TEXTILE AS BUILDING BLOCK FOR LUMINAIRES

Design guidelines for applying textile as a surface finish to product housings

TU Delft

Signify

Textile as building block for luminaires:

design guidelines for applying textile as a surface finish to product housings.

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Master Thesis

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Also a big thank you to my supervisory team: Kaspar Jansen and Sylvia Pont. I would like to thank Kaspar for always challenging me to step up my game and for the many great tips he provided me with. And Sylvia I would like to thank for her kindness and support during all of our meetings and the amazing constructive feedback she always gives.

At the start of this project I contacted a company to ask if I could collect some discarded textile housings at their recycling facility. I was warmly welcomed by Maartje, the team leader of Road2Work in Ede. I was invited to visit and together we dove into the containers of broken products to look for textile housings. I would like to thank her and the company for their hospitality that led to an amazing kickstart of my project.

Prior to the project I was afraid that I would often have to work alone at the faculty because many peer students and friends had graduated and moved away from Delft during the Corona pandemic. Therefor I participated in the Graduation Community Program (GCP) and this way I got to know other graduating students. I really enjoyed the company of fellow students who were on the same graduation boat. We got to inspire, help and motivate each other during our weekly Monday meetings. I would like to thank these peer students for their support throughout my project: Kevin, Jack, Natalie, Asli, Parastou and Adriaan.

In the end I did not have to study alone for a day. I was surrounded by other students, acquaintances and friends and who came and went as they were graduating themselves. I would like to thank some in particular: Anne, Jip, Mees, Ilse and Mirjam. Thank you for the support and for the many coffee breaks we had where I could vent about my project. Thank you for letting me be a part of your graduation processes as well.

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I would like to thank my parents for providing me access to Hotel Mama and Hotel Papa when I stayed the night to visit the High Tech Campus in Eindhoven. I promise to buy you many bags of paprika ribbel chips to compensate after my graduation. A big thanks to Ziva for always wagging her tail so enthusiastically when I returned home from the High Tech Campus. To her I say “woof”.

Lastly I would like to thank Jorik for the many helpful graduation consultancy sessions. He unconditionally helped me to gain new ideas, to prevent self-doubt from creeping in and from eating too many deep frozen pizzas because I was too busy to cook during deadline times. A big thank you for being such an amazing listener!

Executive summary

This Master's thesis report contains research about applying textile to the outer housing surface of products. The research was conducted in collaboration with Signify, a company that creates smart home luminaires for the brand Philips Hue. The goal of the project was to create design guidelines which the designers of Signify can use to create textile building blocks for their luminaires.

The project explores suitable textiles, shaping possibilities and fastening methods. The most relevant insights are summarized on "Design Guidelines" pages. A "Design Decision Tree" (DDT) was created to navigate through the Design Guidelines. The DDT can be used by designers who have a housing shape in mind to learn about the relevant insights for applying textile to their specific surface.

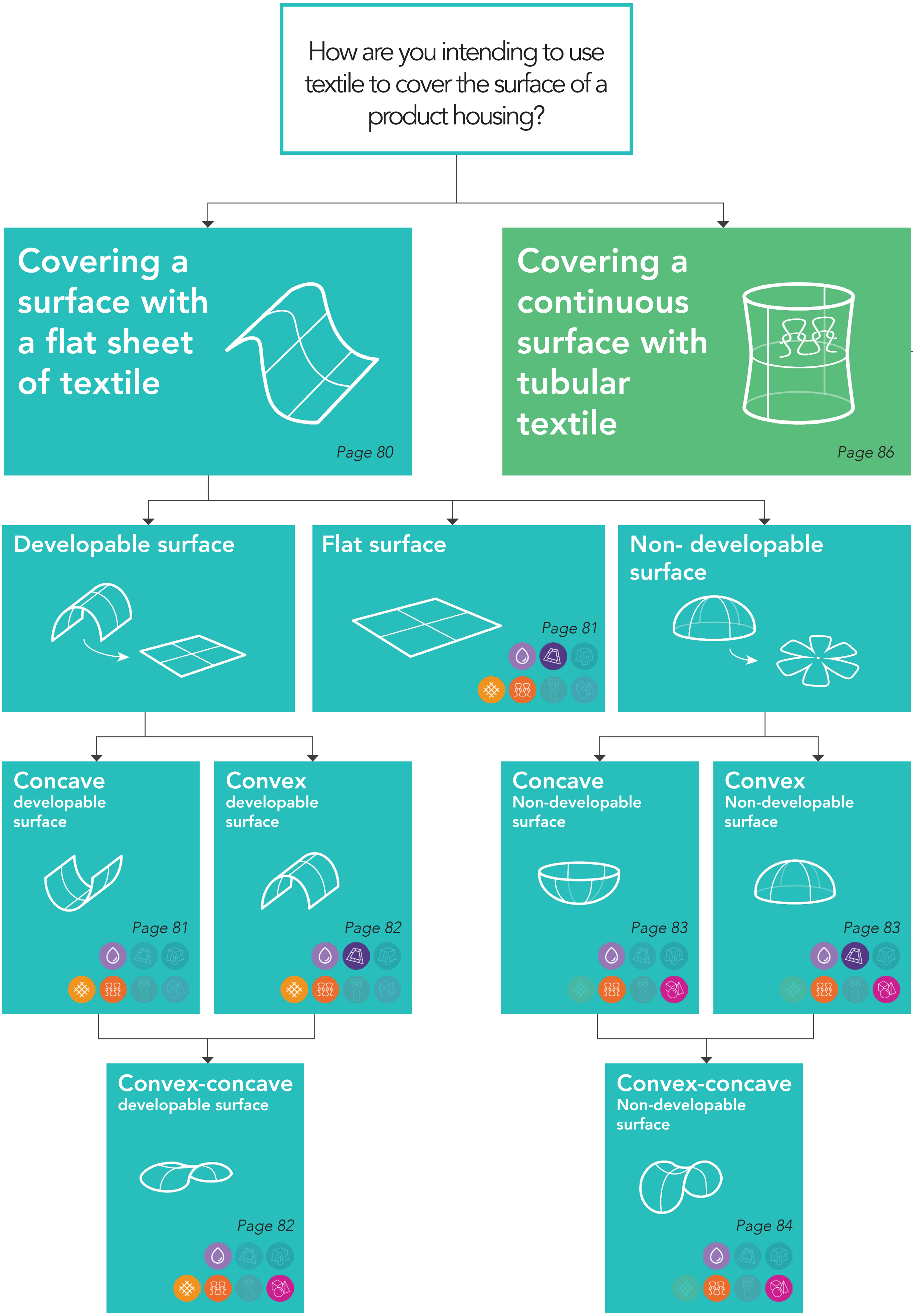
Suitable textiles for surface application are researched. It was determined that knitted and woven fabrics are suitable for surface coverage. Non-woven fabrics are not because of their undesired appearance and minimal required thickness which impedes mechanical fastening.

Shaping possibilities were explored for covering surfaces with flat sheets of fabric as well as covering continuous surfaces with tubular textiles. Depending on the properties of a surface, certain fabrics and fastening methods can or cannot be used. The design limitations per surface category are summarized in the Design Guidelines.

Most current textile housings are fabricated by gluing or welding the textiles to the outer surface and inner edges of the part. This method obstructs easy disassembly. An alternative method was created. This "clamping" fastening method is considered more sustainable because it allows the housing to be disassembled with ease and therefor repaired or recycled more efficiently. A clear use cue was added to the inside of the clamping mechanism to inform the user about its disassembly potential.

In addition to the gluing and clamping method, creating a separate sleeve was explored. To fabricate such a sleeve, 3D-knitting can be used. Literature research was conducted to explore the possibilities of knitting three-dimensional shapes on flatbed and circular knitting machines to cover product housings.

A novel product concept for Philips Hue was created. A prototype of the concept was made to demonstrate textile building blocks in the context of a luminaire. This product concept is called the "Rotation Lamp" and it is used as a tool throughout the report for experimenting and validating. The Rotation Lamp is inviting to touch because of its textile parts. It is intended to be kept close to the user and to enhance their well-being by providing them with a lamp that suits their need for ambience and functional light. Three sets of textile housings were created for the prototype to observe the different product aesthetics that these could create.



How are you intending to use textile to cover the surface of a product housing?
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Developable surface
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Design Decision tree

For applying textile as a surface finish to product housings

Fastening method

- Gluing or welding
- Clamping
- Sleeve

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Textile type

- Woven fabric (flat sheet, non-stretch)
- Flat knitted fabric (stretch)
- Circular knitted fabric (stretch)
- 3D-knitted fabric (stretch)

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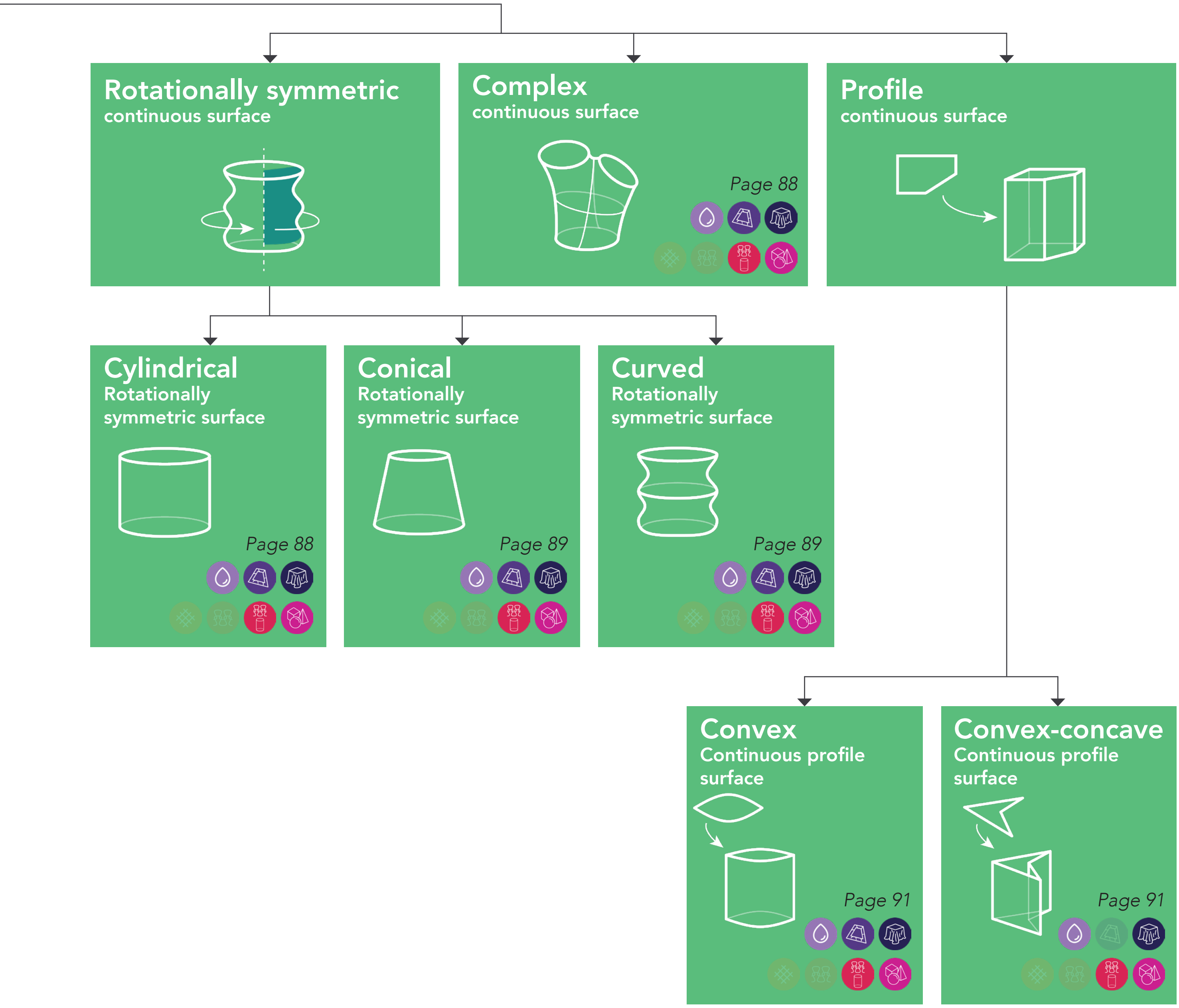

