comparable to concept F. Like concept F it was also considered too weak. Therefore, a very similar design was used to change concept H to make it thicker and sturdier. The major difference to the prior design of concept H was that when further developed, another leg was added for support. Like iteration 1.2 of concept F, concept H had rounded corners on the extrusion. See Figure 32.

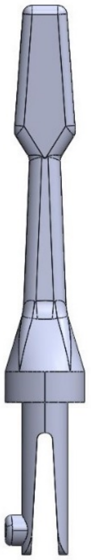


Figure 32. Design of concept H.

Aside from the further development of concept D, concept F and concept H, four new concepts were generated during the first iteration. These were concepts T, concept U, concept V and concept W. See Figure 33.

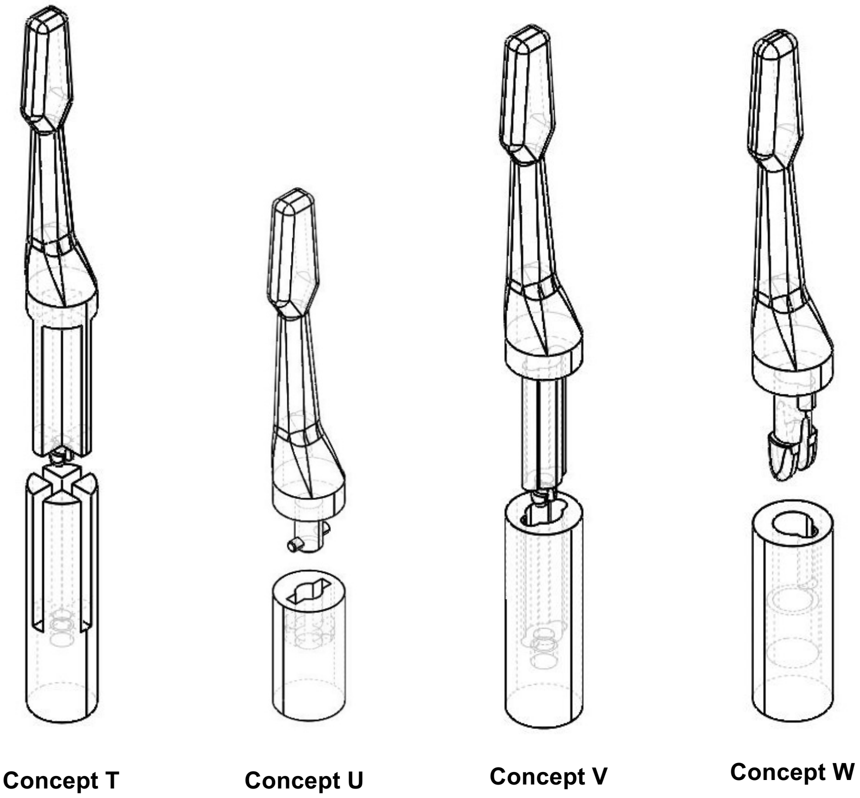
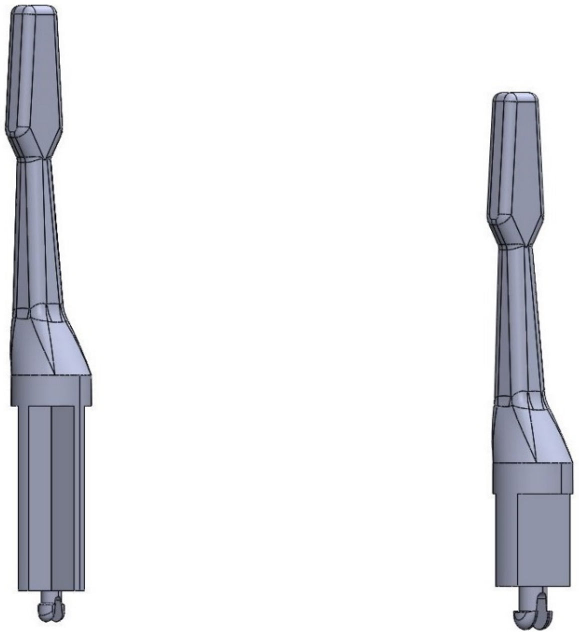


Figure 33. New concepts generated during the first iteration.

Concept T was created based on the idea of having a design that did not allow rotation and would easily be manufactured in wood. Firstly, only the prevention of rotation was considered, and the concept therefore was made to have a cross like design. The design provided a solid shape that was not in need of particularly thick plastic walls. This was believed to make the manufacturing of the handle in wood easy as it only needed to be cut in two directions. At this stage the head was only locked to the handle in radial direction. The solution of securing the toothbrush head with the handle in vertical direction was later added by using the same locking method created in concept W, see iteration 1.1 of concept T in Figure 34. Adding this feature resulted in an extra step in the manufacturing of the wood. It would require a very slim tool to operate in a long distance which could result in possible vibrations and imprecise execution of the hole in the bottom of the cross. Trying to eliminate this problem a new design of concept T was made. Instead of having a design of two walls making a cross, one was disposed of and the remaining wall was made thicker, see iteration 1.2 for concept T in Figure 34. In addition to thickening the wall, a bigger tool could be used to create the hole for the clamp. However, this design was by no means as robust as the earlier construction. Since both solutions had their flaws none of them were chosen to be further developed.



Concept T
Iteration 1.1

Concept T
Iteration 1.2

Figure 34. The two designs of concept T.

Inspiration for concept U came from benchmarking different locking mechanisms. The bayonet mount was found as an interesting solution and was therefore further developed. However, outer cavities were unwanted and therefore the bayonet mount was designed to be completely inside the handle, see Figure 35.

Figure 35. The design of concept U.

Concept V was created with the same reasoning as for concept T but with a different solution regarding the locking method for rotational movement. This design kept the locking method completely inside the handle. The solution for securing the toothbrush head with the handle was once again the same as the one created in concept W. See the design of concept V in Figure 36. When comparing this concept to the others it did not stand out regarding either stability or simple manufacturing and was therefore not chosen to be further developed.

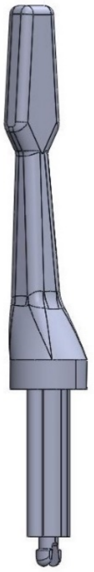


Figure 36. The design of concept V.

For concept W inspiration was taken from concept F with the aspiration of eliminating the outer cavities. The result was an internal clamp with guiding to hinder rotational movement, see Figure 37. All final concepts developed during iteration 1 are illustrated in Figure 38.

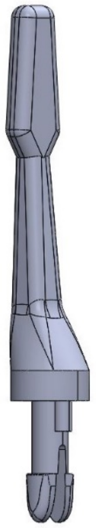
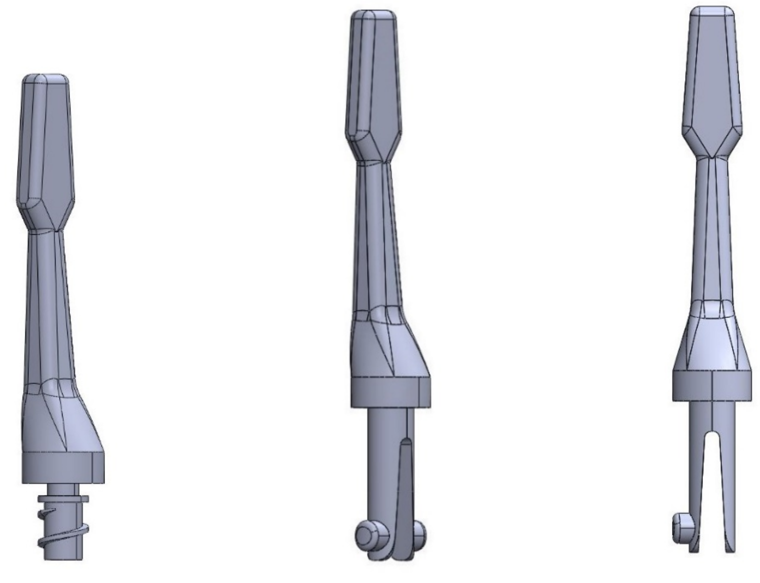
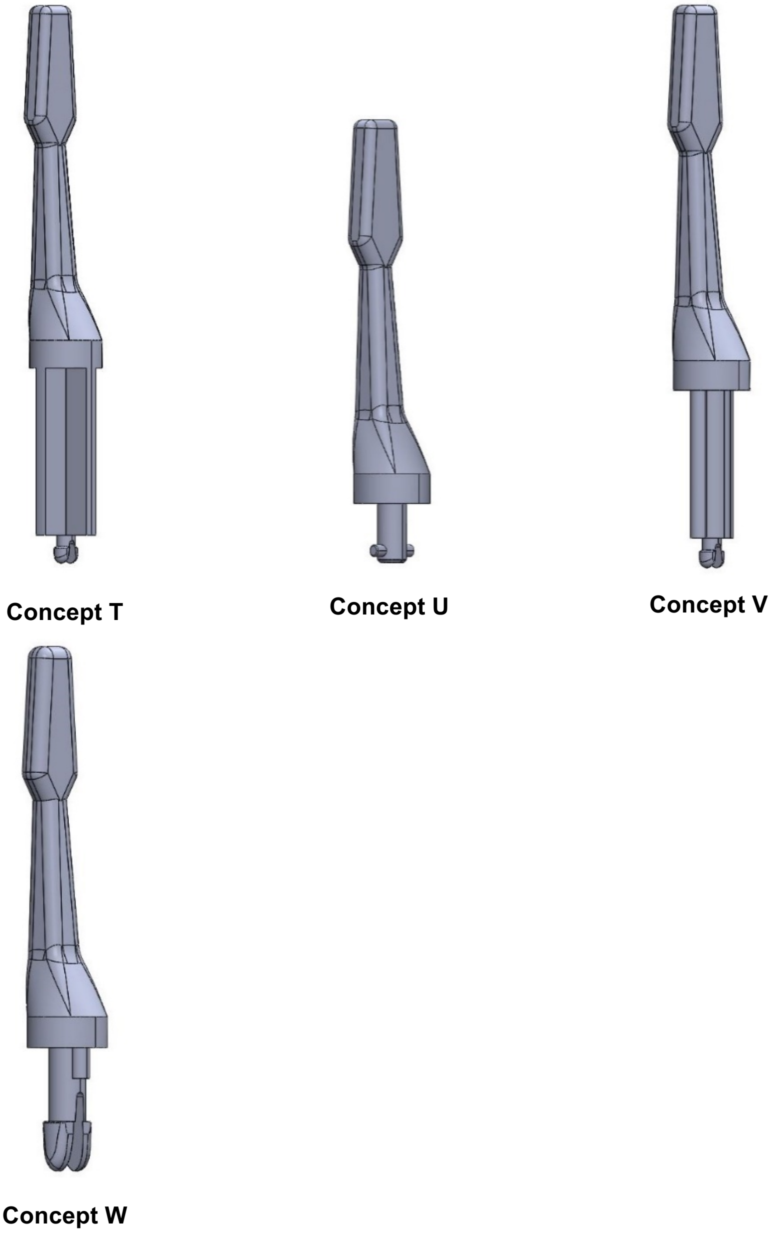


Figure 37. The design of concept W.



Concept D **Concept F** **Concept H**



Concept T

Concept U

Concept V

Concept W

Figure 38. Final concepts from iteration 1.

Parallel to developing the interfaces, different varieties of the handle in wood were designed. A handle having a design of a cross section of a square and a handle with the cross section of a circle were created. Different sizes of the handles were tried out but in order to have enough space for the interface simultaneously as reducing the risk of the handle becoming bulky in the hand, the size was chosen to be 13x13 mm for the square cross section and 13 mm in diameter for the circle.

Prototype handles in wood were made for concept F, concept H and concept W, as these concepts had interfaces in the handle possible to create in wood without using advanced processing.

4.5.2 **Concept Selection**

In contrast to the first concept selection, see chapter *4.4 Concept Selection*, the selection process for the first iteration was set to be more of a discussion about the concepts than scoring them. This due to the process that followed the scoring in the first concept selection. Even though a concept had a high score it would not automatically be chosen for further development after comparing the concepts to one another. To enable the comparison of the concepts during the selection of the first iteration it was decided to have an open discussion guided by chosen questions instead.

The concept selection was done in collaboration with TePe divided into two sessions. The first session included the product development team where focus was set on the design of the toothbrush head in relation to the material properties. While the second session was with a team from operations. In this meeting the goal was to evaluate the assembling possibilities in production for each concept.

3D printed prototypes of concept D, concept F, concept H, concept U and concept W were brought to the meetings and presented. Concept D and concept U had both parts of the interface in 3D printed plastic while concept F, concept H and concept W had the toothbrush head printed in plastic and the handle created in wood. See Figure 39.

Figure 39. Picture of 3D printed concepts with concept F in the front, concept H in the middle and concept W in the back.

Only after everyone participating in the concept selection session had become familiar with the concepts a discussion guided by the following questions took place:

- Which concept do you think is the easiest to assemble for the user?
- Which concept do you think is the sturdiest?
- Which concept do you think is the most durable? (Can withstand to be assembled and disassembled multiple times.)
- Which concept do you think is the easiest to manufacture/assemble in production?
- Regarding all the questions above, which concept do you think should be further developed?

Each meeting resulted in a selection of two concepts considered having the best potential for future development. Parallel to the discussion, notes of the conversation were taken.

4.5.2.1 Evaluation

From the two sessions, three concepts were seen as promising candidates for further development. Concept D was a common favourite among both groups. As for the second favourite choice, the opinions were divided. The product development team considered concept H as one of the most promising concepts since it was easy to assemble and had a clear indication of a correct assembly as the extrusion on the leg would be seen when pressed out from the hole in the handle. Choosing concept H would also result in a simple process of prototyping the handle while it only needed two moments of drilling. The team at operations however, found concept W to be favourable as it enabled an easy assemble in production and had a reduction of outer cavities in comparison to the other concepts.

In addition to having all opinions from the discussions collected after the sessions, two were to be chosen for final changes in the second iteration.

Considering that concept D was selected as a favourite among both groups, it continued to the next iteration. It was viewed as a robust design and easy to understand for the user. This design of using a screw is also frequently used in other products. As a competitive plastic toothbrush in two parts with the same locking mechanism was brought to the meeting by the product development team, it further validated this opinion. Since both parts of the prototype of concept D were 3D printed, discussions about the processing possibilities for the wooden handle were of interest. Taking to account that the threading is not of a standard type it was perceived as most easy to process the handle using a threaded pin. The pin would have to be customised for this concept.

Regarding the different opinions on the choice of the second concept a decision was made without TePe, based on the aspects raised during the consultations. The concept preferred for further development was concept W. This due to both simplified manufacturing and fewer outer cavities which minimises the risk of collecting dirt. Having all processing of the handle done from one side was viewed as more beneficial for the manufacturing than processing the handle from two different directions which was necessary for concept H. Another reason for selecting concept W over concept H was the ability to easy assemble the toothbrush head to the handle in production. For concept H to be assembled to the handle the legs had to be pinched together. This could be solved by either having a robot compress the legs or by chamfering the bottom part of the extrusion on the legs. By introducing a robot to pinch the legs to the process, the cost as well as the time taken for manufacturing would increase. Whereas if the bottom part of the extrusion on the leg was to be chamfered it would result in a large outer cavity. See Figure 40.

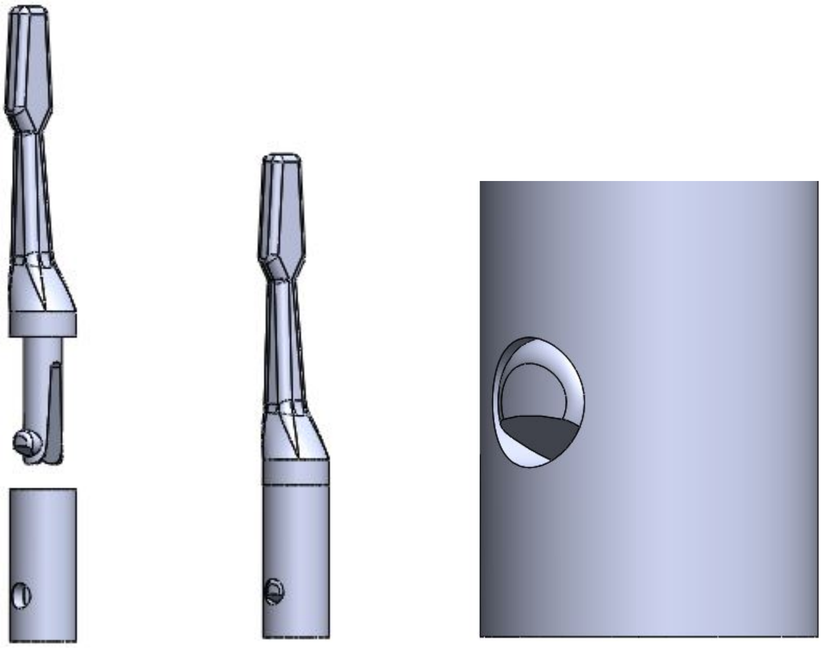


Figure 40. The cavity created in concept H when assembled if having chamfered extrusion on the leg.

None of the two solutions were considered good enough to compete with concept W, and concept H was therefore dismissed.

Appreciation was shown towards both designs of the handle, the circular cross section as well as the squared. But the circular design had some clear advantages when manufactured in comparison to the squared shape. When transporting products, it is essential that they tend to always orient themselves in a specific position. The circular shape had only one flat surface on the toothbrush head and therefore had a habit of always landing on this side when dropped. The squared design on the other hand, had four, which resulted in irregular orientation of the head. Comparing these two designs, the design with a circular cross section resulted in an easier orientation and therefore, the design of the handle was set to have a circular shape.