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Chapter 1:

Introduction

In this introduction the topic of this thesis will be explained. This includes the motivation for the research, its approach, research questions and method. Finally, the Design Decision Tree will be introduced which functions as a guidance throughout this report.

1.1 Project introduction

This thesis project explores the use of textile as a finish to the outer housing of home consumer electronic products. Textile application is commonly used in Bluetooth speakers to create a soft and natural appearance. An exploration of existing textile housing products was executed and can be read in chapter 3. This textile trend has not yet been translated into luminaire products: this provides a great market opportunity for Signify.

Fig. 1.1: Fresh 'n Rebel Rockbox Bold M. Bluetooth speaker with textile housing.

Signify is a company that designs high-end smart home lighting products for the brand Philips Hue. Current Hue products all have plastic or metal outer housings. This allowed the brand to create minimalistic, modern products that fit within every style of interior. Signify wants to differentiate from these current product appearances by expanding their array of surface finishes towards textiles.

Signify will use this textile application for a new category of luminaire products with a well-being proposition. These new products will be inviting to touch and they will bring lighting closer to the user. Textile is a highly suitable material for this purpose. In addition, consumers are increasingly aware of the environmental issues which are caused by excessive use of plastic products. This leads to an increase in demand for sustainable looking and feeling products. Textile can help to create a more natural appearing product.

Fig. 1.2: Sleek Philips Hue products with plastic and metal outer housings.

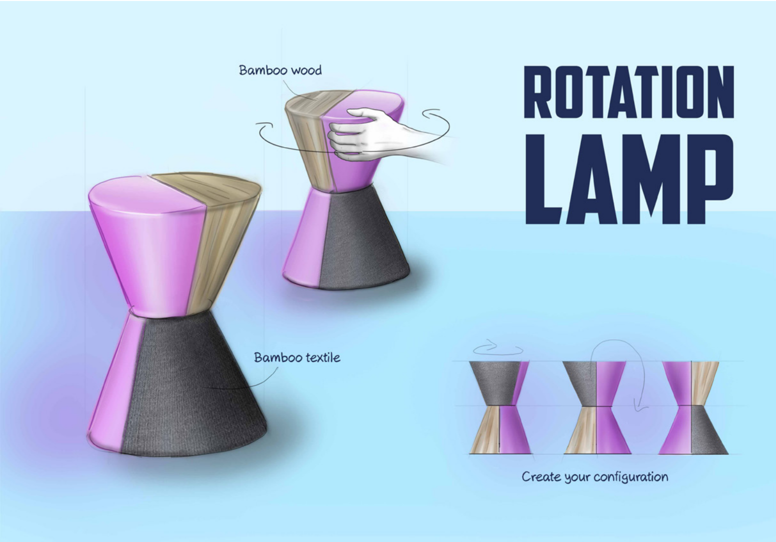


Fig. 1.3: Concept sketch of the Rotation Lamp.


Fig. 1.4: Prototype of the Rotation Lamp.

This project took place at an early stage of the design process. The company had not defined a product concept for the textile to be applied to and neither did they have the required supply base. It was chosen to create design guidelines for this front-end design phase. The guidelines contain information about suitable textiles for housings (chapter 4), shaping possibilities (chapter 5) and fastening methods (chapter 6). At the end of several chapters the main insights are listed on "Design Guidelines" pages. These guidelines are meant for designers to get an overview of the design recommendations and limitations and they can be immediately used in the following design stage. The "Design Decision Tree" was made to navigate through the Design Guidelines. More information on the Design Decision Tree can be read in chapter 1.3.

It was discovered that most textile product housings had its textile glued to the surface. This obstructs correct recycling of the separate waste streams for textile and usually plastic housing materials. For this thesis an alternative circular design solution was created to design more sustainable textile housings. This new solution named "clamping" will be explained in chapter 6.2.

The knowledge that was gained during this project was applied to an innovative product concept to be able to observe the textile application in the context of a luminaire. This "Rotation Lamp" means to inspire and to kickstart the next phase of the design process after this project has ended. The lamp was prototyped with two interchangeable textile housings. These allowed the exploration of the textile building block. Elaboration on the design of the Rotation Lamp can be found in chapter 7.

1.2 Project approach

This chapter will explain the focus of this project as well as the approach towards creating the Design Decision Tree and Rotation Lamp product concept.

1.2.1 Project proposal

What was considered important by Signify to be explored in this project was summarized in a project proposal which can be found in appendix B. This proposal states that among other things the project needed to address the following:

- Suitable textile materials.
- Mechanical fastening of textile.
- Shapes, patterns, look and feel of textiles.
- Application range.
- Lead carrier project for textile introduction.

The scope, research question and method were based on the requirements listed above. These project elements will be elaborated next.

1.2.2 Scope

Given the available types of textiles as well as the degrees of freedom in luminaire designs, a large amount of considerations can to be taken into account when designing a textile luminaire. The boundaries for this project are visualized in the scope on the right.

It was chosen to focus on the elements that are most relevant at the front-end design phase. This is the phase in which this project was executed. Textile types, fastening, shaping and product application are included in the scope.

The industrial implementation, costs and other detailed design considerations will start playing an important role during further stages of the design when a chosen Philips Hue product design is being developed. Analysis of such elements have therefor been omitted in this research.

What is important to mention is the decision to leave the exploration of optical properties out of the scope. This research focusses on the design of textile surfaces where no light is passing through. Translucent fabrics are considered the next step to be explored for Philips Hue.

Fig. 1.5: Project scope.

1.2.3 Research question

The overall research question that this project aims to find an answer to, is as follows:

> ***"What design guidelines should be taken into account when textile is applied as a finish to the outer housing of a Philips Hue luminaire?"***

This question is relatively broad and therefor split in three more tangible sub-questions. They will be elaborated next.

1.2.4 Sub-questions

From the scope these sub-questions were derived. The sub-questions describe the main design topics that were addressed during this project. These questions will each be answered in the chapters of this report. In the conclusion they will be summarized, see chapter 9.

These topics and their questions are as follows:

- *Textiles: chapter 4*
  What kind of textiles can be used for application on product outer housings?
- *Shape: chapter 5*
  What shapes can be achieved with textile when applied to the outer surface of a product?
- *Fastening: chapter 6*
  How can textile be fastened in a way that it can be taken off easily for repairing or recycling?

1.2.5 Method

This thesis was conducted in about 100 days. As a tool for the exploration of textile application a conceptual product was chosen at the midterm (day 40). This way, the largest part of the project could be dedicated to diving deeper into the exploration of textile as building block. This concept allowed the prototyping of tangible housing parts to see the textile elements in the context of a luminaire.

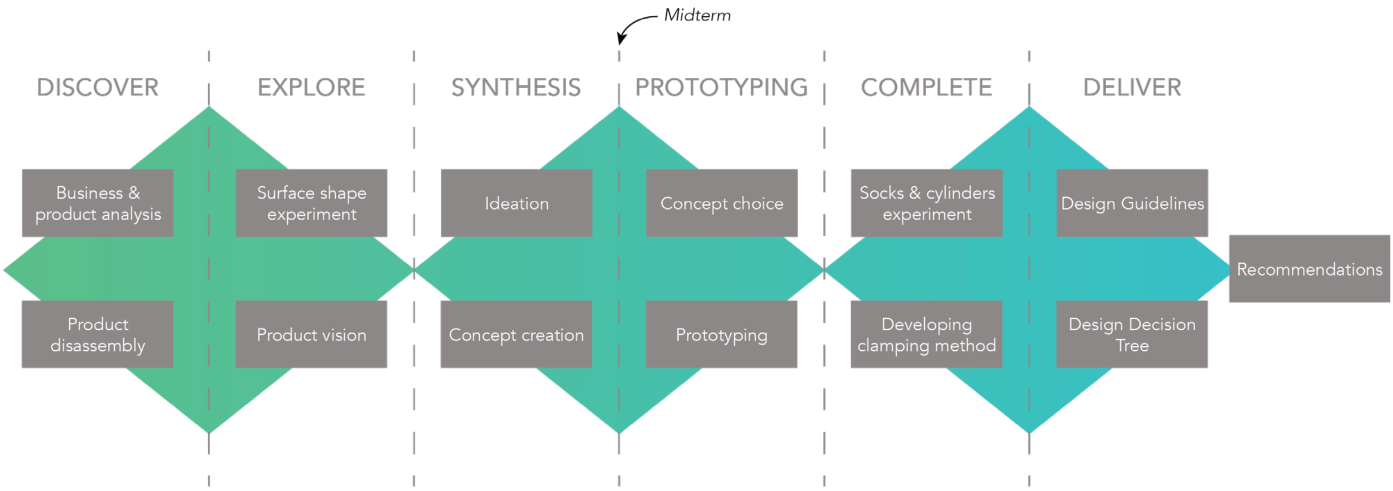


Fig. 1.6: Visualised method of the project, forming a triple diamond.

In the first phase Signify and Philips Hue were analysed to discover the context in which the textile application would take place. Then fourteen existing textile housing products were taken apart to learn about the used textiles and their application techniques.

In the next phase a "surface shape experiment" was conducted where the surfaces of basic shapes inspired by Philips Hue products were 3D-printed and covered with fabric. This resulted in a list of design guidelines for wrapping surfaces with flat sheets of textile. Then a product vision was formulated to start the ideation phase for creating product concepts.

Five concepts were visualized and then discussed during the midterm presentation with the university supervisory team and textile application team from Signify. These visualized concepts functioned as a conversation starter that evoked discussion, from which was learned what needed to be prioritized in the research that followed.

After the midterm one concept was chosen. This was made into a prototype with two detachable textile housing components. Multiple replaceable parts were 3D-printed in varying shapes and configurations to explore textile shaping possibilities and disassembly methods.

In the next exploration phase the "socks & cylinders experiment" was set up with cylindrical shapes and sock samples from a supplier of Signify. Through this experiment the use of circular knitted fabrics for continuous surfaces was explored in order to complete the research about shaping possibilities. In addition, a sustainable alternative fastening method named "clamping" was developed, tested and improved.

In the final phase all of the insights per sub-question were collected. The most relevant insights were bundled onto Design Guideline Pages at the end of several chapters. The Design Decision Tree tool was created which refers to the corresponding Design Guidelines.

The project ended with recommendations and a roadmap for the near future with which Signify can continue to explore this material integration after this project has ended.

1.3 Design Decision Tree

A model was created to help the designers of Signify in the process of designing a textile luminaire. This tool is called the "Design Decision Tree" or DDT in short. This model and its use will be explained in this chapter.

1.3.1 Goal of the DDT

The DDT functions as a guidance throughout this report for finding the Design Guidelines to be taken into account when covering a housing surface with textile. It can be used by designers who wish to learn more about textile surface application. It helps them to navigate quickly to the parts of the research which are relevant for their design. The DDT could be considered as a second table of contents to be used by product designers.

In this thesis you will find "Design Guidelines" pages at the end of several chapters and they can be recognized by a blue-green border. These pages sum up the most important insights of the corresponding chapters. The DDT refers to those Design Guideline pages so the reader can navigate to the chapters in which the content is explained more thoroughly.

Shown below is an illustration of the Design Decision Tree and how it refers to the Design Guidelines. The full-size DDT can be found on page 4 and 5 of this report.

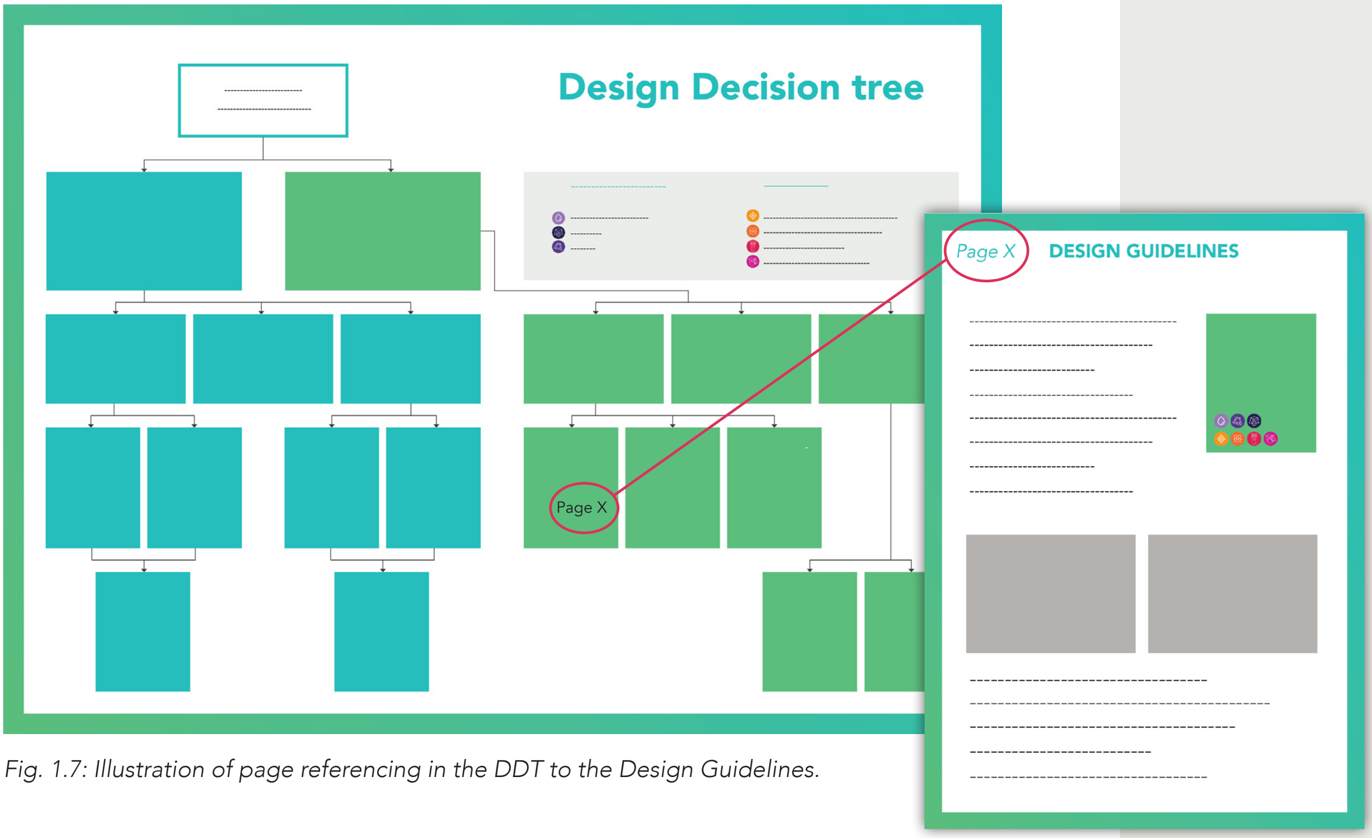


Fig. 1.7: Illustration of page referencing in the DDT to the Design Guidelines.

1.3.2 How to use the DDT

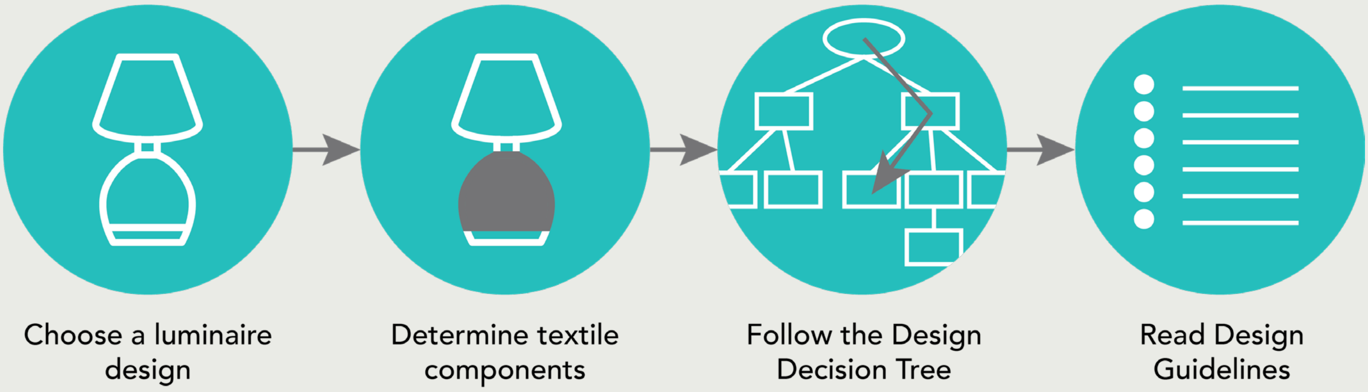
To use this tree the designer needs to have a luminaire design in mind. They should choose which housing component is to be covered with textile. Then the DDT can be consulted to determine which Design Guideline Pages can be read to learn about the textile application possibilities.

The user starts by asking themselves how they intend to use textile to cover the surface of a product housing. This can be done by covering the surface with a flat sheet of textile or by using tubular textile around a continuous surface.

By walking through the steps of the tree the designer asks themselves which boxes best describe the shape of the surface. Consequently they land on the last box which captures the shape of the surface in the best way possible.

To get a full overview of all relevant design guidelines for the shape, all pages referred to in the boxes in line to the last one should be read. The page numbers of the corresponding Design Guidelines can be found in the corners of the blue and green boxes in the DDT.

Fig. 1.8: Steps of using the DDT.



1.3.3 Shape categories

The blue and green boxes in the DDT describe the properties of surfaces that can be wrapped with textile.

There are two fundamental ways to use textile as a surface finish: by wrapping a flat sheet of fabric over a surface or with a tubular shaped textile that is stretched over a continuous surface. These two methods are the main categories at the top of the DDT. The first category is depicted in the blue boxes, the continuous surfaces in the green boxes.

The main categories can be divided into several sub-categories. These "shape categories" will be explained in this chapter so the user of the DDT can get a better understanding of to which category their housing surface belongs.

Important to notice is that the textile is applied on top to the outer surface. This is true for both categories.

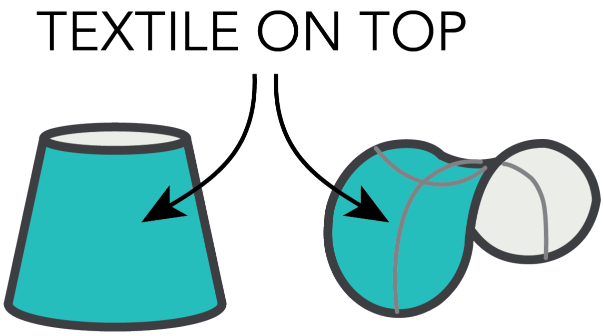
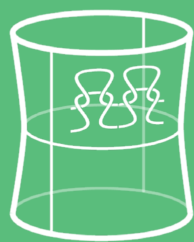


Fig. 1.9: Illustration of the textile applied on top of a surface.

Covering a surface with a flat sheet of textile

Covering a continuous surface with tubular textile



The shape index matrix is used to visualise which surfaces for flat sheets of fabrics fit within each category. In chapter 5.1 this matrix will be elaborated in more detail. The chapter can be read to get a better understanding of the surface categories before using the DDT.