The importance of having an indication of the orientation on the handle was brought up during the session with operations. This would simplify the process of assembling the toothbrush head to the handle by orienting both parts before mounting. An indicator could for example be the TePe logo or a difference in design on a surface of the handle.

It is important to clarify that opinions during the evaluation might have been affected by the fact that some prototypes consisted of a 3D printed head in plastic and a handle created in wood while others had a 3D printed head as well as a 3D printed handle. This might have resulted in better fitting for the prototypes consisting entirely of plastic and given an impression of higher quality and thus having a better chance of being selected.

4.6 The Final Concepts

4.6.1 **Concept Refinements**

From the second evaluation, concept D and concept W were selected as the final concepts to be further developed. At this stage, focus was directed towards refining the concepts before creating injection moulded prototypes of them.

At first, time was spent on integrating the accurate geometry from the toothbrush head of the TePe Select model to the interfaces created in concept D and concept W. This was accomplished by receiving the CAD model for the TePe Select toothbrush head, see Figure 41, and rebuilding the concepts on this geometry. The required adjustment that had to be performed when integrating the correct geometry with the interfaces was to create a transition from a square shaped cross-section to a circular one. The result can be seen in Figure 42.

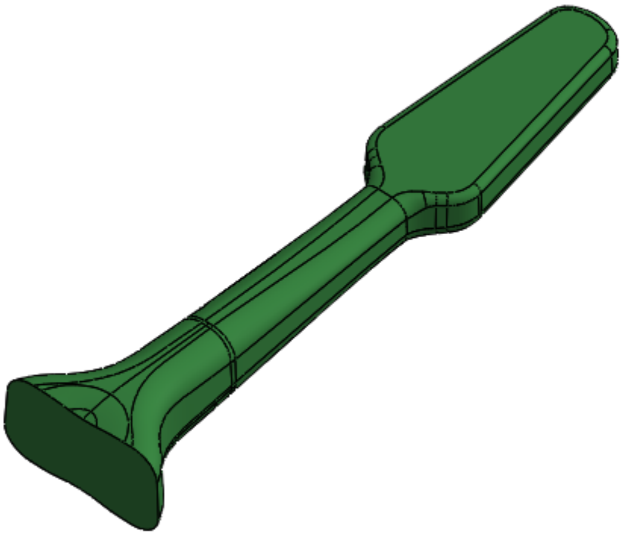


Figure 41. CAD geometry for the TePe Select toothbrush head.

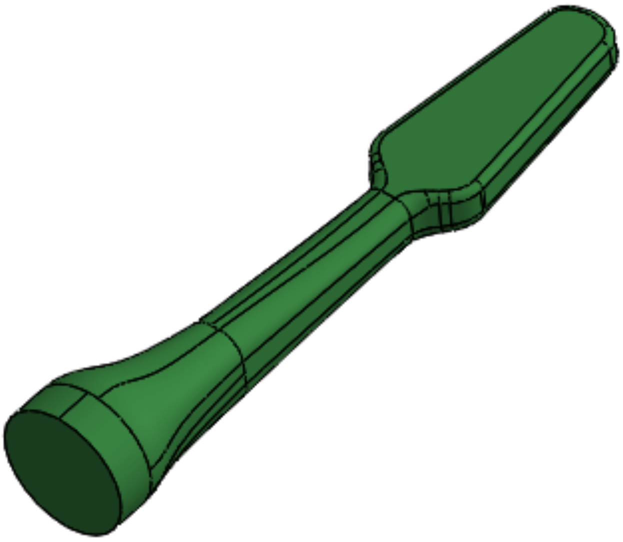


Figure 42. CAD after creating transition from square shaped to circular cross-section.

However, due to limitations regarding the creation of the mould used for the injection moulding of a prototype, many surfaces of the toothbrush head had to be redesigned to be able to create an injection moulded prototype. This because the mould had to consist of two parts with a straight parting line, see Figure 43. This was not the case for the current model which required a parting line in different planes, see Figure 44.

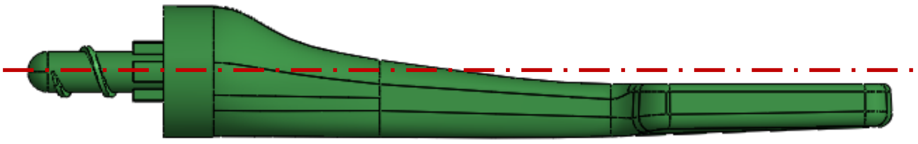


Figure 43. Sideview of concept D with straight parting line (red).

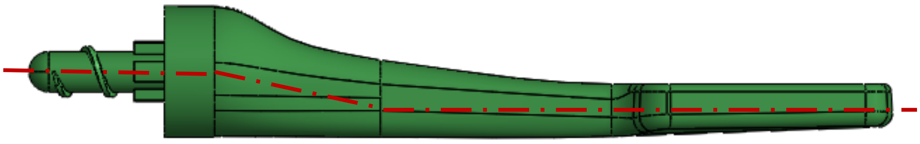


Figure 44. Sideview of concept D with parting line (red) in different planes.

The straight parting line also gave rise to problems at the neck of the toothbrush were the transition from a squared cross section to a circular one was placed. At this area a negative draft occurred, see Figure 45, making it impossible to release the part from the mould when finished. To minimise necessary modifications of the design and keep the current design as intact as possible, the decision came to change the placement of the parting line. Instead of having the parting line on the side of the toothbrush it was placed at the front, see Figure 46. This resulted in inevitable changes of surfaces incorporated in the geometry provided by the company. The prototype of the toothbrush head was therefore no longer equivalent with the toothbrush head associated to the TePe Select model. The changes made to be able to produce an injection moulded prototype, should be seen as temporary and a toothbrush head equivalent with the one found on the TePe Select model is intended to be used for the final design.

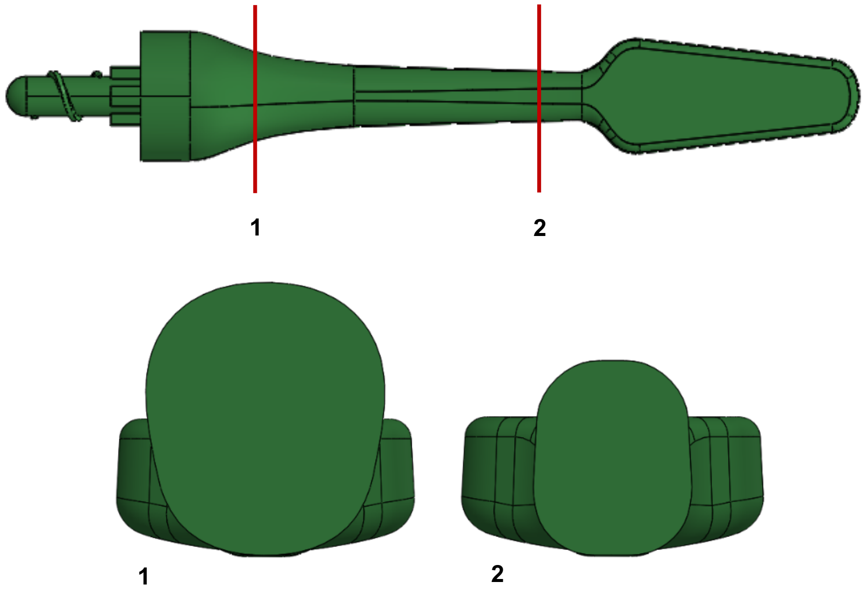


Figure 45. Front view of concept W with red lines illustrating cut section 1 and 2. Cut section 1 shows the negative drafts that occurred.

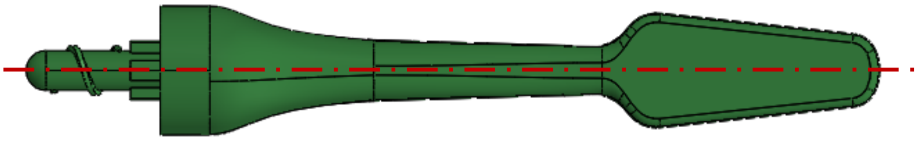


Figure 46. Front view of concept W with new placement of parting line (red).

The first design modification made for concept D was the diameter of the pin which was made smaller. It went from being 6 mm in diameter to 4 mm. The reason for this was that when trying to drill the bigger hole diameter in the wooden handle it resulted in cracks along the side. The predicament was that the wall thickness for the wood became too small with the bigger diameter and therefore it had to be changed in order to be able to manufacture the wooden handle. See chapter *4.7 Prototype in Wood* for more information about the drill testing in wood.

Additionally, the profile of the thread was made smaller. The cause for this was also due to insights given when trying to thread the handle in wood. As mentioned above, the wood was prone to crack along the side and it was believed that a smaller thread might also reduce the risk of cracking the wood during manufacture. Again, see chapter *4.7 Prototype in Wood* for more information about the iterations made on the threaded pin used to thread the wood. By making the profile of the thread smaller, less wood needs to be removed.

Another alteration that was made was the design of the bottom of the pin. This was given the shape of a dome to reduce sharp edges and at the same time create a guidance for the user when assembling. Another opinion in favour of this was that it also made the design look more aesthetically pleasing and inviting to handle.

Further, the O-ring was removed to accomplish a simpler assembling process during production. As replacement of the friction that the O-ring contributed with, four plastic ribs were introduced. They were evenly spaced along the side of the circular cross section at the top of the pin and inspiration for this was found on a toothbrush with a similar concept.

Lastly, a draft of 2 degrees were introduced on all surfaces to be able to perform an injection moulding of the part. The final design for the injection moulded prototype and the final design with the correct geometry for the toothbrush head, intended for real production, can be seen in Figure 47.

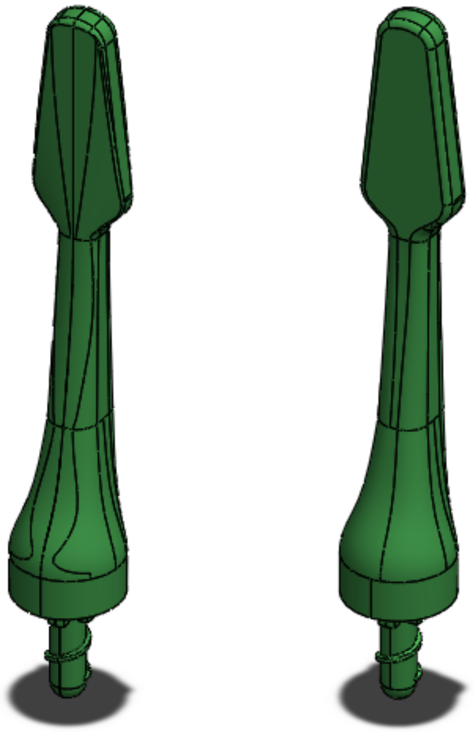


Figure 47. CAD geometry for the injection moulded prototype to the left and accurate CAD geometry for the toothbrush head to the right.

Regarding concept W, the first modification implemented was the length of the clamp. This was shortened with 3 mm by reducing the length of the tip of the clamp. This material was removed because the clamp was believed to have a redundant length.

Another adjustment made on the tip was an increased tapering. The benefits of this were brought up during the evaluation meeting with the operations team where it was mentioned that a more tapered design would facilitate assembly during production. The reason was that if the clamp was tapered enough it would not need an outer force to compress the legs but instead it could directly be pushed in place with force from only one direction.

When diminishing the length of the clamp, the cavity between the legs also had to be shortened in order to preserve the hardness of the design. The length of the cavity was therefore altered from 12 mm to 9 mm.

The top surface of the clamp was also redesigned to align with the diameter from the cylindrical part located at the base of the clamp. By doing so, the protrude of plastic that existed before was removed, see Figure 48. The chamfer along the top surface of the clamp was also changed by increasing the angle, see Figure 49. This was done to ease the extraction of the toothbrush head from the handle.

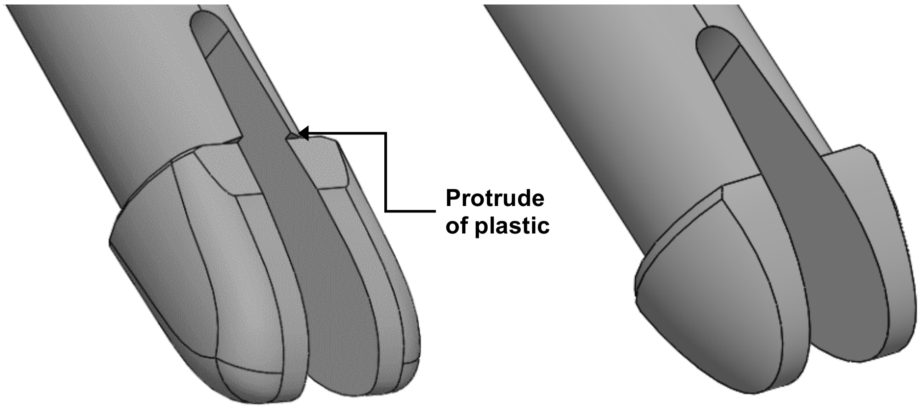


Figure 48. 3D view of clamp before refinements to the left and final concept of the clamp to the right.

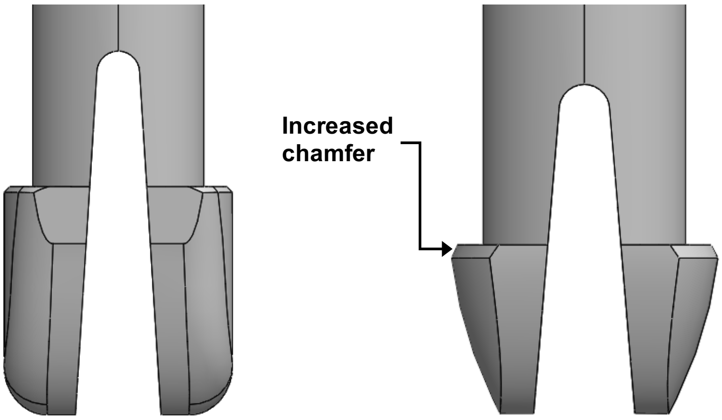


Figure 49. Front view of clamp before refinements to the left and final concept of the clamp to the right.

The guide at the front was also made shorter. The reasoning for this is similar to the one mentioned for the shortening of the length of the clamp, it was believed to have a redundant length.

Lastly, a draft of 2 degrees was added on all surfaces to enable injection moulding of a prototype. Like the injection moulded solution for concept D, the parting line was placed at the front of the toothbrush head. By doing this the orientation of the clamp had to be adjusted with a rotation of 90 degrees to make it possible to release from the mould when finished. The final design for the injection moulded part can be seen in Figure 50 and the final design with the correct geometry for the toothbrush head, intended for real production, can also be seen in Figure 50.

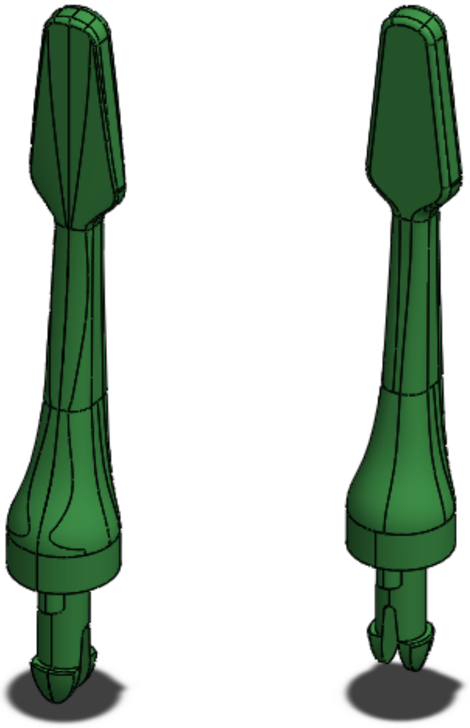


Figure 50. CAD geometry for the injection moulded prototype to the left and accurate CAD geometry for the toothbrush head to the right.

After finalising the CAD models, they were sent to TePe to create a mould for the injection moulding process. The mould contained both concepts in order to be able to manufacture both. See Figure 51 for an injection moulded prototype of concept D and Figure 52 for concept W.

Figure 51. Injection moulded prototype of concept D.

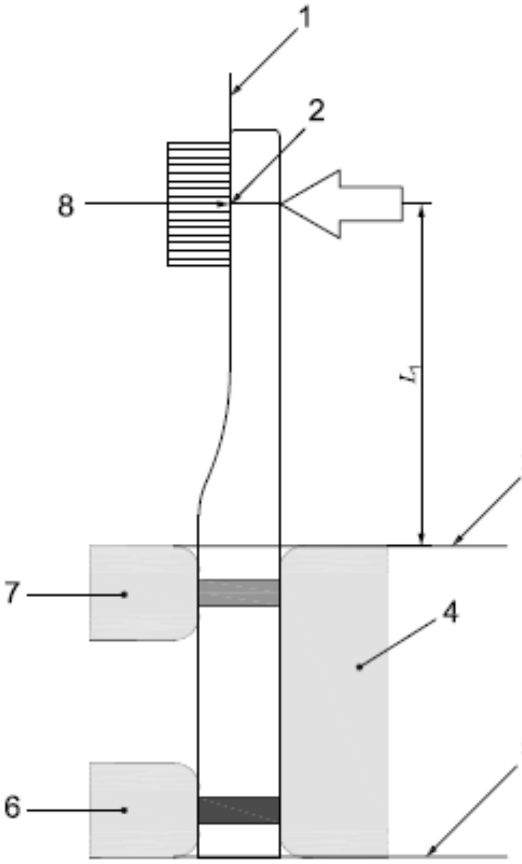
Figure 52. Injection moulded prototype of concept W.