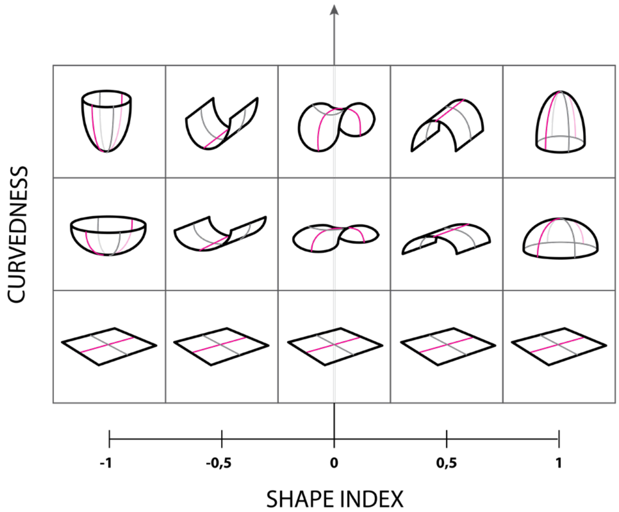
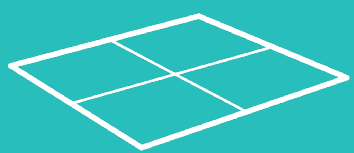
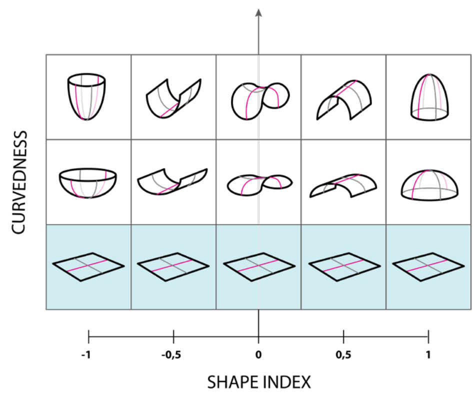


Fig. 1.10: Shape index matrix.

Now, all shape categories will be explained.

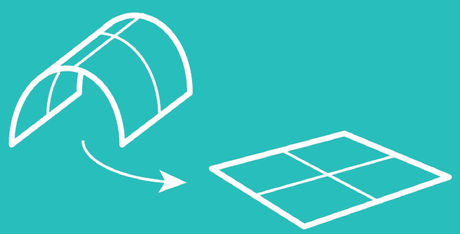
Flat surface

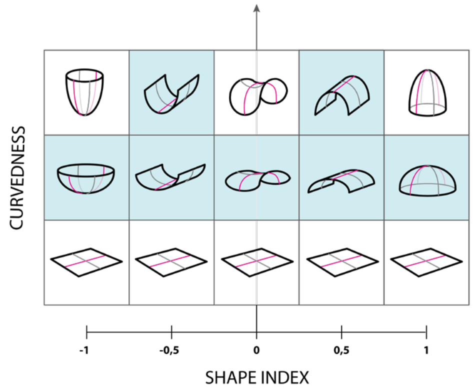




A flat surface has zero curvedness and therefor it is flat. This category is straightforward and covering a flat surface with fabric does not create much design difficulty when it comes to shaping.

Developable surface



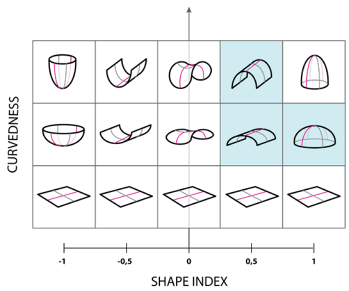


A developable surface can be laid flat without breaking it. This surface can be covered without stretching or damaging the textile: it can be wrapped around the shape with ease. In theory a double curved surface is non-developable. However, textile is always slightly stretchable and this results in the ability to cover shallow non-developable surfaces, even with non-stretch fabrics. Therefor these surfaces are included in this category as well. This can be seen in the shape index matrix above.

Concave developable surface

Concave developable surfaces are curved positively in one axis. This results in a shape that is hollow.

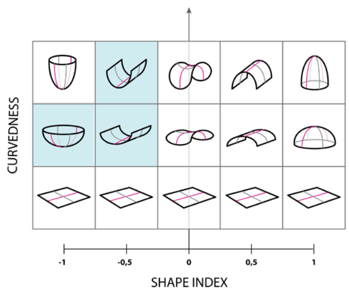
Shallow double curved surfaces are also included in this category because they can be covered with the same methods as single curved surfaces.



Convex developable surface

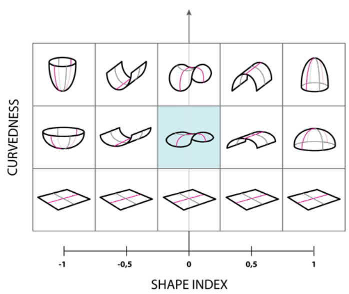
Convex developable surfaces are curved negatively in one axis. This results in a shape that is curved upwards.

Shallow double curved surfaces are also included in this category because they can be covered with the same methods as single curved surfaces.

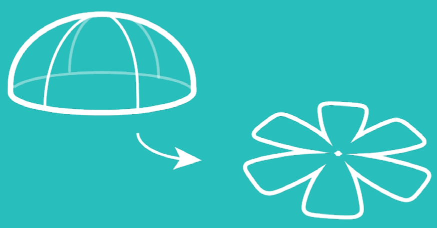


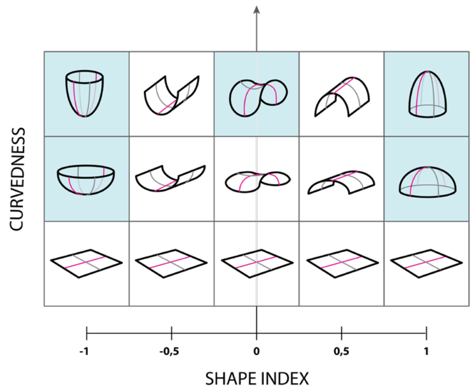
Convex-concave developable surface

Convex-concave surfaces are curved both positively and negatively. These surfaces are also called "saddle shape". These are included in this category because they can be covered with the same methods as single curved surfaces.



Non- developable surface

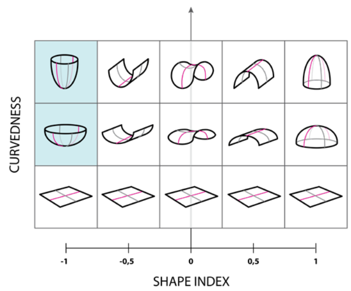




Non-developable surfaces are double curved. Textile should be able to stretch to cover the whole surface. In this model it is required that the textile touches the whole surface area.

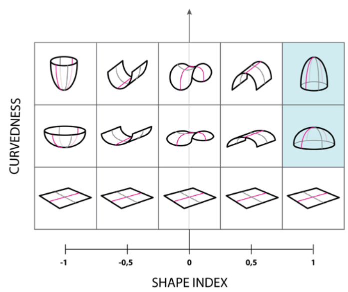
Concave
Non-developable surface

Concave non-developable surfaces are curved positively in both axis. This results in a spherical shape that is hollow.



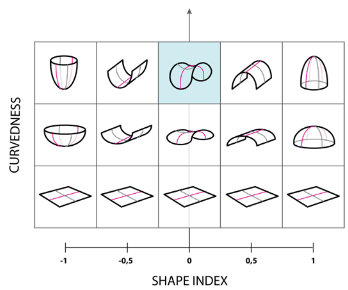
Convex
Non-developable surface

Convex non-developable surfaces are curved negatively in both axis. This results in a spherical shape that is curved upwards.



Convex-concave
Non-developable surface

Convex-concave saddle shapes are double curved. Saddle shapes with steep curves are included in the category of non-developable surfaces because they require fabric to be stretched over the shape.



If the surface can be created by rotating a figure 360° around an axis it can be described as rotationally symmetrical.

Rotationally symmetric
continuous surface

Cylindrical
Rotationally symmetric surface

Cylindrical rotationally symmetric surfaces have a single diameter that does not vary along the height.

Conical
Rotationally symmetric surface

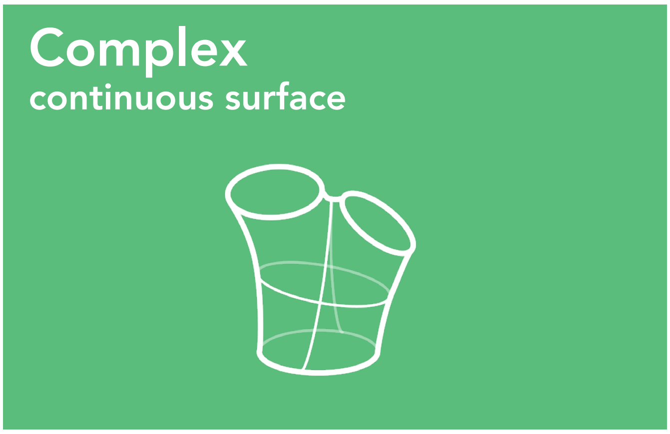
The diameter of a conical rotationally symmetric surface gradually varies from the top to the bottom which results in the shape of a cone. The diameter either expands or shrinks from the top to the bottom.

Curved
Rotationally symmetric surface

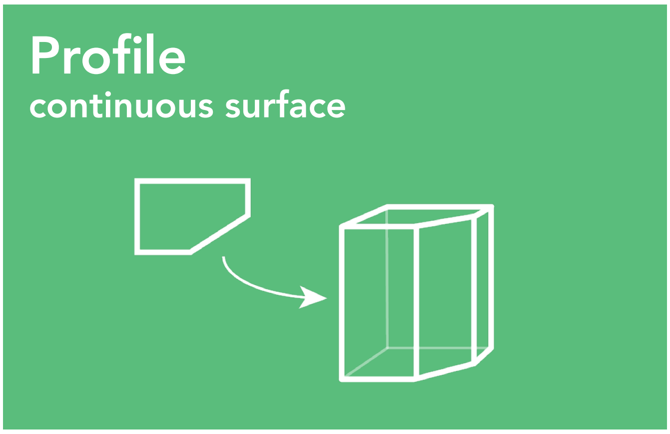
If a continuous surface has a diameter that expands or shrinks multiple times from the top to the bottom this results in a curvy shape. This can result in spherical surfaces as well.

If the continuous surface does not fall into any of the other categories, it can be described as a complex surface. These shapes require a tailored solution for textile application.

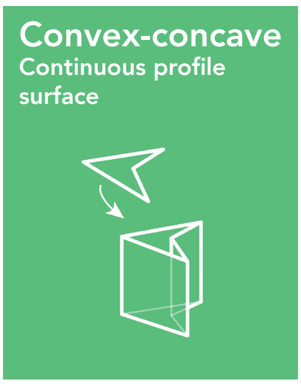
A complex surface can be divided in multiple surfaces which do fit in the shape categories of the DDT. By running through the DDT multiple times, Design Guidelines can be collected for this shape.



If the surface could be made by extruding material through a profile it can be described as a profile surface. These surfaces are likely to contain corners.



If the profile from which this surface is extruded does not have any hollow curves it results in a totally convex profile surface.



If the profile from which this surface is extruded has hollow curves, the shape can be described as a convex-concave profile surface.

1.3.4 Important notices for using the DDT

Important notices to take into account when using this tree are:

- The DDT does not take into account the possibilities for non-wovens because it was decided that these fabrics are not suitable for the envisioned luminaire product application (see chapter 4.1).
- A clear distinction is made in the DDT between stretch and non-stretch, consecutively wovens and knits. The DDT does not take into account woven fabric with elastic yarns resulting in a stretchable textile. If such a fabric is to be applied it should be considered as a knitted fabric to use the DDT model correctly.
- It might be possible that the new product design has multiple textile housings. In this case the DDT needs to be run through multiple times to learn about all the relevant design guidelines.
- If the surface does not fall into any of the categories it could be divided in segments. The DDT can be run through for each segment to learn about relevant Design Guidelines. However, these guidelines are not sufficient so a tailored solution must be explored for these complex surfaces.
- This DDT was made with the product application in mind of designing sleek looking Philips Hue luminaires. Therefor, the option of sewing textile has been excluded since this creates a highly visible seam which does not fit the product appearance of Hue products.
- The categories of the DDT describe the shapes of the outer surface of a housing. The wrapping of textile around the inner edges is not taken into account. To use the DDT the designer needs to consider only the outer shape of the surface. The border for the outer surface lies at the edge where the textile would be wrapped towards the inside for inner edge fastening.

Chapter 2:

Background information

This chapter will provide background information about the company Signify, its consumer smart lighting brand Philips Hue and the prior research that was done by Signify on textile application.

2.1 Signify

Signify is a world leading company in providing lighting products. The company is situated in 70 countries and has over 32.000 employees worldwide (Signify.com, n.d.). Signify is divided in many sub-brands, each with a different focus on professional or consumer goods. It is a broad range from brands that develop lighting for hospitals, offices, greenhouses, to the smart home lighting products of Philips Hue.

Situated at the High Tech Campus in Eindhoven, Signify has been developing new Hue products since its launch in 2012 (Signify.com, 2019). Every year they expand the product portfolio to keep up with trends and to keep consumers and Philips Hue fans enthusiastic. Most Philips Hue designs are developed by the department of Signify in Eindhoven.

This chapter will provide background information about the company.

2.1.1 Sustainability commitments

Signify has high ambitions when it comes to sustainability. With their commitment to "Brighter Lives, Brighter World" they set goals to improve their global sustainability impact. With consumers becoming increasingly aware of global sustainability issues Signify has to push itself further every year to improve its operations and products to become CO_2-emission neutral.

Signifys CEO claims to have achieved carbon neutrality across its entire business operation in September 2020 and that they use 100% renewable electricity and send zero waste to landfills. It is not possible to verify this information. It is also not specified what the entire business operations include.

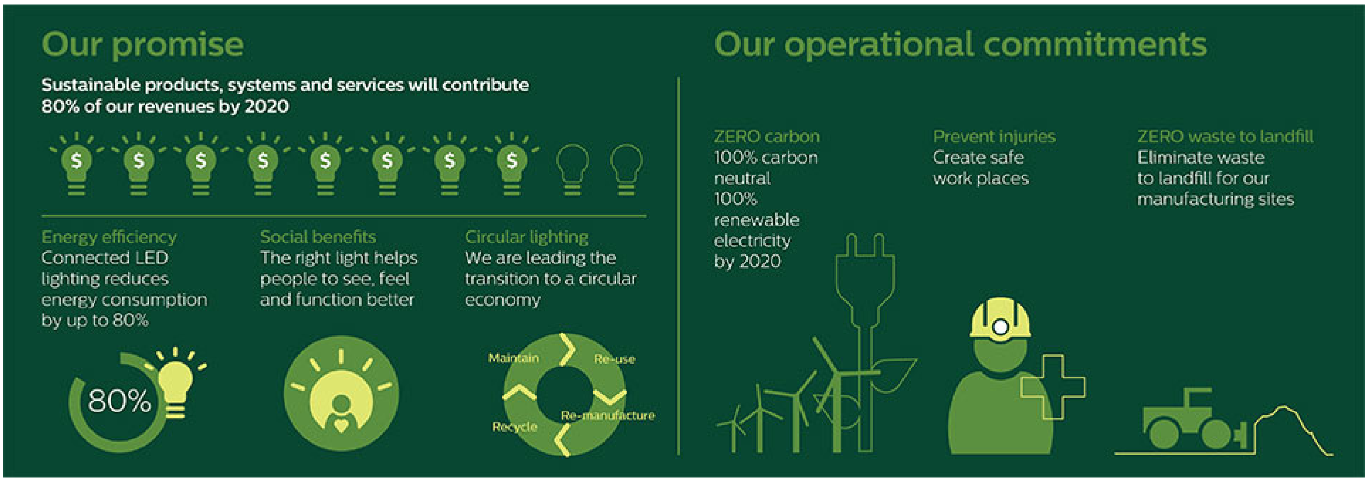


Fig. 2.1: Signifys sustainability commitments from the 2020 annual report ("Annual Report 2020," 2020).

"It is with a lot of pride that we announced that we achieved carbon neutrality across our entire operations in September, that we now use 100% renewable electricity and send zero waste to landfill."

- Eric Rondolat, CEO of Signify. From the annual report of 2020.

We do see proof that Signify is working on bringing sustainable products to the market: for example by street lanterns with solar panels or custom and recyclable 3D-printed lampshades (Signify, 2021).

A company can only achieve a truly sustainable business operation when the principles of a circular economy are being implemented. These are illustrated in the image of the “Butterfly Diagram” on the right (The Butterfly Diagram: Visualising the Circular Economy, 2017). This model describes the ideal life cycle steps for renewable or fossil materials in a circular economy. This diagram can be used by designers to assess and communicate in which steps of their product lifecycle improvements can be made to achieve more circularity. The textile housing products of Philips Hue are likely to be made with finite materials such as plastics, therefor it was chosen to focus on the right side of the diagram for this project.

For consumer products circularity means that all materials should be kept in the loop for as long as possible and no waste should be generated. We currently have a linear economy in which a product is made, used and disposed of at the end of the products life. The transition from the current linear economy to the circular economy is not a revolution, rather a slow transition throughout the whole business operation from design to supply chain to use to disposal and renewal.

This report provides Signify with design solutions for making a circular textile housing product. By providing an innovative method for the easier disassembly of textile housings, this element can be maintained, reused, refurbished and recycled most effectively which helps to keep the product in the loop for as long as possible. This project gives Signify the opportunity to kick-off their new well-being product series with a circular design mindset.

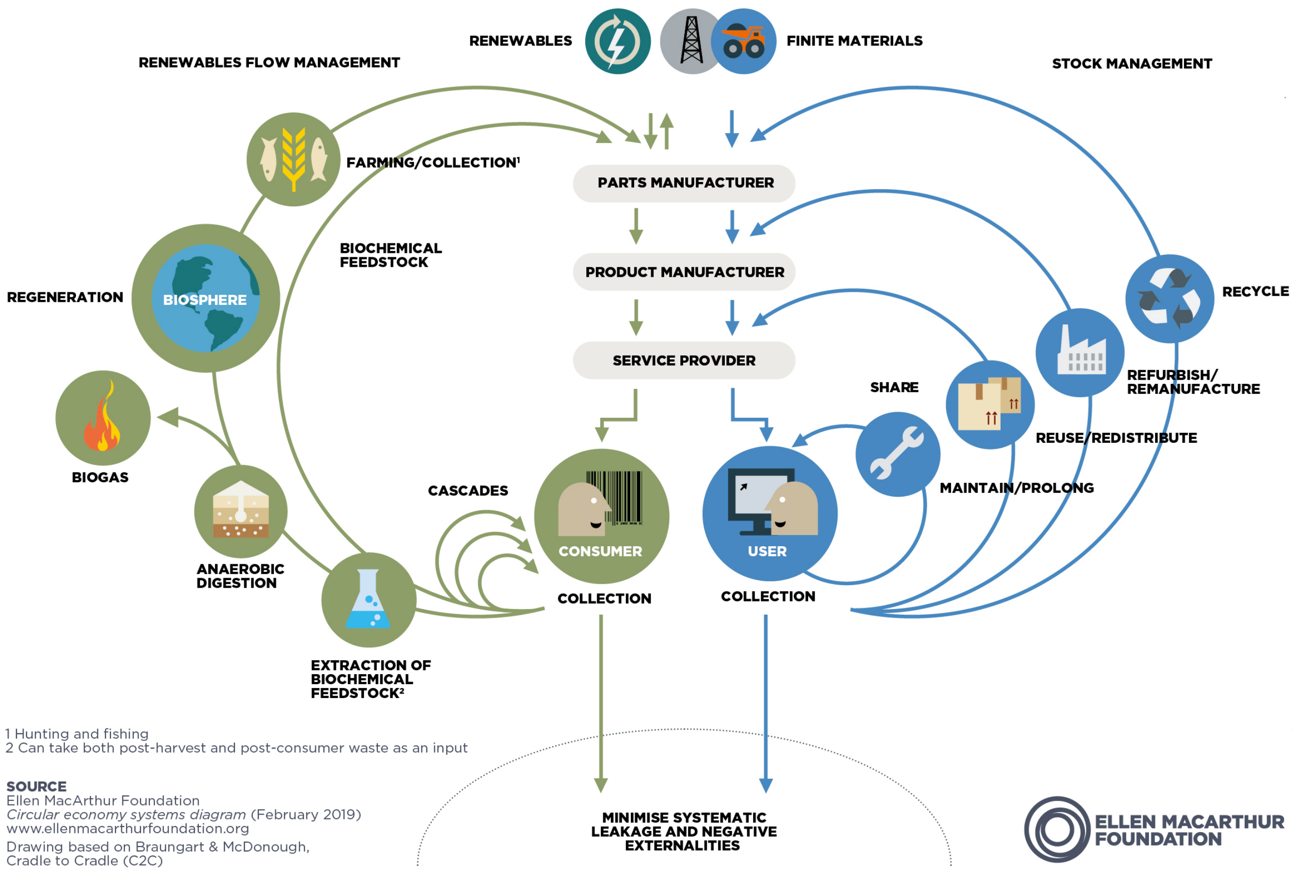


Fig. 2.2: The Butterfly Diagram from the Ellen MacArthur Foundation.