4.6.2 **Concept Testing**

The performed concept test of the injection moulded prototypes, with associated handle in wood, was based on the ISO standard provided by Dentistry – *Manual toothbrushes – General requirements and test methods* (2012). This standard covers requirements and test methods for physical properties of manual toothbrushes to promote safe products for the intended use.

In the ISO standard there are four tests to complete but, in this case, only one test was executed. The chosen test was the handle impact test and it evaluates the toothbrush's ability to manage an initial potential energy of 2.75±0.10 J, without fracturing, when hit at the centre of the tuft-hole area from the opposite side of the tuft-hole surface. The equipment to perform this test can be seen in Figure 53. In Dentistry – *Manual toothbrushes – General requirements and test methods* (2012) the following is defined as pass-fail criteria (2012): "Test eight samples of each type. If none of the eight samples of each type fail, the sample set passes. If one sample does not meet the minimum requirement, test another eight samples. If no more samples fail, the toothbrush passes. If two or more samples out of the sixteen fail, the toothbrush fails."

However, only four tests for each concept were performed even though an amount of eight are stated to be tested in the ISO-standard. The reason for this was the fact that only four handles for each concept existed. Another approach could have been to test eight samples of each concept but using the handles twice. Although, this could also lead to a source of error regarding the result and therefore it was decided, at this stage, to only test the handles once with associated toothbrush heads.



Key

1. tuft-hole plane
2. hitting point for striker edge
3. top plane of the clamping unit
4. main block
5. bottom plane of the clamping unit
6. lower holding block
7. upper holding block
8. centre of tuft-hole area

NOTE The open arrow in the figure shows the striker direction.

Figure 53. Illustration of equipment for the handle impact test. (ISO standard Dentistry – *Manual toothbrushes – General requirements and test methods* 2012)

The handle impact test was executed because it was considered valuable enough to be able to assess whether the current design of the toothbrush was considered good enough to keep performing further tests, or if modifications were needed.

The procedure of the handle impact test was performed as followed:

1. Four toothbrush heads of each design were sampled. Due to problem with fitting the toothbrush head for concept D with the toothbrush handle in wood, material from the plastic ribs on the toothbrush head had to be removed, see Figure 54.
2. The toothbrush heads were attached to the associated handles and placed one by one in the test rig, see Figure 55.

3. The length between the top plane of the clamping unit and the centre of the tuft-hole area was measured to achieve the length 55 mm and then secured in place.
4. The clamping unit was raised to the indicated level at the rest rig and then released.
5. The tested sample was examined.

Figure 54. Picture of the original plastic ribs to the left and the modified to the right.

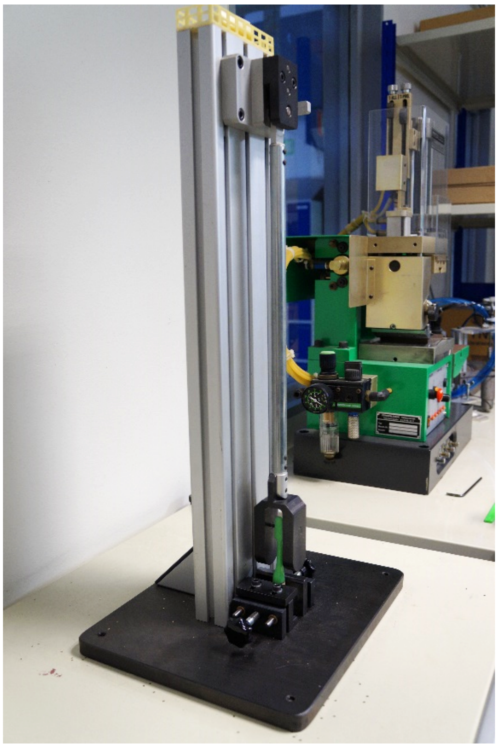


Figure 55. Picture of toothbrush fastened in the test rig for the handle impact test.

Regarding concept D, the procedure was repeated three times. The first time the toothbrush head instantly detached. The second time, two pieces of sheet metal were introduced at the front and back of the clamping unit to raise the edge where the toothbrush was fastened, see Figure 56. This was desired because it was noticed that the division between the toothbrush head and the handle was placed right above the pinch of the clamping unit. By introducing a higher edge for the fastening, it became noticeable if the toothbrush head itself would manage the clamping torque despite the weakness of the interface ability to retain the toothbrush head in the handle. The result showed that the toothbrush head managed the clamping torque when fastened with the sheet metal parts but since the toothbrush would not be able to pass with this added element no more tests of this type were performed. The third and last test were once again without the sheet metal parts and as before, the toothbrush head instantly detached. Since it was concluded that the design would not pass the handle impact test with two fails in two attempts with the correct fastening, no more samples were tested.

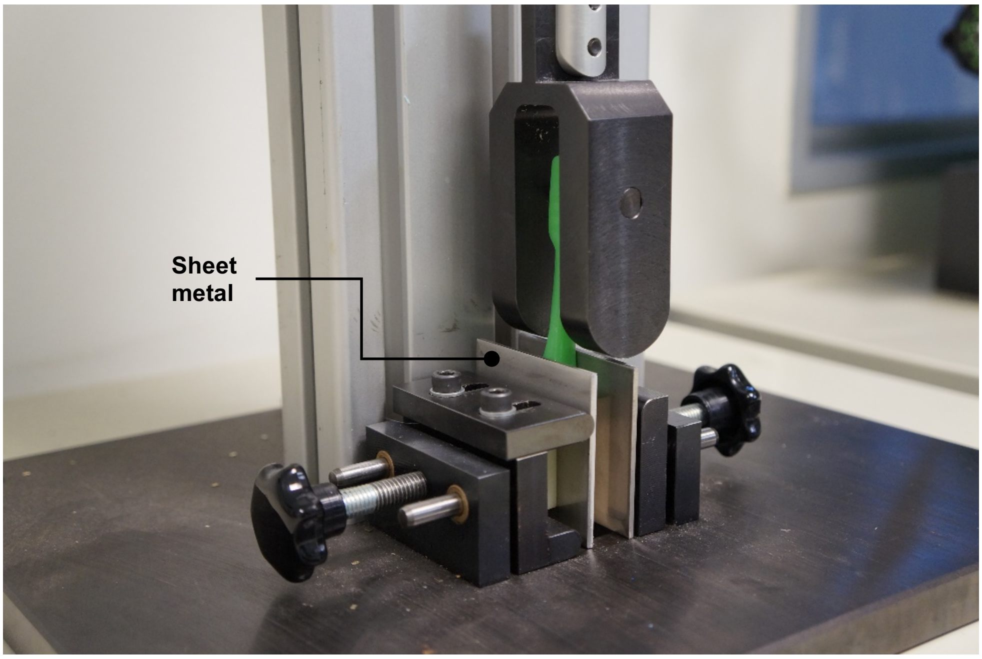


Figure 56. Picture showing the sheet metal parts introduced to raise the placement of the fastening edge for the toothbrush.

For concept W, the procedure was repeated four times. The first and second time the toothbrush head remained attached to the handle. However, a small gap occurred both times, see Figure 57 for example.

Figure 57. Picture of toothbrushes with small gap.

What was noticed after these two tests was that a small plastic form, inside the clamping unit, might have affected the fastening of the handle since it hindered lower support. At the moment when the striker for the pendulum hit the centre of the tuft-hole area, the handle was able to tilt, see Figure 58.

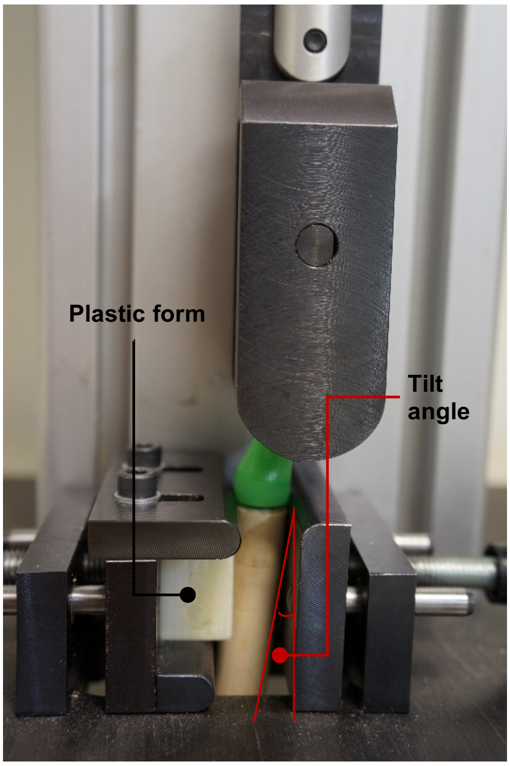


Figure 58. Picture of tilted toothbrush when pendulum hits.

After removing the plastic form, inside the clamping unit, the handle was able to be supported both by upper and lower holding blocks, see Figure 59. This resulted in a fixed handle when exposed to the impact of the pendulum.

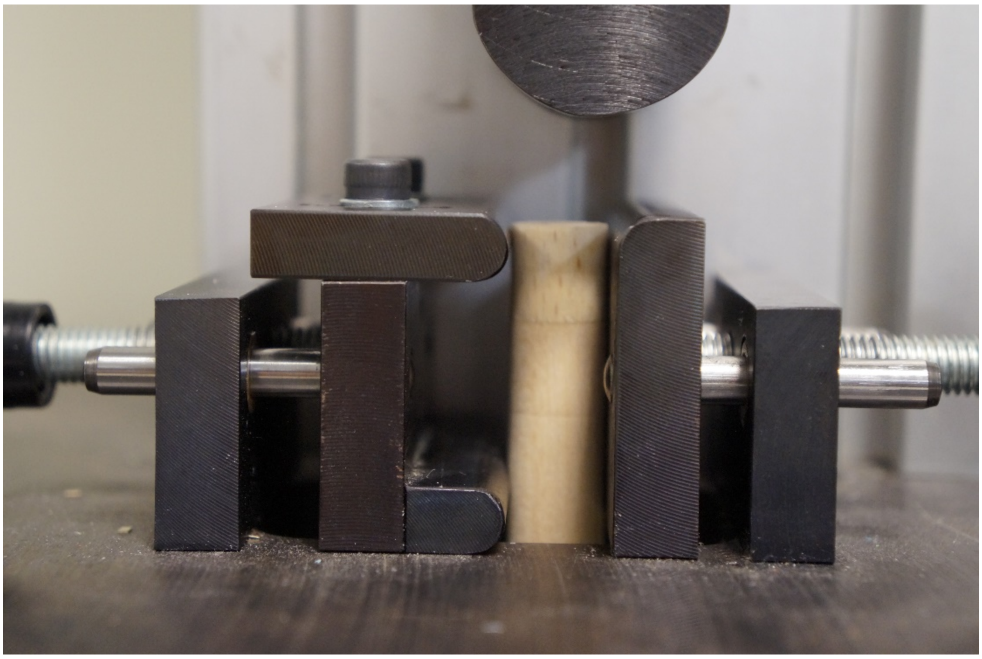


Figure 59. Picture of accurate fastening of the toothbrush.

The third and the fourth time the toothbrush was fastened according to this and the result was that the toothbrush head severely moved, creating a large gap. The impact series for the third attempt can be seen in Figure 60 and for the fourth attempt in Figure 61.

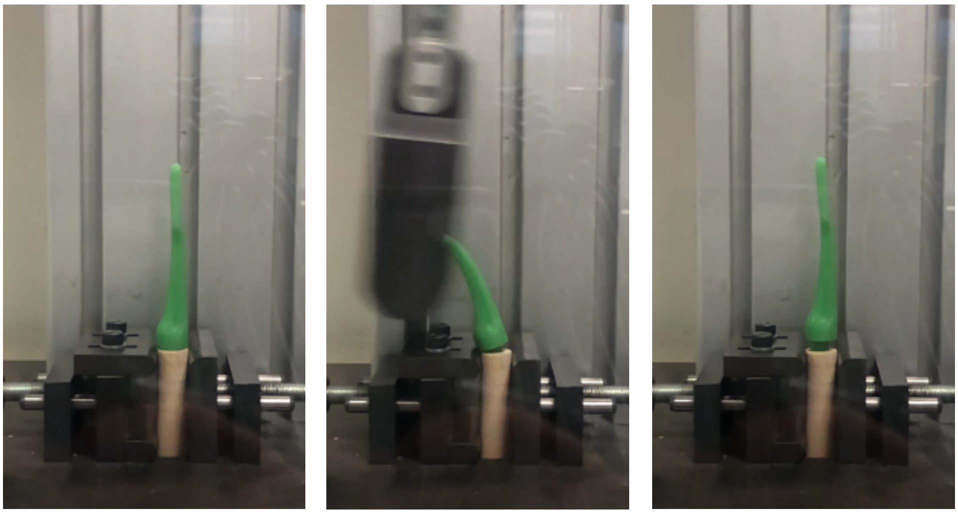


Figure 60. Impact series for the third attempt.

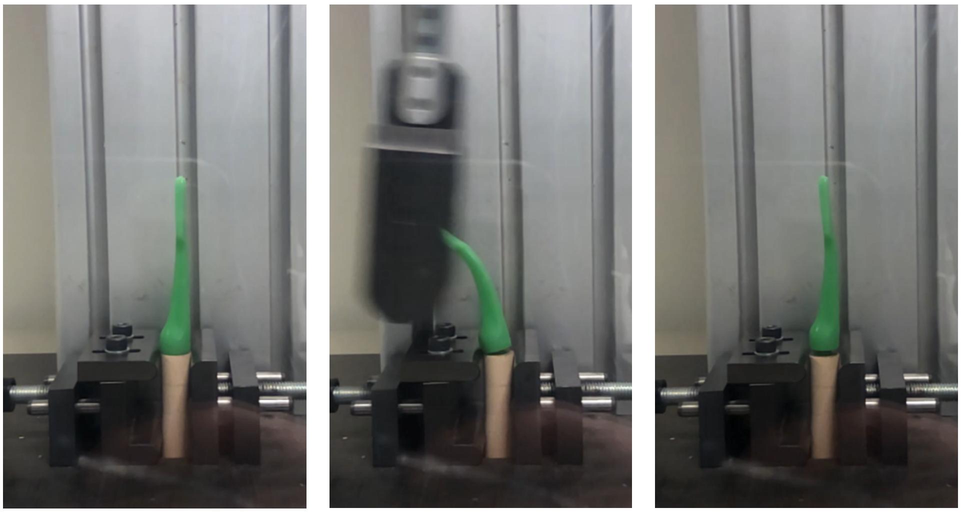


Figure 61. Impact series for the fourth attempt.

One of the conclusions that could be drawn from the handle impact test regarding concept D was that it would not have passed even if eight samples would have been tested. It was learnt that in order to create a design more likely to succeed, either extension of the plastic core inside the handle or the outer geometry of the toothbrush head would need to be implemented. If extending the outer part of the plastic this would imply that the toothbrush would be fastened in the plastic instead of the wooden handle. In this case the interface, now situated below the fastening point, would not be as severely affected by the strike of the pendulum. Detailed information about possible improvements can be found in chapter *6. Discussion.*

For concept W, all four samples passed according to the ISO-standard. No outer fractures were spotted but the toothbrush head moved upwards for all samples. The first two tests may also be seen as having a source of error since a plastic form inside the clamping unit affected the fastening of the toothbrush. When correctly fastened, the toothbrush head remained attached but it also resulted in a greater movement upwards, implying that the toothbrush passed the two last tests but has room for improvement. No accurate prediction can be made whether the toothbrush would have passed the handle impact test if eight samples were to be tested and thus this is something that could be tested in the future. Possible improvements for concept W that was realised after testing was that the length of the clamp should be slightly extended to prevent the toothbrush head from moving as much. On the other hand, the diameter dimension of the inner clamp was believed to be adequate since the toothbrush head remained attached after impact and no visible deformations could be spotted on the inner clamp. More information about future development for concept W can be found in chapter *6 Discussion.*

4.7 Prototype in Wood

Prototypes in wood has been created parallel to the concept development process of the toothbrush interface.

4.7.1 **Material Selection**

Before creating the prototypes of the toothbrush handle in wood, a material was selected. The process began with studying wood as a material to be able to draw better conclusions. The summarised knowledge from this step is found in chapter *2.2 Wood.* After this, benchmarking of products made from wood used in similar environments as a toothbrush was performed. This was followed by searching advise from experts working with wood on a daily basis. Lastly, a selection was made based on all findings.

When benchmarking, a company called Iris Hantverk was found. This is a Swedish company that works with brush binding and most of their brushes are made from natural materials. The wood types ash, beech, birch, maple, oak and walnut were discovered when studying their assortment for bathrooms. The most common wood types used for their products were beech, birch and oak. Only occasional products existed for ash, maple and walnut. Products commonly made from birch or oak were bath brushes. Single products like a hanger for towel drying made from oak or a bathroom mat made from birch was also noticed. Regarding beech, the most hairbrushes found were made from this wood. A soap dish and toothbrushes were also found. The most interesting discovery was the toothbrushes since this product corresponded the most with the toothbrush handle developed in this project. The toothbrushes found can be seen in Figure 62 and Figure 63. It was also learnt that both toothbrushes were waxed. For the toothbrush in Figure 63 it was further specified that the type of wax used as coating was carnauba.

Figure 62. Toothbrush made from beech. (Iris Hantverk n.d.)