2.2 Philips Hue system

Philips Hue is the consumer home electronic brand of Signify. This chapter will firstly discuss the types of light that are being used and then the working principles of the Hue system. Finally an analysis of the existing product portfolio will help to understand the style and design in which the new textile luminaire has to fit in.

2.2.1 Types of light

Philips Hue offers three types of lighting in their products, either integrated into the luminaire or as a separate light bulb. All light sources are dimmable. These types are as follows:

White (W)
One single white colour.

White Ambiance (WA)
Cold to warm white light.

White and Colour Ambiance (RGBW)
16 million colours.

Hue offers light bulbs for all standard lamp fittings which can be used in non-Philips Hue luminaires. Many Philips Hue products however have an integrated LED board. For this they use their lighting building blocks: standardized LED boards with a Hue connector board to communicate with the Bridge hub or Bluetooth system.

Fig. 2.3: Iris luminaire with integrated LED system.

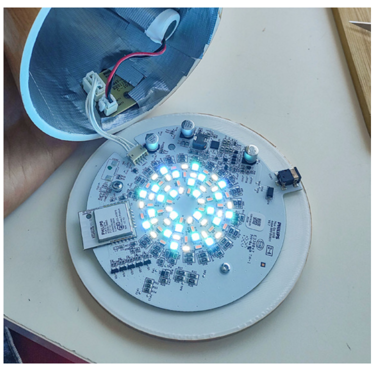


Fig. 2.4: LED building block, used in Rotation Lamp prototype.

2.2.1 Types of light

Philips Hue products can be controlled via the free Philips Hue app. Either via Bluetooth for up to 10 lamps in one room or via wifi up to 50 lamps in the entire house. In case wifi is used the user needs to connect a Hue Bridge to the system. This is an extra device that needs to be installed to the wifi router in order to control the lights via the app.

Connecting the lamps via the Hue Bridge has multiple advantages over using the Bluetooth connection only. It allows the user to combine the lamps with other smart Hue accessories like movement sensors or speech-controlled devices such as Google Nest or Amazon Echo. You can control the lights if you are not home, link them to a time schedule or synchronize them to your entertainment systems for gaming, music and TV.

In the app it is possible to create a personal lighting scheme per room. Each lamp needs to be assigned to the room in which it is placed. The lamp can be controlled separately or via the room which it is assigned to.

For control of the lamps it is possible to add a physical dimmer switch to the system. This device allows the control of the lamps assigned to the switch. This allows the user to set the lights without a smartphone.

There are many standardized lighting schemes to choose from in the Hue app. For each mood or setting there is a suitable pre-set. For luminaires that can generate multiple colours at the same time, like the Signe series shown on the right, it is possible to choose from pre-set lighting effects. This can be a single colour or interesting contrasting colours between the top and the bottom. These lights can also move dynamically along with an entertainment system, so the light reacts to the colour of light that is shown on a screen.

Fig. 2.5: Hue Bridge.

	with Philips Hue Bluetooth App	with Philips Hue Bridge
Max. number of lights	10	50
Range	1 room	Full home
Be creative with 16 million colours	✓	✓
Configure Hue smart accessories	✗	✓
Smart control home & away	✗	✓
Sync with music movies and games	✗	✓

Fig. 2.6: Comparison of possibilities with Bluetooth connection or the Hue Bridge.

Fig. 2.7: Philips Hue dimmer switch.

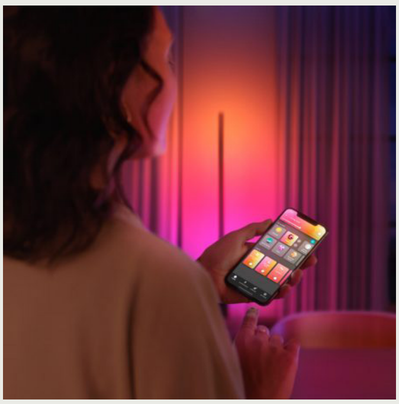


Fig. 2.8: Light effects with Signe floor lamp.

2.3 Philips Hue product analysis

This chapter lists the insights from the product portfolio analysis.

To get a good overview of this brands specific style and used materials, colours and shapes a collage was made of all currently available Philips Hue products.

As a source for this product analysis the official Philips Hue website was used as well as several product review videos on YouTube. Another source was the Signify Experience Centre in Eindhoven where all of these products are being displayed and the materials can be seen in real life.

Fig. 2.9: All Philips Hue products available (March 2022).

2.3.1 Materials and colours

The product portfolio analysis focussed on the outer housings because these are most determinative of the design language and style. It was discovered that there are three main materials being used namely metal, plastic and glass. This is an overview of the colours of these outer housing materials.

Metal:
White, chrome and black.

Buckram

Tuar

Appear

Plastic:
Opaque, transparent, black and white.

Felicity

Iris

Iris

Frosted glass:
Opaque.

Wellner

Wellness

Most lamps are available in white, black and grey. Only the Iris Table lamp is available in more limited edition colours:

Fig. 2.10: All colours of the Iris table lamp, including limited editions.

Looking at a customer review video for the Wellness lamp it can be seen that the bottom part is made from wood which is coated with black lacquer (Aaron O'Maley, 2018). Showing the original colour of the wood could have created a more luxurious appearance. Signify has recently been experimenting with wood veneer to create a more natural luxury surface finish.

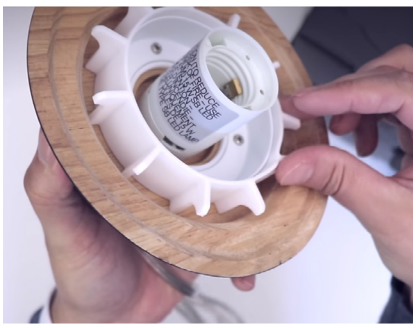


Fig. 2.11: Wooden foot piece of the Wellness table lamp.

2.3.2 Shapes

It was found that each product was designed with one distinctive basic shape in mind. The products are either cylindrical, conical, spherical or rectangular in form. Some products are compound shapes for example when a fixture to the wall or ceiling is required.

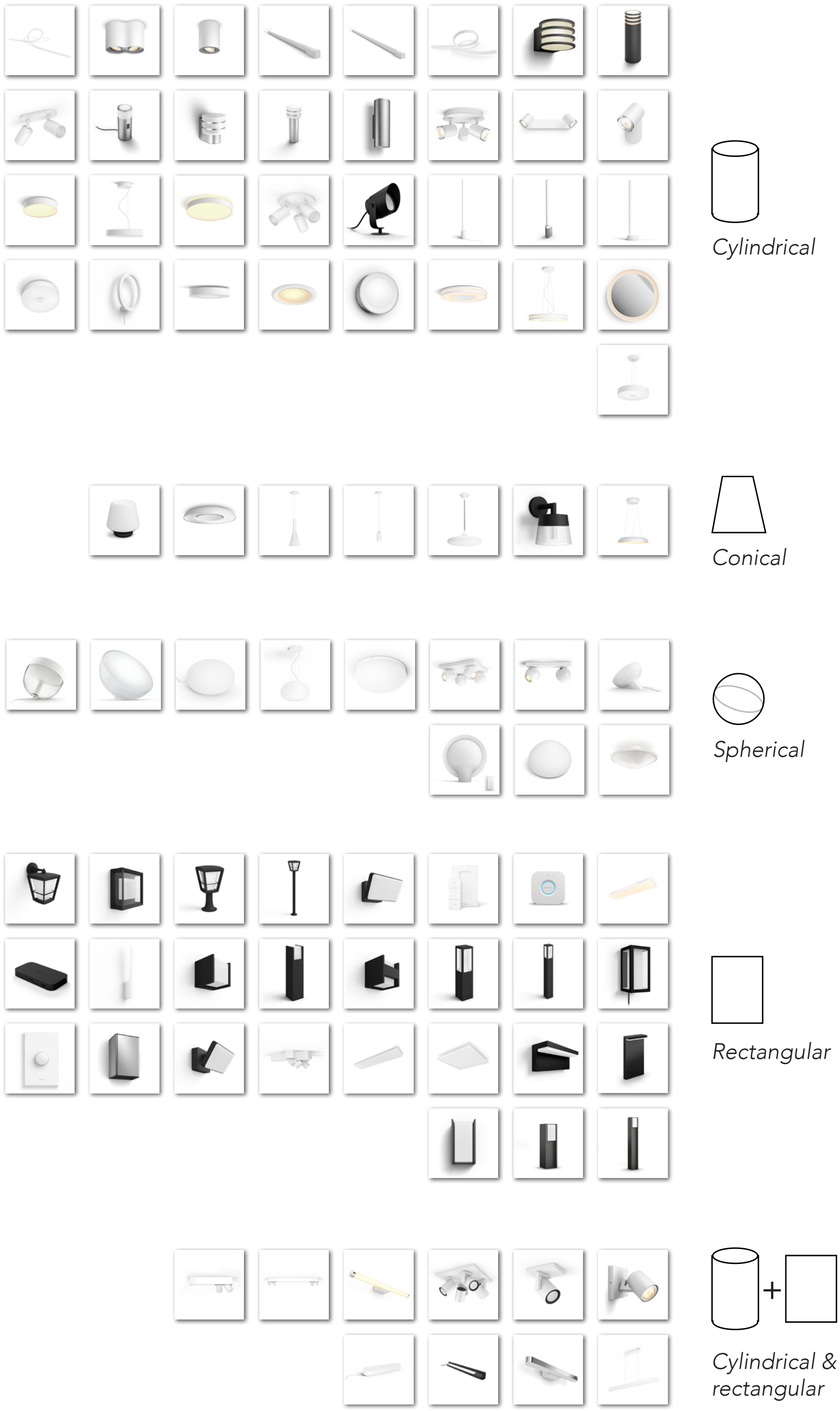


Fig. 2.12: Basic shapes of Philips Hue products.

2.3.3 Product context

With the product context pictures from the Philips Hue webshop a collage of the intended user contexts of the Hue products was created.