Figure 63. Toothbrush made from beech. (Iris Hantverk n.d.)

Other toothbrushes in bamboo, a wooden like material, were also found when benchmarking. However, due to the delimitation of using locally produced material set at the beginning of the project, bamboo was not considered a possible material for the toothbrush handle and therefore not added to the list of material alternatives.

When reviewing the bathroom assortment for IKEA, a Swedish brand known for its products within interior decor, a lot of products were made from bamboo. When looking at their wooden kitchen ware, the most were made from bamboo. However, cutting boards in beech and oak were also found. They also offered wooden spoons in beech.

From Iris Hantverk, the most common materials used for kitchen ware were beech and birch. Products like wooden spoons, dish brushes and cutting boards were found in both materials.

The next step of the material selection process involved experts working with wood on a daily basis. One of these experts came from Swedish Wood, an organisation representing the Swedish sawmill industry and a part of the Swedish Forest Industries Federation. The conversation with the expert from Swedish Wood was initiated by giving a brief introduction to the product developed, i.e. a toothbrush handle in wood. It was then asked if there was any type of woods particularly suitable for a humid environment. The recommendation received was that the material beech could be a suitable alternative due to it being hard, tough and having straight fibres. According to the expert, splinters will not form in the first hand as a result of these properties. It was also mentioned that beech is used for food, like popsicles sticks, because beech does not give of any taste or smell.

Further, another expert working with wood at Lund University was consulted. The same question about types of wood particularly suited for humid environments was asked and the recommendation received was to use broad-leaved trees. This because of their different cell structure compared to coniferous trees. It was also seen as preferable to use dense woods with hardness and tree species such as hornbeam, birch or beech were mentioned.

The last expert, also working at Lund University, performed research about wood in humid environments. From the interview it was learnt that a constant flow of water is necessary for rot fungus to grow. Since a toothbrush normally get wet only a couple of times a day, the grow of rot fungus was not mandatory to consider as a critical issue for the project. On the contrary, mould on the surface of the wood was something that most likely could become a problem. Expansion of the wood as a result of the humid environment in bathrooms was also given as a suggestion to look further into.

Based on all findings three materials were distinguished and these were beech, birch and oak. The study of wood as a material in the beginning of the process showed that the properties of wood may vary not only between different species but also within a single tree itself. To name a few, factors like place of growth, using sapwood or heartwood showed to have a remarkable impact on the properties within a single tree and by extension its value on the material properties. Because of this, it was believed that the certainty of property values found for the different types of wood may not always conform with the reality. Thus, focus instead was directed towards written facts about the different wood types as well as benchmarking and relying on recommendations from experts within the field of wood.

Conclusions that could be drawn after taking part of the written facts were that all three wood types, beech, birch and oak, were told to have good resistance against cracking or breaking under stress, i.e. good toughness. All wood types also had good resistance against scratching, i.e. good hardness. More specifically, it was found that beech had the best hardness, followed by birch and lastly oak, see Table 2 for values. The hardness could have an impact on the users perception of the products quality since a surface more prone to get scratches might be associated with lower quality. Scratches on surface might also facilitate dirt and bacteria to form. For this reason, the hardness of the material was seen as important to consider. Observing the ability to resist rot, oak had good qualities regarding this when using heartwood. It also had rate 2 according to the standard SS-EN 350-2, meaning that it is seen as resistant against rot and insects. For beech and birch the given rate was 5, meaning that they are considered not resistant. Reflecting over the written facts found about the different wood types, oak seemed to have the most advantages in comparison to beech and birch.

On the other hand, moving forward with analysing the benchmarking and recommendation from wood experts, oak was no longer considered the best suited option. This due to the fact that beech and birch was perceived as more common among products made for bathroom environments or for kitchen ware. It was also learnt that oak did not have as dense pores in comparison to beech and birch, which made this material less attractive because it made it easier for dirt and bacteria to attach (Skarbrador.se n.d.). Furthermore, the encounter of the toothbrushes from Iris Hantverk, see Figure 62 and Figure 63, promoted beech as a suitable material since a commercial product was thought to be a good evidence of a working principle.

Considering the recommendations given from wood experts, beech once again appeared as a suitable material. The fact that it does not give of any smell or taste speaks in favour of using this material for the toothbrush handle since it is probable to be in contact with the users mouth.

Based on all the conclusions drawn, beech was selected as the material to be used for the toothbrush handle. Even though it had a lower resistance against rot compared to oak, it had better prospects according to both benchmarking and discussion with wood experts.

4.7.2 **Coating Selection**

Coating alternatives found from benchmarking were linseed oil, tung oil, milk paint, carnauba wax and beeswax. For detailed information about the different coating alternatives, see chapter *2.3.4 Coating.* Depending on which substance is chosen as a coating, it will result in different applying methods and effect the woods characteristics. Oils are applied by rubbing it on the wood, allowing it to penetrate. After being dried, the excess is wiped off. Since the oil is absorbed by the wood it becomes part of the material rather than only being applied to the surface of it. Consequently, to provide a better protection and resistance against moisture, the wood would have to be recoated sporadically. (The Wood Database n.d.)

Like oil, milk paint is absorbed by the wood when applied. It is used for both inside and outside environments and is naturally mould resistant. For use in humid environment it is favourable to have an additional coating over the milk paint. (Sikorski n.d.)

Using oil or wax, as mentioned in chapter *2.3.4. Coating,* will result in a very durable finish. Wax is the only coating of all the mentioned that is not absorbed by the wood but protects by covering the surface. It has a similar application to oil, by covering the wood in wax, letting it dry and wiping away the excess. Wax is not the best coating regarding wear of the wood but is very effective for shedding water. (Rockler 2020)

When choosing the recommended coating for the toothbrush handle, different aspects were taken into consideration. One of the requests from TePe was to create a handle made from locally produced wood in order for it to leave as little impact on the environment as possible. Therefore, this applies to the selecting of coating as well. By having this approach, neither tung oil nor carnauba were possible candidates. But when benchmarking toothbrushes made from beech it was noticed that one was coated with carnauba wax, see chapter *4.7.1 Material Selection*, which implies that wax is a good coating. More benchmarking of toothbrushes led to the acknowledgement that Colgate's bamboo toothbrush was coated with beeswax according to the Colgate page (Colgate n.d.). This further implied wax to be a coating option of high relevance for the cause of use. Since wax seems to be a coating more frequently used compared to the other coatings for natural toothbrushes and the fact that beeswax is an alternative bound to be found locally, the recommendation is to use beeswax as coating for the wooden handle.

4.7.3 **Threaded Pin**

Before designing a threaded pin, inspiration was taken from existing ones with the ambition to imitate the way they are constructed. In order to create a functioning threaded pin, many alterations were made, and the process resulted in five iterations.

The first design seen in Figure 64, was a threaded pin with a 6 mm diameter and a 1.40 mm height of thread profile. The design was 3D printed using the FDM method in the material PLA. Since the plastic material is brittle the threading was done in pinewood as it is of softer characteristics, but despite doing this, it broke upon trying. The operation was not a success as it did not create a thread mark in the wood and the threaded pin also broke at the neck where the circular cross section turned into a square. Threading also resulted in fracture of the wood.

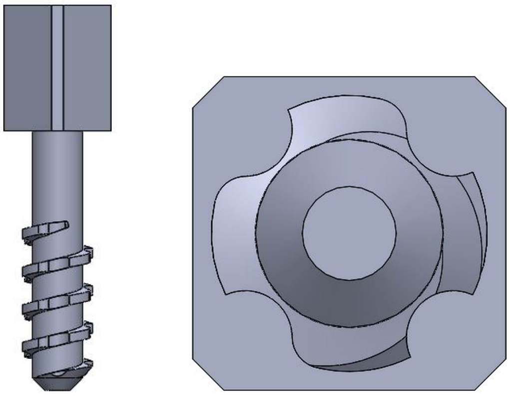


Figure 64. CAD model of the first design of the threaded pin seen from the side and from the bottom.

Keeping in mind the aspects of what went wrong in the first design while altering it in the first iteration, changes regarding the neck was made as well as the way the cutting edge was formed, see Figure 65. The neck was made shorter and a radius was introduced, making a smoother transition from the circular cross section into the squared. This was done with the hopes of resulting in less stress created in this vulnerable area when threading the handle. The cutting edges were also made sharper to easier cut the wood. The diameter and the height of the thread profile remained the same, 6 mm and 1.4 mm. Even though the alternations were made, the 3D printed threaded pin in PLA, again, broke at the neck and the wood resulted in cracking. The breakage occurred quicker than for the first design.

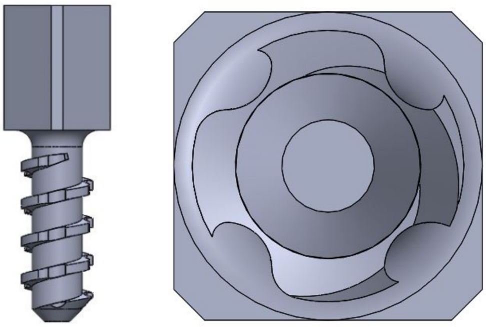


Figure 65. CAD model of the first iteration of the threaded pin seen from the side and from the bottom

To try to prevent the breakage in the second iteration the cutting edges were made much less sharp, resulting in a design with the same cross section of the edge as the first design. Same dimensions (6 mm and 1.4 mm) as the two previous designs were used regarding the diameter and the height of the thread profile. The only difference between the first design and the design of the second iteration seen in Figure 66 is the radius in the transition between the circular cross section and the squared. This radius was made larger than the radius in the first iteration. In order to minimise the stress created in the handle and the threaded pin the operation was divided into two stages using two pins of different sizes. An identical threaded pin was created with the only difference of being cut by an outer circle making the height of the thread profile shorter. It resulted in a 1 mm thread height instead 1.4 mm, see Figure 67. These threaded pins were 3D printed in PLA and used for threading in pinewood. The operation began with the smaller threaded pin with a 1 mm thread, seen in Figure 67. After the first part of the operation was finished the process was followed by rethreading the same trace with the threaded pin seen in figure Figure 66 that had a thread height of 1.4 mm. This resulted in the wood still cracking but a thread was able to be made. Although the edges were made blunter and the operation being divided into two operation it resulted in stress big enough to break the PLA print at the same place.

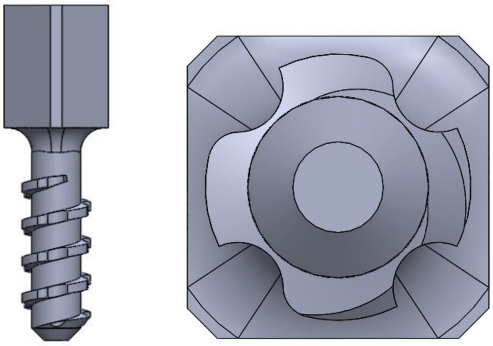


Figure 66. CAD model of the second iteration of the threaded pin seen from the side and from the bottom.

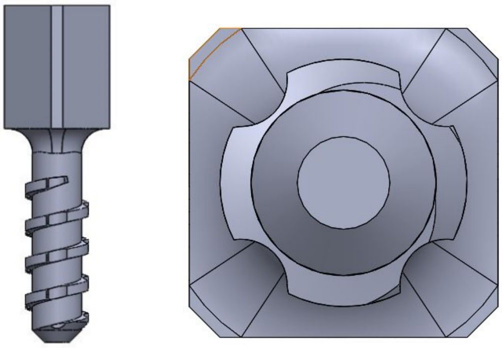


Figure 67. CAD model of the shortened thread profile of the second iteration. The threaded pin can be seen from the side and from the bottom.

A conclusion drawn from the attempts was that the large diameter of the thread resulted in the wooden handle having too thin walls and therefore being more prone to break. By making the diameter smaller it was believed to minimise the risk of it happening. The diameter was therefore changed from 6 mm to 4 mm. The height of the thread profile remained the same at 1.4 mm. As the breakage always occurred in the same part of the threaded pin the transition was eliminated by creating a squared shape by cutting away flat surfaces from the circular profile rather than by adding material to it. The previous designs had four cutting edges but for the third iteration it was changed to three. Having fewer cutting edges enables them to be made bigger and therefore hopefully also sturdier. The cutting edges were also made sharper for this iteration. See the design of the third iteration in Figure 68. The third iteration of the threaded pin was also printed in PLA and used for threading. When threading the pinewood, the threading pin did leave a thread in the wood but the plastic broke. After further studying the design it was noticed that this design made it impossible to cut the wood with its edges as it had no room for the wood being cut to be stored. Instead of cutting away the wood this design pressed the wood and by doing this also created a thread. As a consequence, this design created large pressure in the wood.

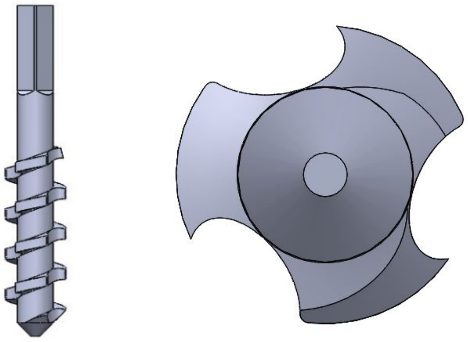


Figure 68. CAD model of the third iteration of the threaded pin seen from the side and from the bottom.

With regard to the problem mentioned for the third iteration the fourth iteration of the threaded pin was altered. When redesigning the threaded pin, a profile cutting the core cylinder was therefore made as seen in Figure 69. The hollow section enabled the wood that had been cut to transport itself up when threading and thus not creating pressure inside the hole. The diameter remained 4 mm, but the height of the thread profile was changed from 1.4 mm to 0.8 mm. Two CAD models of this design was sent for print, both can be seen in Figure 69. One design having a longer part in the bottom of the threading pin that will act as a guiding and the other lacking this extra part.

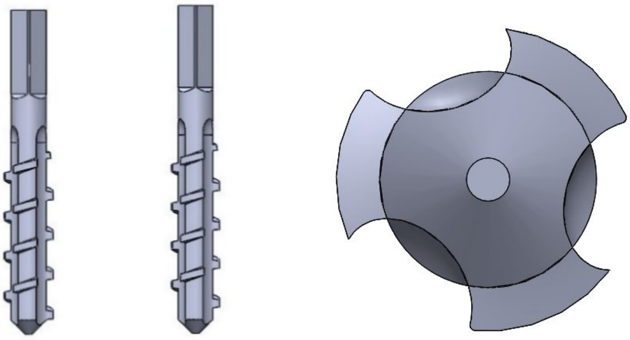


Figure 69. CAD models of the final designs of the threaded pins. One with a steering part and one without. The picture shows the CAD models from the side and from the bottom.

The final designs were believed to have potential and were therefore sent for print in aluminium. See Figure 70 for the 3D printed parts.

Figure 70. The 3D printed threaded pins in aluminium.

When using the 3D printed aluminium threaded pin to thread in pinewood, the operation went flawlessly. The thread mark can be seen in Figure 71.

Figure 71. Threaded mark in pinewood using the aluminium threaded pin.

Therefore, the operation was also tried on beech, a wood with harder characteristics, and again left a clear thread in the wood as can be seen in Figure 72.

Figure 72. Threaded mark in beech using the aluminium threaded pin.

4.7.4 **Toothbrush Handle**

For the prototyping in wood, both pine and beech were used. This due to the fact that pine is a softer than beech which made it easier to process by hand in the wood workshop. Primarily, dowel rods were used, see Figure 73. This facilitated the prototyping phase since the design of the handle was intended to have the same shape. However, a prototype with a square shaped cross-section was also produced in order to explore different designs.

Figure 73. Dowel rods in pine and beech.

4.7.4.1 The First Prototypes

The first prototype created was made from a pine dowel. The diameter of the dowel was 13 mm which exactly correlated with the diameter of the toothbrush head connecting to the toothbrush handle. Processing of the pine dowels surface was therefore not needed. The dowels were sawed to pieces with a length of 120 mm. This length was set in accordance to obtain the same total length as the Supreme model from TePe, with the toothbrush head attached.

To make the prototype of the toothbrush handle for concept D, a hole was drilled with the intention to form a small play relative to the core of the threaded pin. The last step involved using a tap wrench, see Figure 74, to thread the hole by hand. A candle was also used to lubricate the threaded pin in order to minimise the friction and risk of breaking the pin.

Figure 74. Threaded pin and tap wrench used to thread the hole.

For the toothbrush handle to concept W, the sawed pieces had to be sawed once again to be able to create the inner hole geometry. The two pieces were 12 mm respectively 108 mm. The longer dowel was drilled with an 8.5 mm drill to a depth of approximately 10 mm in order to fit the lower part of the clamp. The shorter dowel was firstly drilled with a 6 mm drill all the way through. This was followed by drilling a 3 mm hole at the edge of the larger hole with a depth of 5 mm. Lastly, the two pieces were glued together using wood glue and pressed.

The last concept to be produced was the toothbrush handle for concept H. This concept was created in two different shapes, both square and circular. To create this toothbrush handle a hole of 8 mm was firstly drilled to a depth of approximately 25 mm to fit the length of the legs. This was followed by drilling a hole on the side, going all the way through, with a diameter of 5 mm.

The resulting prototypes from the first prototyping stage can be seen in Figure 75 - Figure 76.

Figure 75. The resulting prototypes from iteration 1. Concept W can be seen in the back, followed by concept H with a circular cross section in the middle and concept H with a squared cross section at the front.

Figure 76. The resulting prototypes from iteration 1. Concept W can be seen in the back, followed by concept H with a circular cross section in the middle and concept H with a squared cross section at the front.

4.7.4.2 The Second Prototypes

The second prototypes were made from beech dowels. Since no beech dowels with the correct diameters were found a 16 mm dowel had to be processed in a lathe to attain the right dimensions. The dowel was first turned to a diameter of 14 mm and then once again to 12.7 mm. The reason for making the diameter 12.7 mm was that the injection moulded toothbrush heads had variations between 12.5-13 mm in diameter and therefor the value between these measures were chosen. Lastly the dowel was polished with finer sandpaper. Figure 77 shows the dowel fastened in the lathe before being turned to the accurate diameter and polished. The following processing then diverged depending on which concept the toothbrush handle was intended for.

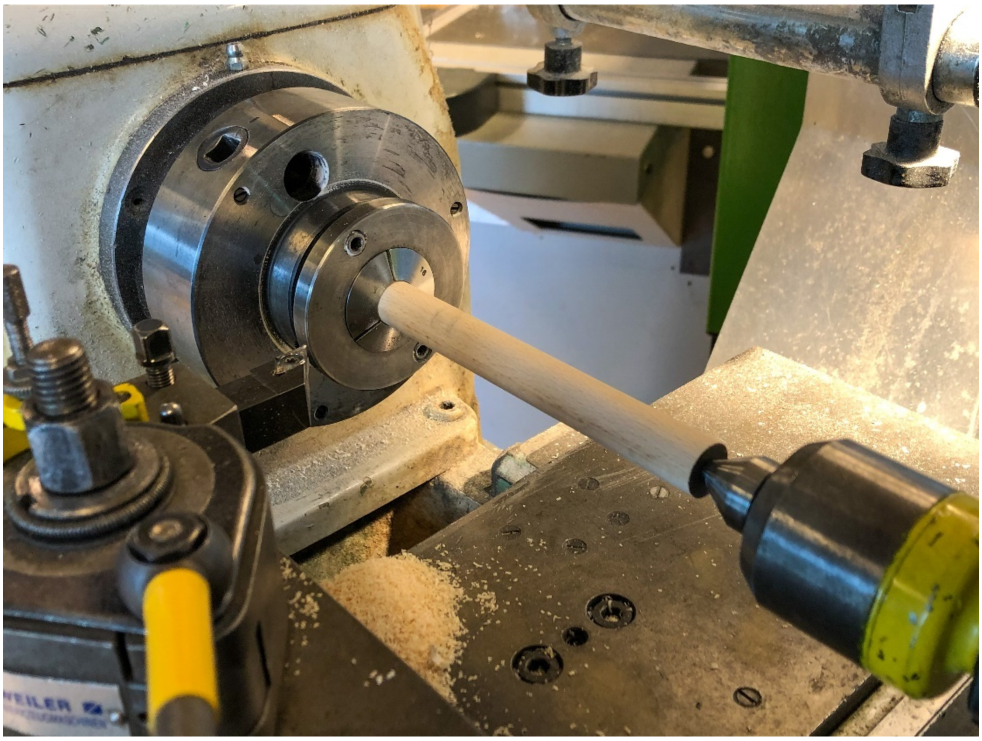


Figure 77. Dowel fastened in the lathe before turning it to the accurate diameter and polishing the surface.

Regarding concept W, a dowel with a drilled hole of size 6 mm was created. The depth of the hole was made approximately 50 mm. This dowel was then placed in a drill press to create the offset hole of 3 mm in diameter, placed at the edge of the bigger hole. The depth of drilling this hole was 5 mm. The dowel was then sawed to the correct length of 12 mm. To make the second part of the toothbrush handle the lathe was used to drill a hole of 8.5 mm with a depth of at least 6 mm to be able to fit the lower part of the clamp. The two parts were then glued and pressed to form the complete prototype. An illustration of the top part of the handle after these operations can be seen in Figure 78.

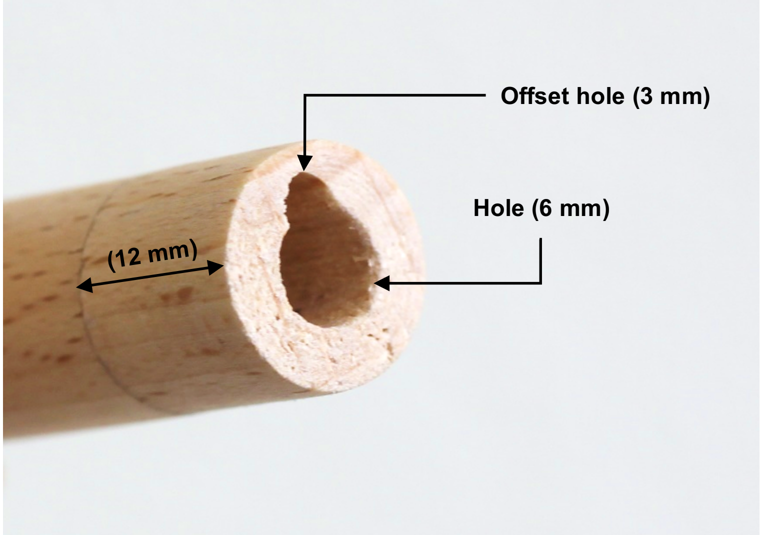


Figure 78. Illustration of the drilled holes and the top part glued to the rest of the handle.

For concept D, the dowel was placed in the lathe and a hole of 4 mm with depth 15 mm was drilled. Another hole was then drilled with a diameter of 6 mm and depth 5 mm. The larger hole was created to allow the plastic ribs on the toothbrush head to fit.

The resulting prototypes from the second prototyping stage can be seen in Figure 79 - Figure 80.

Figure 79. Picture of resulting prototypes from second round.

Figure 80. Picture of resulting prototypes from second round.

5 Result

This section illustrates the result of the final prototype.

5.1 Final Prototypes

The result of this master thesis is two different designs for the toothbrush head with an associated handle. The toothbrush heads have been injection moulded in the same PE material as used for the TePe GOOD series and the handle is made from beech. A total of eight complete prototypes were provided. The result can be seen in Figure 81 - Figure 90.

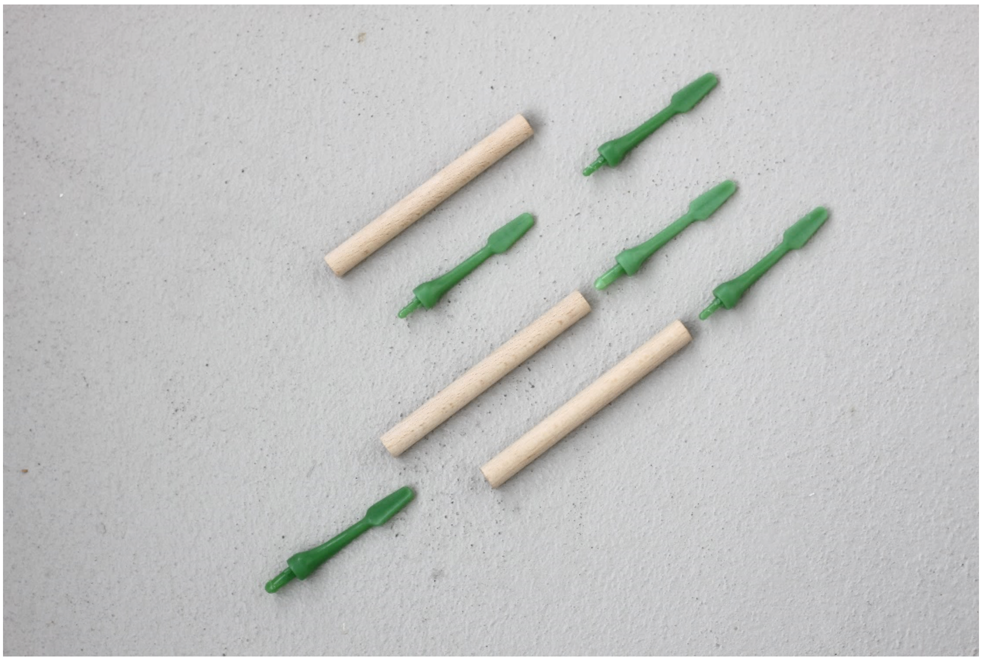


Figure 81. Selection of toothbrush heads and handles.

Figure 82. Three complete prototypes.

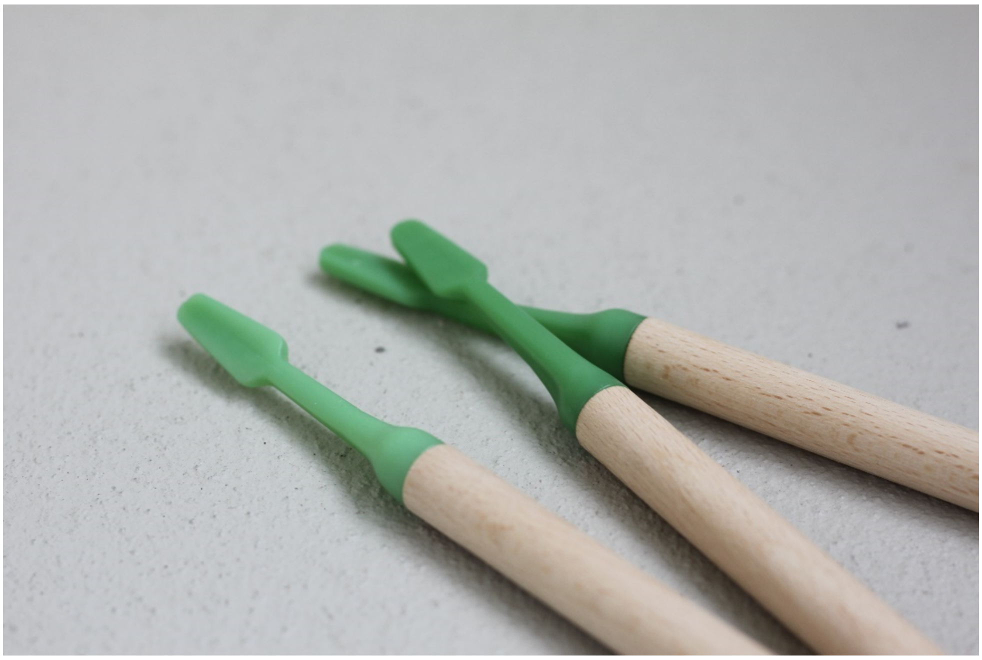


Figure 83. Close up of complete prototypes.

Figure 84. Close up of complete prototypes.

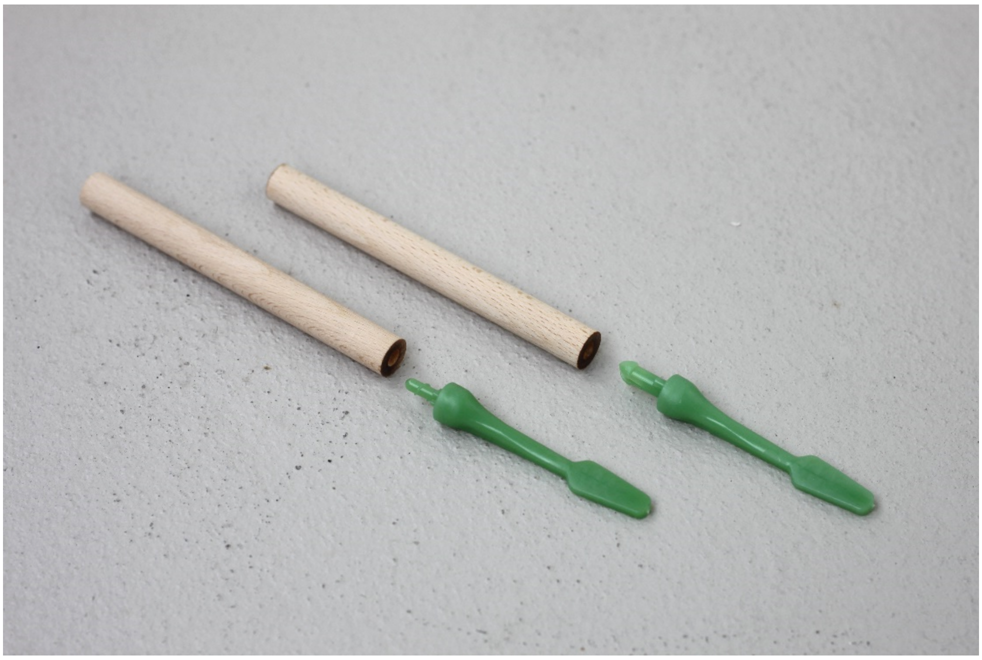


Figure 85. Prototypes before being assembled.

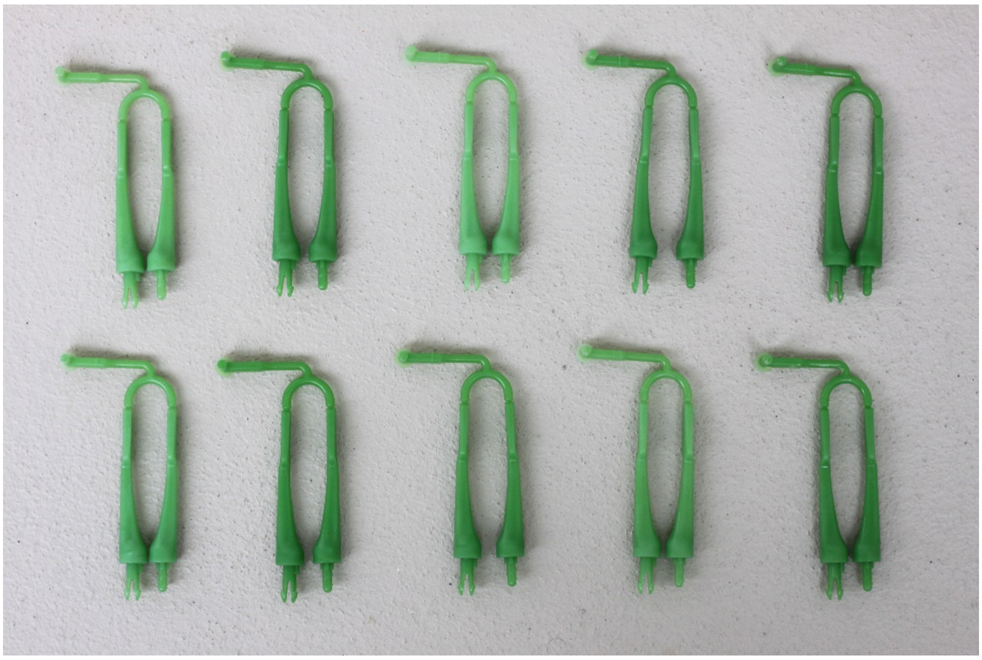


Figure 86. Selection of injection moulded prototypes before separation.

Figure 87. Selection of injection moulded prototypes before separation.

Figure 88. Three complete prototypes.

Figure 89. Complete prototype beside TePe GOOD S model.

Figure 90. Holding the complete prototype.

6 Discussion

In this section, the result is discussed by examining it from different points of view. Recommendations for future development are also provided. Finally, a conclusion of the project is found.

6.1 Result

The final prototypes of this master thesis fulfil the part of the goal set at the beginning of this process which states that a prototype with a toothbrush head in plastic and a toothbrush handle in wood should be presented. By reflecting on the result, activities that are believed to have had a larger impact on the outcome as well as future improvements are realised and discussed in the text below. This primarily covers the activities concept selection, manufacturing of the injection moulded prototypes and concept testing.

Regarding the concept selection, the highest ranked concepts from the scoring matrix were ignored and instead an interpretation of the discussion held during the evaluation became the deciding factor for which concepts to further develop. The result of this was that lower ranked concepts moved on for further development, which by textbook should not have been the case.

Despite this, ignoring the result from the scoring matrix is still considered to be the best alternative since the foundation on which the evaluation was built upon showed to be insufficient. An argument in line with this is the fact that no reference concept was used. Instead, all concepts were individually assessed and with an amount of 17 concepts it became difficult to remain consistent when judging the concepts. For example, the last concepts were often compared to previously seen concepts resulting in an unstructured evaluation.

A solution might have been to restrict the discussion when comparison with other concepts began in order to get an isolated judgement of each concept. However, to restrict a discussion when evaluating at this stage of the process, might lead to missing out on opinions that could be of importance for future development. A different approach could instead be to choose a single concept as reference and compare all other concepts with this single concept to create an equal ground for assessment.

When manufacturing the injection moulded prototypes, alterations from the original design of the final concepts were needed. One alteration that is considered to have had an influence on the result of the final prototypes is the fact that the smallest milling tool available to create the mould had a radius of 0.25 mm. This meant that a radius that had not been taken into consideration when creating the 3D models were introduced.

For concept W, no remarkable changes of the function could be observed despite the added radius. For concept D on the other hand, this radius resulted in problems with fitting the toothbrush head with the toothbrush handle. The reason was that the threaded profile for the toothbrush head had become smaller with the applied radius of 0.25 mm. This abled the toothbrush head to be pulled out of the toothbrush handle for some of the prototypes when it only should have been possible to disassemble by unscrewing it.

To solve this problem, a milling tool with a smaller radius is recommended to be used when creating the mould. One could also redesign the thread itself to obtain bigger dimensions but referring to the findings from the development of the threaded pin, it was noticed that the wood became more prone to crack when larger amount of wood was removed. By enlarging the thread, it would result in more resistance when creating the tread, which could increase the risk of the wood cracking during manufacture.

Another alteration that mainly affected the geometry of the tuft-hole area for the toothbrush head was the change of placement for the parting line. This geometry had to be made thinner in order to obtain a sufficient draft for the injection moulding process. In turn, this could have had an effect on the result regarding the concept testing. It is possible that a decreased thickness of the tuft-hole area might have contributed to the toothbrush head being more easily bent. By extension this could mean that the handle was subjected to less force compared to what the impact would have been with the original and stiffer design of the tuft-hole area.