Philips Hue products are meant for consumers to be used at home, outdoors or indoors. The Hue website provides outdoor products like bollards and spots and also luminaires to be attached to outer walls, like floodlights or wall lanterns.

Indoor products are suggested to be used in the living room, kitchen, dinner table, workroom, bathroom or corridor. For indoor use the consumer can choose wall lights, ceiling lights, pendants, moveable or fixed spots, table lamps or portable products.

For the new textile luminaire Signify has indicated a preference for creating a table-top indoor lamp. This context suits well with the intended textile application and well-being proposition.

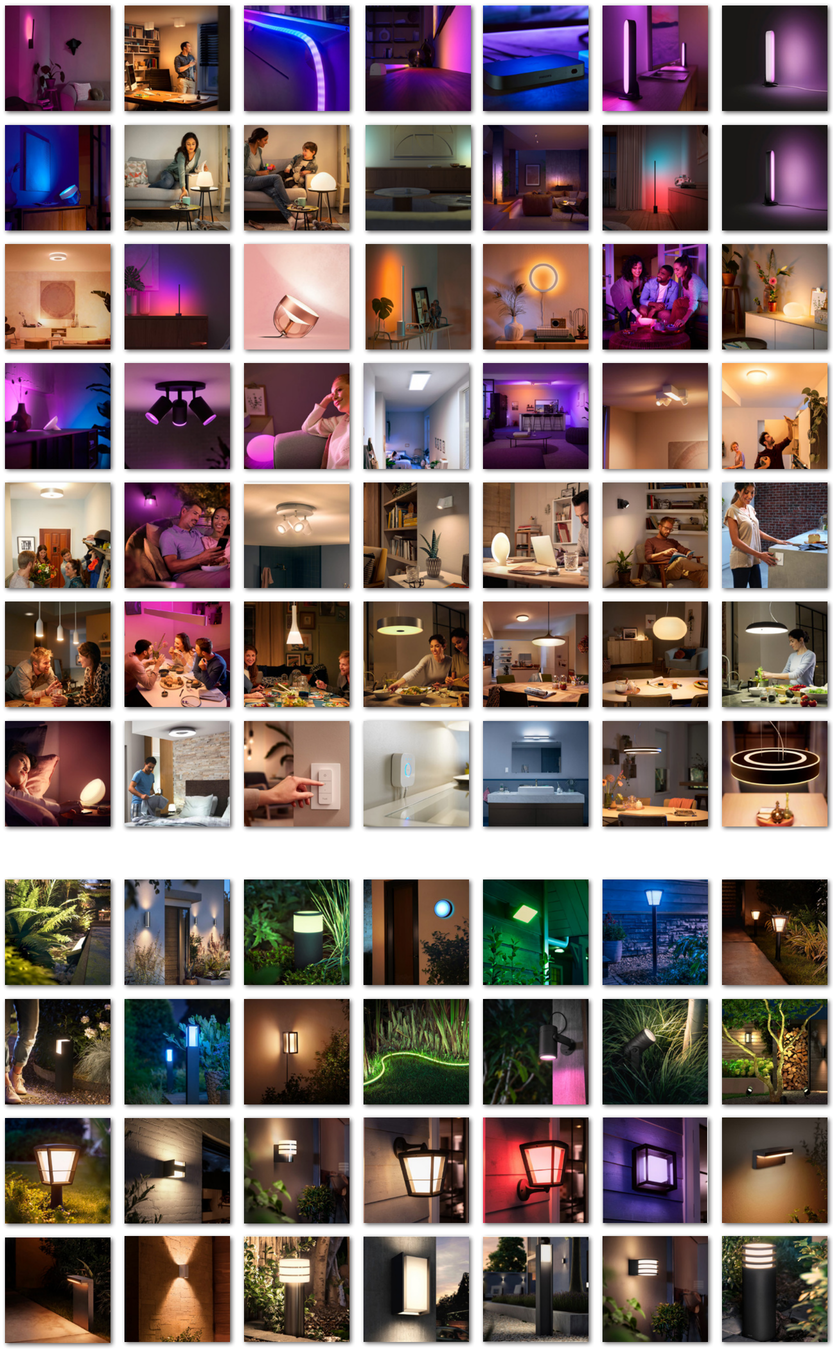


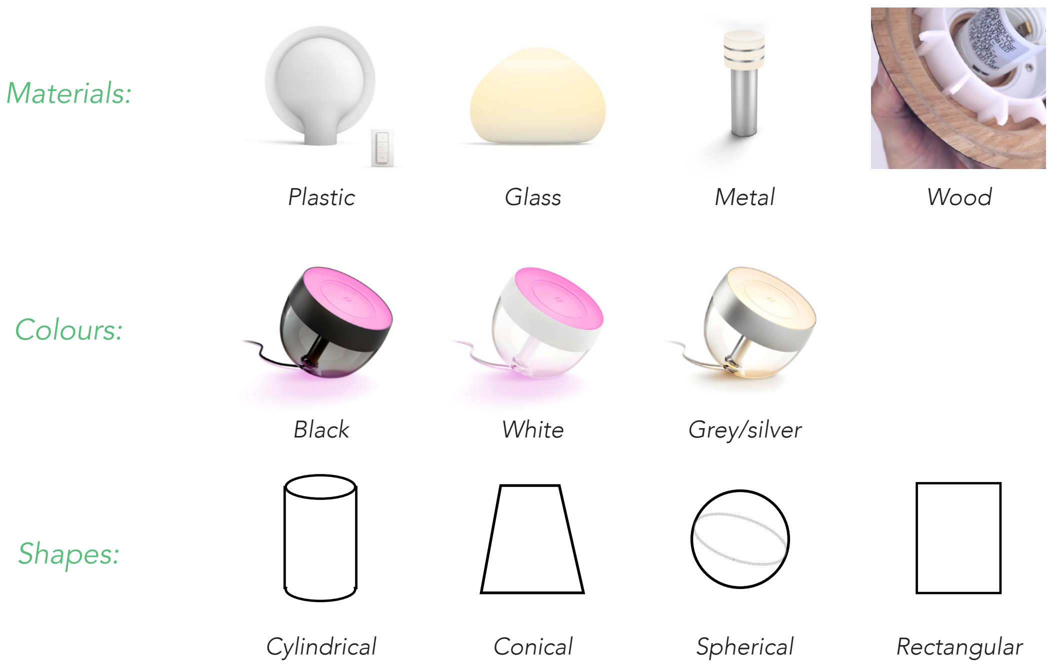
Fig. 2.13: Philips Hue products presented in their intended user context.

2.3.4 Summary of product portfolio analysis

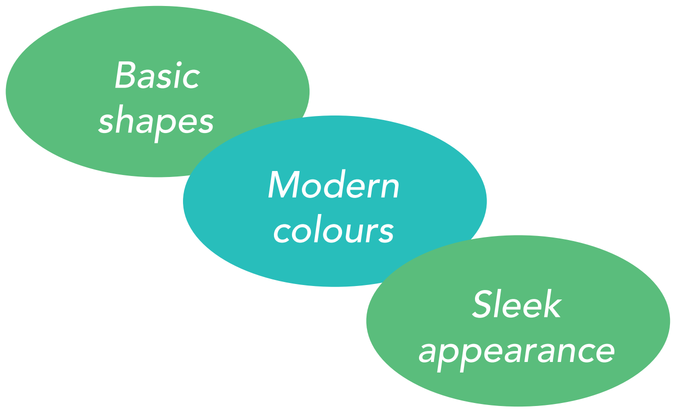
The design language of basic shapes and colours create a modern and sophisticated look for the Philips Hue products.

The products come in four basic shapes: cylindrical, spherical, conical and rectangular. Combining these with neutral colours (white, grey, black) created products that leave room for the products to be spectacular in their light and to not influence the colour perception.

In addition the products are meant to be sleek modern products which can fit within every style of interior rather than becoming an eye-catching piece of furniture themselves.



Judging from the existing product portfolio we could summarize the following design language to be kept in mind during the design process for a new Hue luminaire:



2.4 Prior textile application research

Signify had been working on the exploration of textile application for several years before this thesis project started. They disassembled several competitor textile products and they made explorative prototypes of textile luminaires. They also experimented with creating laminated textile diffusers with patterns.

In this exploration three main methods for using textile in luminaires were identified:

1. Using textile as a diffuser by laminating it to plastic with great optical properties.
2. Using textile in the housing element of a luminaire where no light is passing through.
3. Covering a complete product in textile, light will be passing through parts of the textile.

Considering the front-end design phase of this project it was chosen to focus on the second category where light is not passing through the textile. A great challenge was identified in learning about the properties of textile and mechanical fastening before application in Hue products could be realised. Translucent and optical properties of textiles make for an interesting research topic in a following stage of the design process.

The prior research was presented at the beginning of this project in a briefing presentation. This presentation can be found in the confidential appendix. (This appendix is not included in the published version of this report: contact the author to ask for access to this separate document).

Chapter 3:

Exploring existing textile housings

To learn about the current methods of textile application existing textile housing products were researched. This chapter starts with the observation of products from different brands and then a disassembly analysis of fourteen products follows. The insights of each analysis will be listed.

3.1 Observational research

This observational analysis is split in two parts: a desk research and field research. Both are meant to explore the existing array of textile housing products. What type of products are they? What shapes do they have? What fabric is used and how are user interfaces integrated into the design? How can Philips Hue differentiate from these products to gain competitive advantage?

Applying textile to a housing surface is not novel. Stationary home speakers have been covered with textiles for a long time because of their great acoustic qualities. A new textile trend can be observed in the use of portable Bluetooth speakers. By observing speaker brands we can learn what textiles and application techniques are currently being used and could thus be applied to the products of Philips Hue in the near future.

3.1.1 Desk research

Pictures from textile products were collected online. There was a focus on products from renowned brands like Google and JBL because these are considered to be of a comparative quality as the products of Philips Hue. The complete overview of observed products can be found in appendix C.

Textile housings can mainly be found in speakers, either stationary or portable. These textile products look soft and inviting to touch. Brands like Google and Harman Kardon choose basic colours like grey, white and black or soft pastels. These colours fit within every interior and also exude a robust and qualitative product look. These are mostly stationary products meant as interior design elements.

Other brands like Ultimate Ears and Fresh ’n Rebel purposely use bright colours to exude a young, fresh brand image. These are portable products and could be considered more of a fashion item than an interior design product.

Home decor products:

Fig. 3.1: Harman Kardon Citation.

Fig. 3.2: Google Nest Audio.

Fig. 3.3: Bang & Olufsen Beosound Balance.