Furthermore, neither of the handles could be determined to have passed the handle impact test from the ISO standard for manual toothbrushes. This due to the fact that only four samples of each concept were tested instead of eight which was required to pass the test from the standard. Despite this, insights of improvements for the different designs was still achieved even though the result from the test was inaccurate. For the future it is suggested to produce more wooden handles in order to perform the test on an accurate number of toothbrushes.

Concept D was detached instantly when the pendulum hit during the handle impact test. This led to new insights regarding the design of the plastic pin inserted in the handle. A possible solution that might reduce the risk of detachment is to make the inserted pin in plastic longer.

An alternative to this is to instead make the plastic part of the toothbrush head right above the inserted pin longer. This will result in the toothbrush being secured against the plastic part rather than against the wooden handle when performing the handle impact test and thus being thought of less likely to detach when hit by the pendulum.

In fact, this theory was briefly tested during the handle impact test by using two metal sheets to fasten the toothbrush higher and thus securing it against the plastic part instead of the wood. When secured liked this, the toothbrush head remained attached to the handle.

However, a more thorough investigation should be performed concerning which adjustment is most beneficial. For an investigation like this it could be interesting to look at differences between the amount of plastic that is used for the different solutions. It might also be of importance to analyse how a longer inserted pin may affect production time as well as time for assembly. To drill longer holes and in a later stage perform assembly on the longer distance is most likely to increase the time needed for both procedures. Even if the time might be considered marginal, it could contribute with a larger cost in the long run compared to altering the dimension of the head right above the inserted pin and thus keep the shorter distance for the pin.

Moreover, drilling a deeper hole can also have an impact on the quality of the handle as it becomes hollower with the risk of decreasing the strength of the part. If making the inserted pin thicker instead of altering the length, the outcome would be a thinner wall thickness, which as mentioned before might lead to the wood being more prone to crack when manufacturing the associated interface.

On the other hand, enlarging the inserted pin that is hidden when assembled instead of elongating the plastic that is seen, might give the impression of a toothbrush consisting of more wood than plastic. Taking the perspective of a potential customer, this might give a feeling of an eco-friendlier product.

As for concept W, one recommended improvement is to change the angle of the legs. In the final prototype the legs are vertically oriented, but since the material PE is soft and lacks the ability to flex back after being compressed in the handle, it permanently deforms and results in the legs being bent inwards. By slightly tilting the legs outwards and having this as starting position, the permanent deformation inwards might not be as big after the compression. Another possible solution could also be to alter the design of the cut-out between the legs of the clamp. By making the area of the cut-out smaller it might result in a sturdier construction less likely to deform, even for the softer material PE.

Regarding the handle, it has big potential for further development. In the final prototype the cross section is consistent through the whole handle. This can be developed by introducing a grip mark or other alterations that may enhance the ergonomics or the aesthetic look of the handle.

Redesigning the bottom part of the wooden handle to make it less likely to mould is also an important part to take into consideration for future development. If the bottom area of the toothbrush, more likely to be in contact with water when stored for example in a toothbrush mug, is minimised, it is believed that the risk of accumulation of mould can be decreased. A suggestion for minimising this area is to redesign the toothbrush handle to have a pointier characteristic.

The shrinkage and swelling of the wood should also be further investigated to gain knowledge about the effect it might have on the different interfaces. It is important to ensure that the ability to attach the toothbrush head to the handle is not reduced. Methods for evaluating this, as well as the selected material and associated coating for the handle, should also be defined and implemented. Furthermore, the target specification list mentioned in chapter *5.2 Target Specification*, may also be used in the future to evaluate the concepts further.

User tests are also recommended to be performed to better understand how the different concepts are perceived by future customers and to see how the concepts would manage in a real environment setting.

6.2 Conclusion

The fundamental goal for this master thesis was to provide a prototype with an interface that connected a toothbrush head in plastic with a toothbrush handle in wood. At the end, two different concepts were chosen and prototypes were created for both. A total amount of eight prototypes, four of each concept, with a toothbrush head in plastic and a toothbrush handle in wood were manufactured. The goal regarding the presentation of prototypes is therefore considered to have been met. Furthermore, both prototypes were manufactured by injection moulding, the same production method intended to be used for the commercial products. This made it possible to more accurately evaluate the result and ended up in exceeding the initial expectations of the final prototype.

Other goals were to compile suggestions for potential production methods regarding the prototyping of the wooden handle, as well as proposals concerning production methods for the commercial product. The latter only carried out if possible. Unlike the first goal, the two following were not fully met. Regarding the compilation of production methods, the subject was briefly touched by providing information about the manufacturing for the final two wooden handles that were developed for the master thesis. Focus was mainly directed towards the development of the interface, resulting in a limited amount of time for a general presentation of production methods for prototyping in wood. This was also the case for production methods for the commercial products.

Even though all goals were not met, we are satisfied with the results gained. Selection of a concept after additional testing, followed by refinement of the concept, is needed in order to be able to commercialise the product.

To conclude that wood is a more sustainable option for the handle compared to a plastic made from renewable raw material, further analysis must be done. According to the questionnaire completed in the beginning of this project, the majority of the people were positive to the idea of a replaceable toothbrush head and many also expressed the desire for a more sustainable toothbrush. If the solution of having a wooden handle shows itself to be more environmentally friendly the result of this master thesis fulfils both these needs. Not only does it fulfil the needs but will also result in it being the only toothbrush on the market to have a handle in wood and a toothbrush head in plastic. Because of these reasons we believe that the product has big potential of being well received on the market if commercialised.

References

Advantage Lumber. (n.d.) *Janka Rating Scale*. https://www.advantagelumber.com/janka.htm (Retrieved 2020-05-23).

Amazon. (n.d.). ecoboom Bamboo Toothbrush Eco-friendly with Replaceable Heads for Biodegradable Soft Bamboo Charcoal Bristle, for Men, Women & Kids, Zero Waste Gift. [Image] https://www.amazon.com/ecoboom-Toothbrush-Eco-friendly-Replaceable-Biodegradable/dp/B07XL1VCXX/ref=pd_sbs_194_img_0/140-3780088-4978629?_encoding=UTF8&pd_rd_i=B07XL1VCXX&pd_rd_r=0128a759-4feb-4017-9af2-580d827d3963&pd_rd_w=bnZ2c&pd_rd_wg=eGcnb&pf_rd_p=5cfcfe89-300f-47d2-b1ad-a4e27203a02a&pf_rd_r=8JR3PYARPRMSMFQASF84&psc=1&refRID=8JR3PYARPRMSMFQASF84 (Retrieved 2020-04-20).

American Chemistry Council. (2005). *Plastics - How plastics are made*. https://plastics.americanchemistry.com/How-Plastics-Are-Made/ (Retrieved 2020-05-18).

Ardec. (2015). *Linseed oil, a natural solution for Wood Finishing*. https://ardec.ca/en/blog/22/linseed-oil-a-natural-solution-for-wood-finishing (Retrieved 2020-05-11).

Boutelje, Julius B and Rydell, Rune. (1986). Träfakta. *Träindustri.*: 22

Braskem. (2019). *High Density Polyethylene SGD4960.* https://fkur.com/wp-content/uploads/2018/03/Technical-Data-Sheet-Green-HDPE-SGD4960-ASTM.pdf (Retrieved 2020-05-28).

Britannica. (2019). *Beeswax*. https://www.britannica.com/topic/beeswax#info-article-history (Retrieved 2020-05-11).

Bruder, Ulf. (2013). *Värt att veta om plast.* 3rd edition. Malmö: DotGain AB.

Colgate. (n.d.). *Colgate bamboo charcoal soft toothbrush*. https://www.colgate.com/en-gb/products/toothbrush/colgate-bamboo-charcoal-soft (Retrievd 2020-05-22).

de Freitas, Claisa Andréa Silvade; de Sousa, Paulo Henrique Machado; Soares, Denise Josino; da Silva, José Ytalo Gomes; Benjamin, Stephen Rathinaraj and Guedes, Maria Izabel Florindo. (2019). *Carnauba wax uses in food.* https://www.sciencedirect.com/science/article/abs/pii/S0308814619306181?via%3Dihub (Retrieved 2020-05-11).

Ecostainable. (n.d.). *Full Circle 'Laid Back 2.0' Dish Sponge Refill.* [Image] https://ecostainable.com.au/products/full-circle-laid-back-2-0-dish-sponge-refill (Retrieved 2020-04-20).

Elner-Haglund, Katarina. (2020). *Bioplastics-It's a better choice.* Helsingborg: Nordisk Bioplastförening. http://www.e-magin.se/paper/96523t54/paper/1#/paper/96523t54/17 (Retrieved 2020-01-27).

Engineers Edge. (n.d.). *Injection Moulding Design Considerations for the Process*. https://www.engineersedge.com/manufacturing/injection-molding-design-considerations.htm (Retrieved 2020-05-18).

Favorite, Mary Jane. (2012). *Understanding Wood: Four Structure Types*. [Image] https://www.popularwoodworking.com/wood/understanding-wood-four-structure-types/ (2020-05-25).

Formlabs. (n.d.). *3D Printing Technology Comparison: FDM vs. SLA vs. SLS.* [Image] https://formlabs.com/blog/what-is-selective-laser-sintering/ (Retrieved 2020-05-27).

Formlabs. (n.d.). *Guide to Selective Laser Sintering (SLS) 3D Printing*. https://formlabs.com/blog/what-is-selective-laser-sintering/ (Retrieved 2020-05-18).

Good Science. (n.d.). Properties of Metals. https://www.goodscience.com.au/year-10-chemistry/properties-of-metals/ (Retrieved 2020-05-23).

Grosser, Dietger. (n.d.). Structure of deciduous wood. [Image] https://www.wolman.biz/en/infocenter_wood/from_tree_to_wood/wood_properties/aufbau_der_laubhoelzer/index.php?thisID=331 (2020-05-25).

Hydro. (n.d.). *Fakta om aluminium*. https://www.hydro.com/sv-SE/om-aluminium/fakta-om-aluminium/ (Retrieved 2020-05-22).

Live Science. (2013). *Fused Deposition Modeling: Most Common 3D Printing Method*. https://www.livescience.com/39810-fused-deposition-modeling.html (Retrieved 2020-05-18).

MatWeb. (n.d.). *Overview of materials for Nylon 12.* http://www.matweb.com/search/datasheet.aspx?matguid=0e37a459c4eb452faa9d92659f9a0ccc (Retrieved 2020-05-28).

MatWeb. (n.d.). *Overview of materials for Polylactic Acid (PLA) Biopolymer.* http://www.matweb.com/search/DataSheet.aspx?MatGUID=ab96a4c0655c4018a8785ac4031b9278&ckck=1 (Retrieved 2020-05-28).

Moritz, Tassilo and Maleksaeedi, Saeed. (2018). *4 Additive manufacturing of ceramic components. Additive Manufacturing*. https://www.sciencedirect.com/topics/materials-science/selective-laser-melting (Retrieved 2020-05-22).

My Painted Door. (n.d.). *Milk paint frequently asked questions.* https://www.mypainteddoor.com/milk-paint-frequently-asked-questions (Retrieved 2020-05-14).

Olsson, Olle G.. (n.d.). *Biomassa.* Nationalencyklopedin. https://www.ne.se/uppslagsverk/encyklopedi/lång/biomassa (Retrieved 2020-05-27).

Real Milk Paint. (n.d.). *Frequently Asked Questions*. https://www.realmilkpaint.com/about/faq/ (Retrieved 2020-05-12).

Rockler. (2020). *Understanding Oil and Wax Finishes*. https://www.rockler.com/learn/understanding-oil-and-wax-finishes (Retrieved 2020-05-14).

Shield, Charli. (2019). *The plastic crisis isn't just ugly – it's fueling global warming.* https://www.dw.com/en/the-plastic-crisis-isnt-just-ugly-its-fueling-global-warming/a-48730321 (Retrieved 2020-06-10).

Skarbrador.se (n.d.). *Träskärbrädor.* https://skarbrador.se/sidor/traskarbrador (Retrieved 2020-05-07).

Skogskunskap. (2016). *Lövskogen i Sverige.* https://www.skogskunskap.se/skota-lovskog/om-lov/lovskogen-i-sverige/ (Retrieved 2020-05-25).

SkogsSverige. (2019). *Björk (Vårtbjörk).* https://www.skogssverige.se/skog/svenska-trad/bjork-vartbjork-0 (Retrieved 2020-03-16)

SkogsSverige. (2019). *Bok.* https://www.skogssverige.se/skog/svenska-trad/bok-0 (Retrieved 2020-03-16)

SkogsSverige. (2019). *Ek (Skogsek).* https://www.skogssverige.se/skog/svenska-trad/ek-skogsek (Retrieved 2020-03-16)

SkogsSverige. (2019). *Tall.* https://www.skogssverige.se/skog/svenska-trad/tall-0 (Retrieved 2020-03-16)

Swedish Wood. (n.d.). *Durability and resistance.* https://www.swedishwood.com/wood-facts/about-wood/from-log-to-plank/durability-and-resistance/ (Retrieved 2020-02-10).

Sveriges Lantbruksuniversitet. (2020). *Produktiv skogsmark.* https://www.slu.se/centrumbildningar-och-projekt/riksskogstaxeringen/statistik-om-skog/senaste-statistiken/produktiv-skogsmark/ (2020-05-25).

TePe Munhygienprodukter AB. (n.d). *TePe GOOD Compact Soft tandborste.* https://www.tepe.com/sv/products/toothbrushes/adult/p-good-compact-soft/ (2020-03-18).

The Wood Database. (n.d.). *Wood Finishes: What works When.* https://www.wood-database.com/wood-articles/wood-finishes-works/ (Retrieved 2020-05-13).

Thomas Tsoumis, George (2019). *Wood.* https://www.britannica.com/science/wood-plant-tissue (Retrieved 2020-05-23).

Träcentrum. (n.d.). *Träslagsinfromation*. http://www.tracentrum.se/http-www-tracentrum-se-sv-bra-kompetens-tank-tracentrum-sok-nu/publikationer/traslagsinformation/ (Retrieved 2020-02-10).

Träguiden. (2017). *Träets styrka och styvhet*. [Image] https://www.traguiden.se/om-tra/materialet-tra/traets-egenskaper-och-kvalitet/mekaniska-egenskaper1/traets-styrka-och-styvhet/ (Retrieved 2020-05-23).

Träguiden. (2017). *Träets styrka och styvhet*. https://www.traguiden.se/om-tra/materialet-tra/traets-egenskaper-och-kvalitet/mekaniska-egenskaper1/traets-styrka-och-styvhet/ (Retrieved 2020-05-23).

Träguiden. (n.d.). *Naturlig beständighet.* https://www.traguiden.se/om-tra/standard/bestandighet-och-traskydd/bestandighet-och-traskydd/naturlig-bestandighet/ (Retrieved 2020-04-7).

Wolman. (n.d.). *Structure of deciduous wood*. https://www.wolman.biz/en/infocenter_wood/from_tree_to_wood/wood_properties/aufbau_der_laubhoelzer/index.php?thisID=331 (2020-05-25).

Woodwork Details. (n.d.). *Tung Oil*. http://www.woodworkdetails.com/knowledge/finishing/tung-oil (Retrieved 2020-05-14).

Appendix A Work distribution and time plan

In this section the contribution of each student participating in the master thesis is described. The initial plan of the project and the actual outcome are also visualised.

A.1 Work distribution

The work distribution for the different activities has been performed in cooperation and therefor a division of 50% is to be considered. This is also the case for the amount of work performed by each student for each activity.

A.2 Project plan and outcome

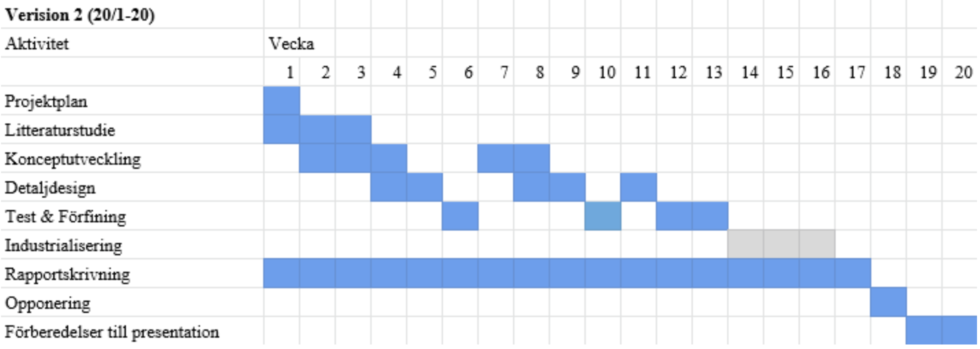
The planned project plan can be seen in Figure A.1 and the performed project plan can be seen in Figure A.2.

The most distinguishing differences are the activities research, production methods and concept testing.

Regarding research, it prolonged more than initially thought. The reason was that all facts needed for the project could not be found solely for the three first weeks as stated in the planned project plan, more time was inevitable to be able to gain sufficient information.

The activity concerning production methods was completely disregarded due to time limitation.

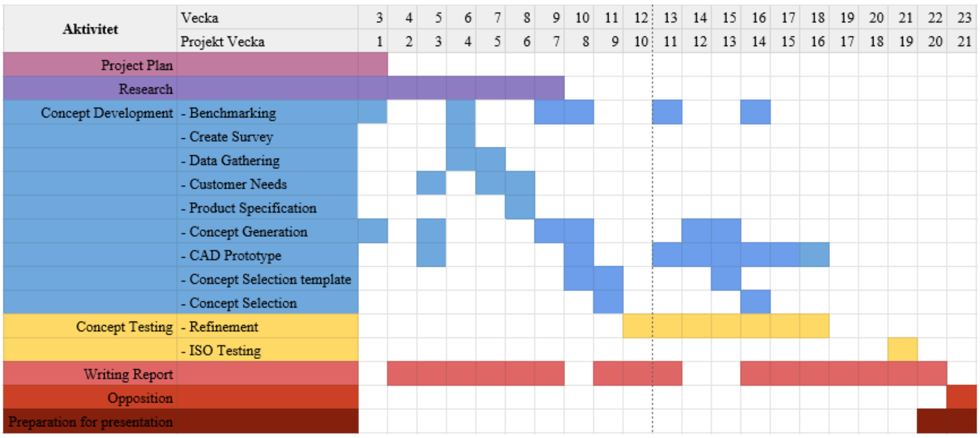
As for concept testing, it was also more time consuming than initially believed and was carried out parallel to the concept development.



Version 2 (20/1-20)

Aktivitet	Vecka																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Projektplan	■																			
Litteraturstudie	■	■	■																	
Konceptutveckling		■	■	■			■	■												
Detaljdesign				■	■			■	■		■									
Test & Förfining						■				■		■	■							
Industrialisering														■	■	■				
Rapportskrivning	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Opponering																		■		
Förberedelser till presentation																			■	■

Figure A.1. Planned project plan.

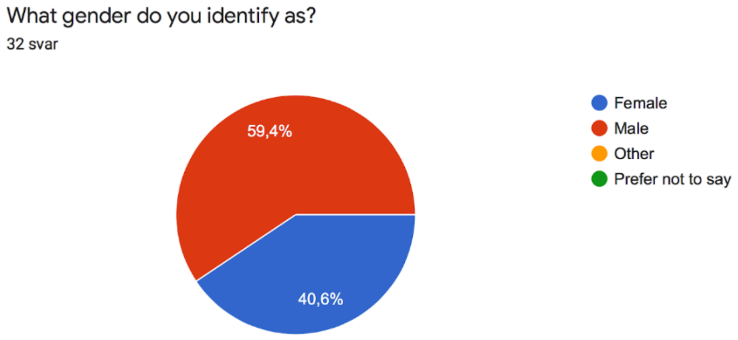


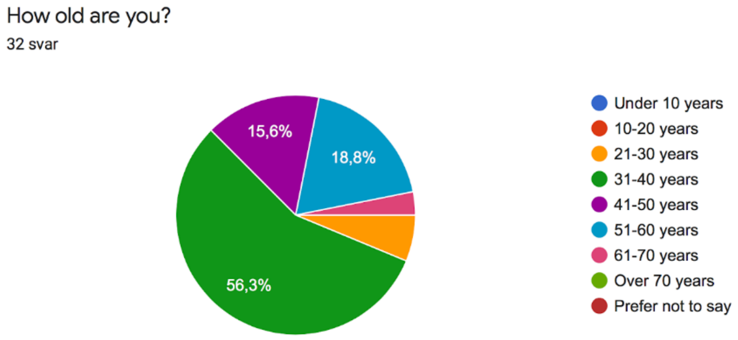
Aktivitet	Vecka	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Projekt Vecka	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Project Plan		■																				
Research		■	■	■	■	■	■	■														
Concept Development	- Benchmarking	■						■	■			■			■							
	- Create Survey				■																	
	- Data Gathering				■	■																
	- Customer Needs			■		■	■															
	- Product Specification						■															
	- Concept Generation	■		■				■	■				■	■								
	- CAD Prototype			■					■			■	■	■	■	■	■					
	- Concept Selection template								■	■				■								
	- Concept Selection									■					■							
Concept Testing	- Refinement										■	■	■	■	■	■	■					
	- ISO Testing																			■		
Writing Report			■	■	■	■	■	■		■	■	■			■	■	■	■	■	■	■	
Opposition																						■
Preparation for presentation																					■	■

Figure A.2. Performed project plan.

Appendix B Result from questionnaire

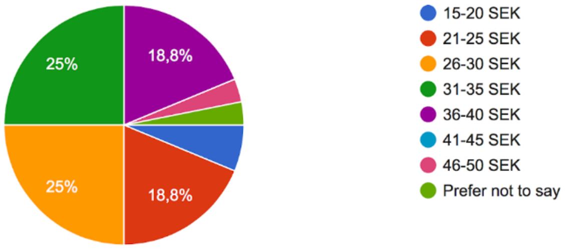
The responses gathered from the questionnaire are visualised in this section.





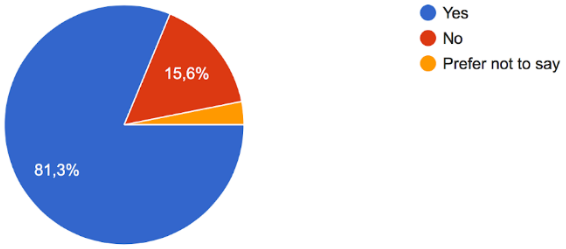
The most common price for a single toothbrush on the market today is between 15-25 SEK. What is the highest price you would be willing to pay fo...l we mean physical matter that comes from plants.)

32 svar



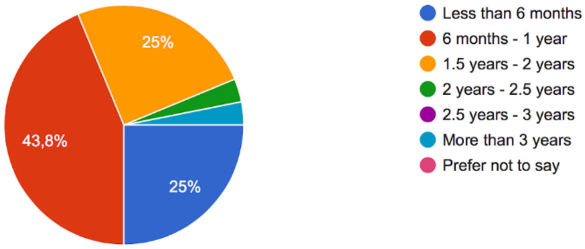
Would you appreciate the possibility to keep the toothbrush handle and only replace the worn-out toothbrush head with a new one?

32 svar



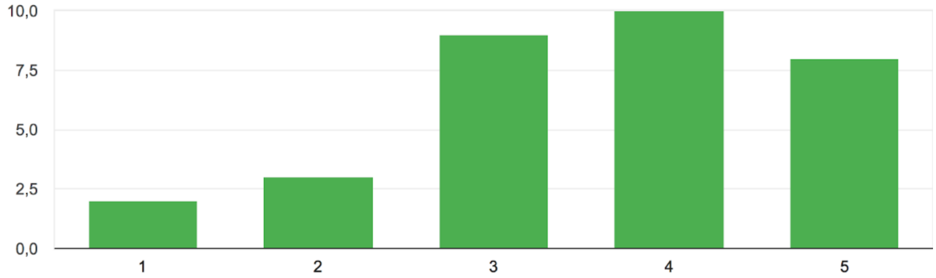
For how long would you consider using the same toothbrush handle made of natural material? (By natural material we mean physical matter that comes from plants.)

32 svar



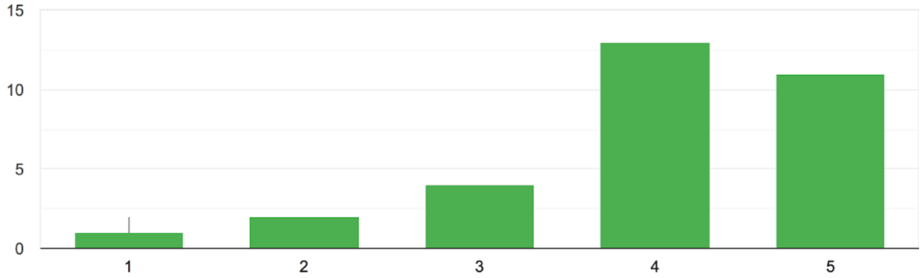
It is important that the natural material is locally produced. (By natural material we mean physical matter that comes from plants.)

32 svar



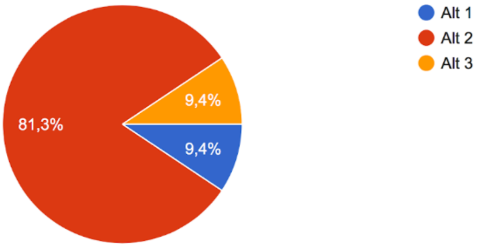
I believe that it is beneficial for the environment to keep the toothbrush handle and only replace the worn-out toothbrush head.

31 svar

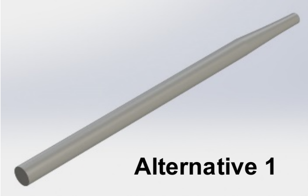


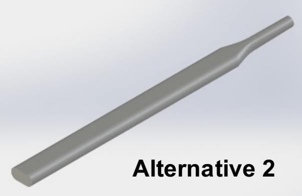
Which one of the handles are you most likely to purchase? (Note: Toothbrush head not included.)

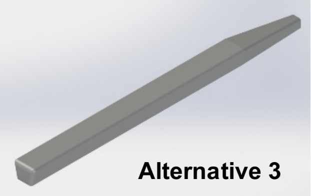
32 svar

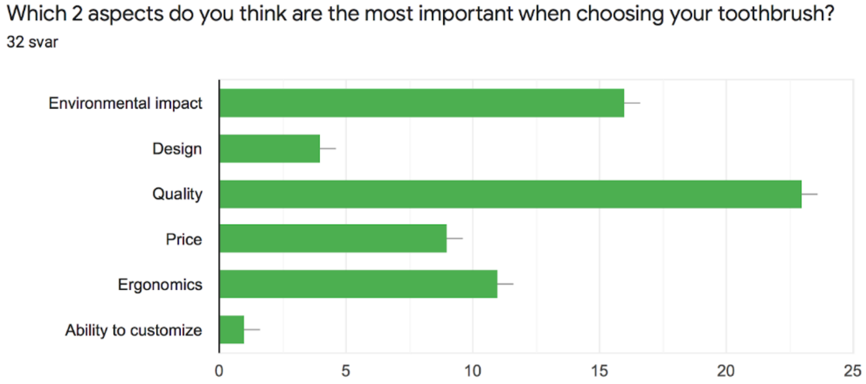


The alternatives being the ones in the pictures below:








Which 2 aspects do you think are the most important when choosing your toothbrush?

32 svar

What do you appreciate the most about your toothbrush?
The way it cleans.
Material, design and filament softness
It is effective and easy to use, Top rounded filaments and softness
That it does the job! Quality before design
Hur den känns att hålla i och hur fräsch den känns att använda. Hur stråna känns mot tandköttet.
The feeling of the bristles in the mouth and on teeth. Working at TePe I´ve had the opportunity to try out many different types. As a customer I would probably pay more attention to design, and even now if I buy a brush, I must choose depending on how the bristles look rather than feel.
Quality of the bristles
Feeling that it leaves (effectiveness)
It does the job easily
That I feel fresh and clean in my mouth
Quality
Small brush head, soft filaments. But I also use electrical toothbrush often.
The good grip and reach
It does a good job cleaning the teeth.
Quality
Quality, sustainable product
That make feel clean and fresh
Softness
Quality

Cleanliness - easy to clean from toothpaste etc.
Ease of use (Clean the teeth and be able to clean it fast and efficient without consume too much time and water
A brush that prevent damage to the gum
It is functional without, tapered toothbrush head for good reach in the back areas. The filaments are end rounded so they will not do any damage to hard or soft tissues.
The durability.
That it fills its purpose
Clean teeth
It is durable and quickly cleans the teeth.
Soft filaments (I love Supreme)
I know how it's made and the efforts and the strategies of the company. I believe the working conditions are better here than at the competitors
Easy to use
Simplicity, durable brushes, easy to keep clean
The grip and how thoroughly it cleans
Sensation in mouth that it is cleaning properly - soothing yet cleaning
Soft filaments and small brush head
It is simple
That it fulfils its purpose with oral hygiene
Cleaning abilities
Cleaning efficiency
That I find it easy, bright color.
It cleans and is gentle to m my teeth
Was bought at my local grocery store - didn't have to go anywhere different to get it. It isn't too soft. Looks recognizable. Except from that, it doesn't really matter what it looks like/ the brand.
The smoothness
A Good grip and quality bristels
That it is not too soft
My best, a usual toothbrush, not electric.
The Quality and how good it is at cleaning
Resultatet
Ease of use
That the bristles are not to soft!!
It reaches everywhere and it is not to soft nor to hard.
The tongue scrape
That it is a product with high quality
Results
Feeling after brushing, quality, env. impact
It is electrical. (What about replaceable environmentally friendly toothbrush heads for electrical ones? Never seen one)
How good it is cleaning my teeth
Being there for me, even though the darkest of days.
That its cleans good, not to big

Bra på att Rengöra mina tänder
Good quality so I can keep the same brush for a long time
A good feeling on the gums and teeth, easy to use, tells you when the head needs to be changed.
Longevity
Good quality, feels good in your mouth, easy to brush
It is cheap and comfortable
Soft bristles
Den har mjuka strån och huvudet är inte speciellt stor
Good feel and size of brush head
Bekvämt handtag och ganska smalt vid borthuvudet
Healthy smile :)
Borstar effektivt (tror jag) (den är elektrisk)
Easy to use

Is there something you would like to change about your toothbrush?
Have it last for an eternity.
More sustainable if possible
I would like to be able to replace the head to minimize usage of resources and to be able to purchase it through a ´´racer blade model´´ subscription
No, I have an electric one that I like
No
I´ve tried brushes with replaceable parts before. Key for it to work long term is that the connection point is outside the mouth. It is easy to think that you want the replaceable part to be as small as possible when you buy it the first time. But no, if it is to small it doesn´t dry out properly between brushes and gets nasty quickly. Also as for handle shape ergonomics is more important than design.
Slightly different design on the handle for better ergonomics
It´s made out of plastics
Less plastic
A sustainable Supreme Compact. Or a TePe electrical toothbrush :)
More design options
No, not that I can think of.
No
Not really. But an environmental footprint should be reduces at least by half
No
Updated, modern design
An indicator in the handle that indicates when too much force is applied would be nice
I use TePe Select, and for me it is the perfect brush.
Changeable head
Everlasting
To replace all the different petroleum-based parts with environmentally sustainable materials.
Yes, a more sustainable handle
Nothing that I can think of
More sustainable
I dislike when stuff gets stuck at the base of the brush strands

No
Truly sustainable - ideally and eventually biodegradable
More sustainable
Nope, I've been using the model for so long
More environmentally friendly even at a higher price
No
The filaments. Should be smoother and more filaments (our select compact has more filaments than our select...)
Name tag on it?
I would love my toothbrush to be completely environmentally friendly and made of sustainable materials
It’s made of plastic because my local store doesn’t have any better alternatives. I have to buy new ones quite often.
A handle that can be used with different kind of heads, i.e. a normal one and a small one (mellanrumstandborste) etc.
Durability
I have one made out of wood, but I don't like the feel of it... It is so rough compared to plastic.
Bought in Germany, eurodont, easy to hold.
Nej
The brush should last longer
That it is plastic.
Mabey the quality and thus make it last longer
That it is sustainable
Pressure control
The less material the better
Longer lasting perhaps
No
Design.
The design, most are ugly. You hide it in the cabin
Mindre plast och längre hållbarhet
Perhaps even better quality so the time between having to buy a new toothbrush is increased
Last longer!
Nej, jag gillar min tandborste
removable heads would be nice
A little longer neck
Not really

Appendix C Criteria established for concept selection 1

In this section, the full description of all criteria used for the first concept selection is presented.

Concept Selection - Round 1

Criteria to evaluate:

- Ease of assembly
- Interface robustness
- Ability to keep fresh
- Ease of manufacture
- Design (Aesthetic) (Subjective assessment at the end)

Ease of assembly (disregard the impact of clearance) - Rate factors:

1. The concept is **very unsatisfying**. The solution is not working and needs major improvement.
2. The concept is **unsatisfying**. The solution is not working well but can be acceptable with improvements.
3. The concept is **neutral**. The solution is acceptable but can be further improved.
4. The concept is **satisfying**. The solution is working well but can be further improved.
5. The concept is **very satisfying**. The solution is working very well and only needs minor adjustments.

Interface robustness (for example: stability when assembled, tolerance for human error or ability to not break) - Rate factors:

1. The concept is **very unsatisfying**. The solution is not working and needs major improvement.
2. The concept is **unsatisfying**. The solution is not working well but can be acceptable with improvements.
3. The concept is **neutral**. The solution is acceptable but can be further improved.
4. The concept is **satisfying**. The solution is working well but can be further improved.

5. The concept is **very satisfying**. The solution is working very well and only needs minor adjustments.

Ability to keep fresh (when assembled) - Rate factors:

1. The concept is **very unsatisfying**. The design has many surfaces prone to collect dirt and is impossible to fully reach for cleaning.
2. The concept is **unsatisfying**. The design has many surfaces prone to collect dirt and is hard to clean.
3. The concept is **neutral**. The design is acceptable. It has some surfaces prone to collect dirt and is moderately easy to clean.
4. The concept is **satisfying**. The design has some surfaces prone to collect dirt and is easy to clean.
5. The concept is **very satisfying**. The design has no surface prone to collect dirt.

Ease of manufacture - Rate factors:

1. The concept is **very unsatisfying**. All manufacturing steps of the design requires manual processing. Will probably have a long cycle time.
2. The concept is **unsatisfying**. Most manufacturing steps of the design requires manual processing. Cycle time can be shortened with improvements.
3. The concept is **neutral**. The manufacturing steps and cycle time of the design are acceptable but can be further improved.
4. The concept is **satisfying**. Most manufacturing steps of the design can be manufactured automatically. Cycle time can be improved with minor adjustments.
5. The concept is **very satisfying**. All manufacturing steps of the design can be manufactured automatically. Short cycle time is achievable.

Appendix D Data gathered from concept selection 1

In this section, all data gathered from the first concept selection is presented.

Concept A

Ease of assembly: 3
Comments: Går att linjera men bättre om rund eftersom man kan sätta den fel. Rotationsberoende i detta stadie. Halvmåne hade också funkat för att förhindra rotation.

Interface robustness: 3
Comments: Risk att den lossnar. Litet arbetande tvärsnitt vilket är en nackdel vid slagtest.

Ability to keep fresh: 3
Comments: Glipa kommer troligen att fyllas med tandkrämsrester.

Ease of manufacture: 5
Comments: Måste ha drag på huvudet, verktyget kommer därmed bli mer komplext så därför inte en 5:a. Fräs inte det optimala. Att göra piggen i träet istället förenklar tillverkningen. Förbättring kan vara att honan är som en krage över hela handtaget. Handtaget är tappen.

Design (Aesthetic):
Comments: Känns inte förtroendeingivande med bara en träplugg. Och att man kan vrida fel känns inte helt bra. När den är monterad känns det som en 4.

Mean value:
Other thoughts:

Concept B

Ease of assembly: 3
Comments: Just nu sämre än förra men om det hade passat så samma som koncept A.

Interface robustness: 3
Comments: Samma som koncept A. Tillför inte lika mycket som det kommer kosta.

Ability to keep fresh: 3
Comments: Samma som koncept A. O-ringen tillför inte så mycket.

Ease of manufacture: 4
Comments: Lite jobbigare än koncept A. Tappen blir också vekare med den lilla halsen.

Design (Aesthetic):
Comments: Monterat läge ger samma intryck som koncept A.

Mean value:
Other thoughts:

Concept C

Ease of assembly: 4
Comments: Tagit bort aspekten av att sätta fel om handtaget inte har något bak och fram.

Interface robustness: 3
Comments: Kommer gå av lika lätt som koncept A men kan inte vridas. Fortfarande vek i tapp, kanske att man ska göra något som grepar utifrån istället för att få större area.

Ability to keep fresh: 3
Comments: Samma som de tidigare koncepten A och B.

Ease of manufacture: 5
Comments: Kommer krävas någon typ av bearbetning.

Design (Aesthetic):
Comments: Samma som koncept A-B

Mean value:
Other thoughts:

Concept D

Ease of assembly: 4
Comments: Jobba med att ändra längden av varje varv, stigning osv.

Interface robustness: 3
Comments: Går inte att göra fel pga att den är rund. Svagaste länken är återigen tvärsnittet (piggen). Frågan är dock hur robust en trägänga är.

Ability to keep fresh: 4
Comments: Samma som de andra koncepten. Kanske något bättre eftersom man kan få bort glipan då man kan skruva åt hårt.

Ease of manufacture: 2
Comments: Lite mer komplex än de tidigare koncepten. Idé är att vända på gängan. Borra ner i träet och ha gängan ut i plastdelen.

Design (Aesthetic):
Comments: Ser bättre ut än de tidigare. Trevlig. En fyra.

Mean value:
Other thoughts:

Concept E

Ease of assembly: 4
Comments: Lätt att assembla i GOOD-materialet men kanske även lättare att den lossnar.

Interface robustness: 3
Comments: Robusthet kanske går upp. Det runda tvärsnittet gör så att man inte kan göra fel. Flänsen tar kraften vid slagtestet (piggarnas översta del, där den fäster i toppen). Vid runt tvärsnitt begränsas inte tappens tjocklek lika mycket som vid ett kvadratiskt → positivt.

Ability to keep fresh: 2

Comments: Hålet in i träet gör det lite sämre.

Ease of manufacture: 3
Comments: Svår att tillverka. Behöver kärndragning. Botten, och från sidorna. Kanske bara två piggar. Träpinnen känns enkel att tillverka. Kan förenkla genom att ha färre piggar.

Design (Aesthetic):
Comments: Samma som koncept D. Ser dock onödigt komplex ut.

Mean value:
Other thoughts: Vad fjädrar tillför genomfört med en tapp kan man fundera vidare på, det blir mer komplext att tillverka jämfört med en vanlig solid tapp så frågan är om det inte tar ut varandra. Kanske räcker med två ben för att kunna ha i ett öppna stäng verktyg.

Concept F

Ease of assembly: 2
Comments: Fungerar bra när det är styvt material men med GOOD material kanske det inte kommer funka lika väl. PE flexar inte tillbaka. När man deformerat det så tappar det sin form. Måste linjera, måste ha lite fingerfärdighet när man monterar ihop delarna på tandborsten.

Interface robustness: 2
Comments: Du kan göra fel, inte alla som uppmärksammar att de ska klicka i hålen, finns ingen guidning. Flänsen avgör hur stabil den är, hålen hade nog kunnat gå åt andra hållet.
Kan lägga till guidning för att underlätta för användaren hur man ska föra in den.

Ability to keep fresh: 2
Comments: Samma som koncept E.

Ease of manufacture: 3
Comments: Samma som koncept E, lite men två olika borr gör att det blir lite mer komplext att tillverka. Hade behövts vrida för att hålen på tandborsten ska bli bra, delningslinje måste gå i samma plan som hål för borst.

Design (Aesthetic):
Comments: Kan kännas genomarbetat och färgkontraster som tittar ut från skaftet. 3-4.

Mean value:
Other thoughts: Kommer nog inte få ett bekräftande klick med PE.

Concept G

Ease of assembly: 3
Comments: Hyfsad styrning. Kortare ben och lite bredare kan förbättra. Nu måste man lufta och trycka in den istället för bara i en linje.

Interface robustness: 1
Comments: Känns väldigt vek, benen kommer ta all kraft, låsningen kommer bli svår att få till med grön PE.

Ability to keep fresh: 2
Comments: Många linjer.

Ease of manufacture: 3
Comments: Behöva vrida piggarna 90 grader för att kunna ha formsprutningen i två delar i rätt riktningen.

Design (Aesthetic):
Comments: 3 .

Mean value:
Other thoughts: Kan bli utmaning med grön PE.

Concept H

Ease of assembly: 4
Comments: Bättre än en tapp, får indikation att den är i botten. Svårt att göra fel.

Interface robustness: 2
Comments: I denna utförandet är den inte bra. Men man kan förbättra.

Ability to keep fresh: 2
Comments: Samma som koncept F.

Ease of manufacture: 3
Comments: Sämre än koncept F. Svårare att göra delen i trä.

Design (Aesthetic):
Comments: Designen ger en signal när den är i botten.

Mean value:
Other thoughts:

Concept J

Ease of assembly: 2
Comments: Inte så jobbigt att trycka in en lös del. Lite jobbigt med lös del som man ska ha koll på.

Interface robustness: 2
Comments: Blir man av med lilla tappen fungerar inte konceptet längre, vilket drar ned betyget. Är den korrekt monterad är den väldigt stabil. Eftersom tappen kan tappas bort är den unsatisfying. Lös att den inte kan tappas bort.

Ability to keep fresh: 3
Comments: Rätt mycket linjer som kan täppas igen. Större ytor, lättare att rengöra.

Ease of manufacture: 3
Comments: Kommer krävas två backar för så som den ser ut nu. Komplext verktyg.

Design (Aesthetic):
Comments: Hade man fått till det hade det varit något, fint med trä kontrast. Inte lika högt som den runda → betyg 3.

Mean value:
Other thoughts:

Concept K

Ease of assembly: 4
Comments: Ganska lik H, svårt att göra fel, den har en styrning.

Interface robustness: 1

Comments: Lurig att få bra eftersom en djupare tapp kan göra montering svårare. Går att vända för att få bättre hållfasthet.

Ability to keep fresh: 2
Comments: Samma som H.

Ease of manufacture: 3
Comments: Två hål på sidorna istället hade gjort det lättare med formsprutningen.

Design (Aesthetic):
Comments: Lite rolig ifall det går att funka. 4

Mean value:
Other thoughts:

Concept L

Ease of assembly: 2
Comments: Snarlikt G, biffar man upp G kommer den bli ännu styvare.

Interface robustness: 2
Comments: Får man till klick så är den bättre än G.

Ability to keep fresh: 2
Comments: Samma som G.

Ease of manufacture: 1
Comments: Svårare att tillverka än G. Kommer bli svår att göra bra.

Design (Aesthetic):
Comments: Som G. Betyg 3.

Mean value:
Other thoughts:

Concept M

Ease of assembly: 1
Comments: Lösa delar. Samma som koncept J. Max en tvåa.

Interface robustness: 2
Comments: Vänd klämma åt andra hållet för att öka robusthet.

Ability to keep fresh: 2
Comments: Massa delar att rengöra.

Ease of manufacture: 4
Comments: Ska man ha två verktyg för klämman så ska man få ut extremt mycket ur funktionalitets aspekt. Man kan designa in ena biten i plasthuvudet samt ha den andra som en påsklämma så att den trycks ner. Smådelarna kan tillverkas i ett och samma verktyg.

Design (Aesthetic):
Comments:

Mean value:
Other thoughts: Inte här man ska börja utan det finns enklare koncept som är värda att arbeta vidare med innan.

Concept O

Ease of assembly: 1
Comments:

Interface robustness: 1
Comments:

Ability to keep fresh: 2
Comments: Många delar.

Ease of manufacture: 1
Comments:

Design (Aesthetic):
Comments:

Mean value:
Other thoughts:

Concept P

Ease of assembly: 4
Comments: Kan vara att man vänder åt fel håll men inget stort problem.

Interface robustness: 2
Comments: Ease of assembly jobbar mot interface robustness. Kan vara en idé att vrida klämman 90 grader.

Ability to keep fresh: 3
Comments: Svårt om man vill dela på den och rengöra.

Ease of manufacture: 3
Comments: Samma som G gällande trähandtag. Svårare att formgjuta.

Design (Aesthetic):
Comments: Kan vara lite åt design hållet. 3-4

Mean value:
Other thoughts:

Concept Q

Samma som koncept P. Slå ihop båda för ett nytt koncept kanske.
Ease of assembly: 4
Comments:

Interface robustness:
Comments:

Ability to keep fresh:
Comments:

Ease of manufacture:
Comments:

Design (Aesthetic):
Comments:

Mean value:

Other thoughts:

Concept R

Ease of assembly: 4
Comments: Enkel att montera.

Interface robustness: 2
Comments: Behövs en låsning till för att bli mer stabil.

Ability to keep fresh: 2
Comments: Samma som koncept G.

Ease of manufacture: 3
Comments: Träpinne känns rätt lätt. För att tillverka ett huvud behövs 2 backar, som koncept P.

Design (Aesthetic):
Comments: Hyfsad, finns roligare, en 3:a.

Mean value:
Other thoughts:

Concept S

Ease of assembly: 3
Comments:

Interface robustness: 1
Comments: Gör piggen längre så att den blir mer lik koncept A.

Ability to keep fresh: 2
Comments: Spår i trähandtag. Långa spår gör det svårt.

Ease of manufacture: 2
Comments: Tunnväggigt gör det svårt att fylla med ett trögflytande material som PEn i GOOD-serien. Kommer behövas 5-axlig fräs.
Gör kortare svans och gör den tjockare.

Design (Aesthetic):
Comments: Innovativ. Personligt tycke en 3:a.

Mean value:
Other thoughts:

Övriga tankar som diskuterades:

Med tanke på grön PE så var den mest tilltalande gängade men tvärtom med hona och hane, att den är rund. En idé är att kombinera med koncept P för att få ett klick mot slutet. När man vrider så låser delarna ihop sig.

Man hade kunnat kombinera C och P för att kunna låsa när den är på plats.

Någonting som gör det robust och något som låser det på plats.

Appendix E Basis for concept selection 2

In this section, the basis for the second concept selection is presented in form of arrangement of the execution and questions asked.

1. Presenterar alla koncepten
2. Påbörja diskussion med de. Har följande frågor till hjälp:
   - Vilken tycker du är lättast att montera?
   - Vilken tycker du är mest stabil?
   - Vilken tycker du är mest hållbar? (Tål att monteras av och på flera gånger)
   - Vilken tycker du är lättast att tillverka?
   - Med avseende på alla punkter vi nu diskuterat, vilket koncept tycker du att vi ska arbeta vidare med?
3. Berätta om våra favoriter och varför vi tycker som vi gör.

Appendix F Answers and discussions from concept selection 2

In this section, the answers gathered from the second concept selection and the discussions that arose, are presented.

Möte med Produktutvecklingsavdelningen på TePe:

- Om det finns produktionsfördelar med kvadratiskt tvärsnitt ser de inte ett problem med detta.
- Borde inte påverka att borrning sker i fler riktningar. Invändiga klämman kan ha något längre tid på grund av att det ska ske en flyttning för håligheten inuti.
- Negativa geometrier är inte optimalt. Har man en liten vinkel i bajonettlåset så kan man göra så att huvudet sugs ner inåt mot handtaget. Har små geometrier som kan vara problematiska.
- På bajonett kommer öronen bli väldigt klena i PE.
- Bör nog ha 2-2.5 mm godstjocklek för trä.
- Måste finnas en kravställning på hur många gånger man kan montera av och på huvudet.
- På TIO borste så använder man nya huvudet för att få loss det gamla.
- Ha så mycket trä som möjligt i hela handtaget och dölj plasten.
- Gällande gänga, kolla hårdhet för plast kontra trä för att se om man kan gänga träet med plasten. Plastens hårdhet är 64D.
- Kolla på deformation liknande skruvkorkflaskor.
- Bättre att slippa o-ring.
- Anpassa gängan på huvudet efter standardgänga komponent om det finns.

Vilken tycker du är lättast att montera?

> Klick ska också orienteras, bra med ljud som indikerar att den klickar, kan bli svårt att få i PE dock. Gillar gängan för att den är intuitiv, att den kan gängas ned och få en liten springa. Gänga och invändig klämma är favoriter.

Vilken tycker du är mest stabil?

> Bajonett eller gänga, de andra lite inbyggda glapp. För bajonett så kilar man t.ex. ihop, får man inte åtdragningsmoment så får man alltid ett litet glapp.

Vilken tycker du är mest hållbar? (Tål att monteras av och på flera gånger)

Gällande inre klämman, så kommer nog PE inte ha så stor möjlighet att snäppa. Bör nog sälja paket med specifikt antal huvuden för att undvika att man använder trähandtaget för länge.

Vilken tycker du är lättast att tillverka?

Bajonetten är lurig men kommer behöva delas i två för hylsan. Huvudena är likvärdiga i svårighetsgrad.

Med avseende på alla punkter vi nu diskuterat, vilket koncept tycker du att vi ska arbeta vidare med?

Gänga och inre klämma med en release.

Möte med Operationsavdelningen på TePe:

- Någon slags orientering hade varit bra, 1mm tjockare på en sida räcker för att kunna orientera. Då kan geometrin bara passera på ett håll. Bra att ha någon planare yta som den kan lyftas på. Sugpropp lyfter oftast. Den runda landar mycket bra!
- Prata med plasthallen som kan ge feedback på formverktygen.
- Kan bli problem om det rinner ut vätska från hålen.
- Man kanske kan lösa med en läpp i plasten för att förhindra att vätska rinner in i gränssnittet.
- Ha alltid med någon indikator/hack som hjälper maskinen orientera.
- Idé är att bränna TePe loggan med laser samtidigt som styrningen läggs till. Hjälper då att orientera.
- Göra om klämman så att man inte ska behöva trycka in den utan att den trycker in sig själv. (Kan bli problem med hålrum men kan lösas genom att göra piggarna längre)

Vilken tycker du är lättast att montera?

Alla känns lätta att montera. Koncept med yttre knapp är känt från paraply, igenkänningsfaktor. Känns ohygieniskt med stor spalt, därför känns bajonett bra för att man kan få den väldigt tät då. Gällande produktion hade det varit skönt att slippa hålet. Tror inte att o-ring behövs.

Vilken tycker du är mest stabil?

Bajonett, sitter bra, är tät. Tror inte på knapp, kärvar, samlar smuts. Gängan sitter bra också.

Vilken tycker du är mest hållbar? (Tål att monteras av och på flera gånger)

Alla borde klara av att bytas 3-5 gånger. Mest kritisk är de med knappar, lite utmanande att få till så att den sitter fast, inte glappa. Ett helt rakt spår istället för styrning som finns på inre klämman kan vara en idé. Eller fler hål som den passar i för att inte behöva orientera så exakt.

Vilken tycker du är lättast att tillverka/montera?

> Fyrkantigt lättast vid montering då den har tydliga lägen. Göra om klämmor så att de inte ska behöva tryckas ihop.

Med avseende på alla punkter vi nu diskuterat, vilket koncept tycker du att vi ska arbeta vidare med?

> Gängan känns bra ifall det går att få till. Gillar inte koncepten med hålen ut. Som konsument gillar de bajonettlåset då det är tydligt hur man använder den och att man får ett klick som indikerar när den är fast. Gängan kanske man får skruva länge på. Knappen är nog tydligast på hur man ska klicka in nästa tandborste. Kan bli problem att man kastat förpackningen så bra att tänka på den så att instruktionen blir kvar när man ska använda tandborstarna 3-6 månader senare. Bra att ha en förpackning där man förvarar andra huvudena med instruktioner på. Plopparna gör att man förstår mer. Att dra är nog det enklaste konceptet för montering och konsument men ohygieniskt. Kan lösas med en krage i plast. Tycker om plopparna men max en att trycka in när man drar.
>
> Enligt Operations ska vi gå vidare med gänga och invändig klämma.