Portable fashionable products:

Fig. 3.4: JBL Flip 5.

Fig. 3.5: Ultimate Ears Wonderboom 3.

Fig. 3.6: Fresh 'n Rebel Rockbox Bold M.

Philips Hue luminaires fall into the category of sleek home decoration products. Therefor it is advised to choose neutral textile colours.

Textiles are not often used in luminaires in the same way. Only one luminaire product with a textile housing was find during the online observational research. This product with an integrated textile housing was a handheld projection lamp found on Amazon.

An alternative way to integrate textile on the surface of a product, but not fixed to the housing was seen in a product from Fatboy. The brand Fatboy offers a separate textile cover for their luminaire. This "Hoodie" for their Edison the Petit lamp can be seen in the picture on the right.

Fig. 3.7: Handheld children's projector (Amazon.nl, n.d.).

Fig. 3.8: Fatboy Edison the Petit with hoodie.

3.1.2 Consumer electronics store field research

Through desk research only it was not possible to get a sense of the tactile experience of textile housing products. Two electronics shops were visited to hold and examine the products in this category. Pictures were taken of all the different textile products available. A focus was kept on the textile components and user interface elements such as displays and buttons.

It is evident that the use of textile in speaker housing products is a trend. Almost all of the speakers had this material integration. Few products consisted of solely plastic or metal surface finished housings.

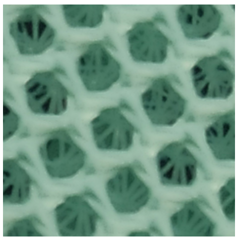
In appendix C you will find an overview of every product that was observed. The insights that were gained during this field research will now be discussed, mainly focussing on the textiles.

Fig. 3.9: Speaker department of consumer electronics store MediaMarkt.

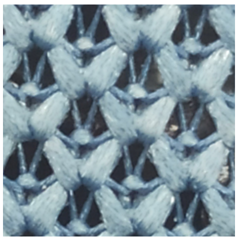
Textile types

Both woven and knitted fabrics can be observed in the products. These are categorized below. Interestingly none of the products contained non-woven fabrics.

Knitted fabrics:

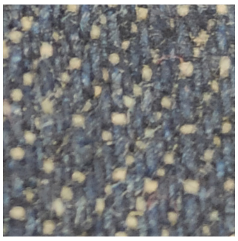


Spacer fabric (Fresh 'n Rebel).



Knitted smooth yarns (Sony, JBL Horizon, JAM and more).

Woven fabrics:



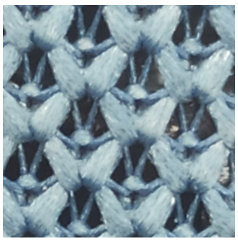
Denim (House of Marley).

Woven smooth yarns (JBL, PEAQ, Harman Kardon Go and more).

Woven rough yarns (Harman Kardon Citation, Philips multiroom TAW).

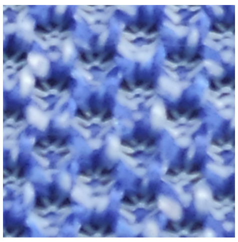
Colours

When it comes to colour there are a few types to distinguish. The fabrics are made with single coloured, two coloured or mixed coloured yarns or printed to give it a coloured appearance.

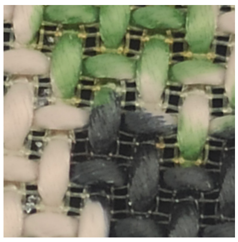


Mono colour fabric, mono colour yarns.

Mixed colour fabric, monocolour yarns.



Mixed colour fabric, mixed yarns.

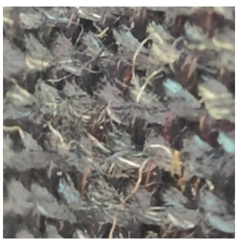


Printed coloured fabric.

Branding

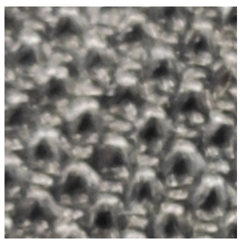
Most brands have a distinct fabric for every separate product line. Brands like JBL, Google and Harman and Kardon create a family of products within their own brand by giving all products the same look. In addition brands differentiate between eachother with their fabrics. Each brand has their own signature textiles.

See appendix C for a complete overview of fabrics per brand.



Harman Kardon Citation.

Harman Kardon Go.



Harman Kardon Onyx.

3.2 Product disassembly analysis

Fourteen products were disassembled to get a more in-depth view on the used textile types and fastening methods. They were disassembled up until the point where the textile housing could be isolated from the rest of the components. Then the textile was peeled off to be able to inspect it under a microscope.

The aim of this disassembly analysis was to learn the following:

- How the textile is formed around the shape.
- What type of textile is used.
- How the textile is fastened.
- How user interaction elements are incorporated into the textile.

Nine of these products were collected at a recycling facilitation named "Road2Work". This company gains knowledge on the disassembly potential of products and their recyclability to share this information with others. When visiting this facility insights were gained about the poor recyclability of these textile elements. A report of this visit and insights can be read in appendix D.

The other five products were bought new or second hand.

In appendix E you will find the complete step-by-step product disassembly. The most relevant insights per topic will now be discussed in this chapter.

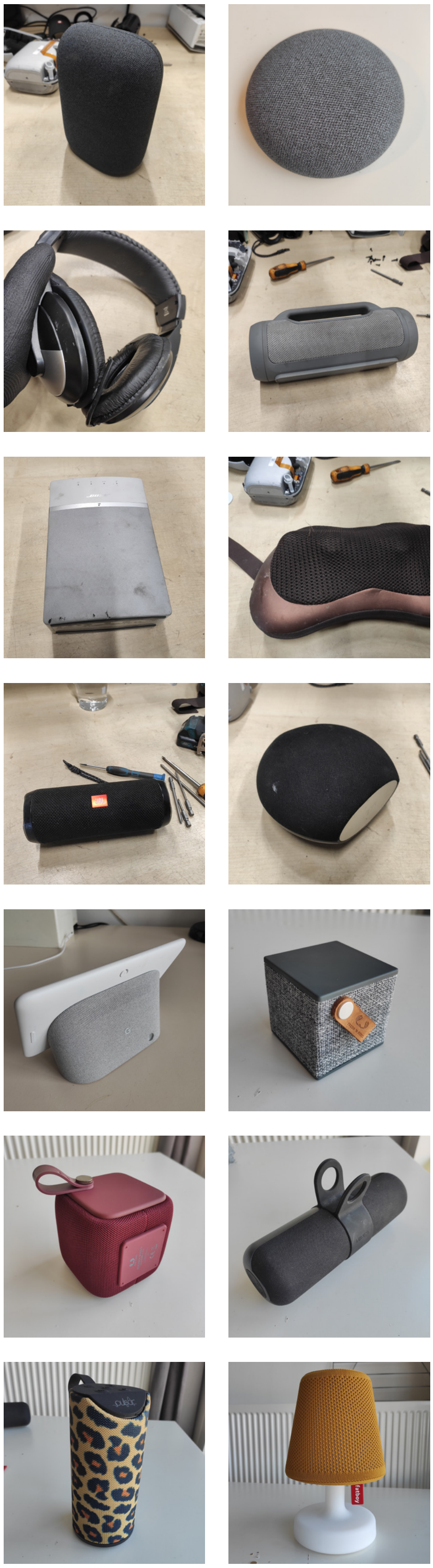


Fig. 3.10: All textile housing products that were disassembled for this thesis project.

3.2.1 Shaping

Products of distinctly different shapes were chosen for this analysis. The insights for shaping possibilities in this chapter are grouped per category based on the shapes of Philips Hue products discussed in chapter 2.2: cylindrical, spherical, conical, rectangular.

Fig. 3.11: Cylindrical, conical and spherical products.

The fabrics used in these products are flat sheets before they are applied around the shape. There were no clues present to believe that any of these fabrics were circular- or 3d-knitted. They might have been pre-formed before being applied to the housing but this could not be discovered during this disassembly process.

Fig. 3.12: Rectangular shapes with sharp and rounded edges.

To better understand how flat sheets of fabrics can be formed around a shape, we distinguish two types of surfaces. Developable and non-developable surfaces. When a surface is developable it means that it can be laid out flat without breaking the it. Non-developable shapes can only be laid out flat by cutting or breaking the shape at strategical places.

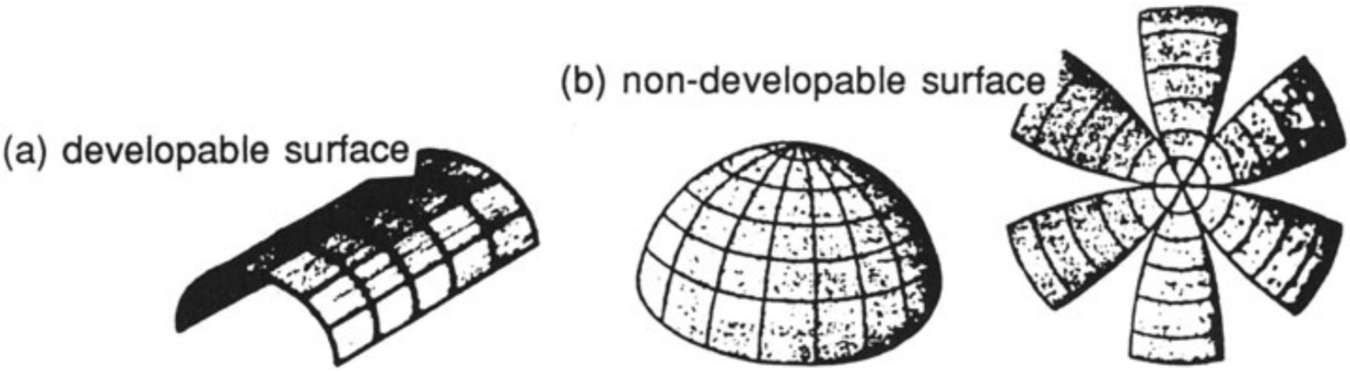


Fig. 3.13: Developable and non-developable surfaces (Farshad, 1992).

Non-developable surfaces can only be wrapped with textile if it is stretched, sewn or otherwise pre-formed.

On the next pages the insights about shaping from this disassembly analysis are listed. They are grouped in the four categories of Hue products.

Fig. 3.14: Stretching fabric.

Cylindrical

Fig. 3.15: Developable surface of the JBL Flip 4.

Both developable and non-developable shapes can be made. The shape of the JBL Flip 4 is developable and covered with a textile that is non-stretch.

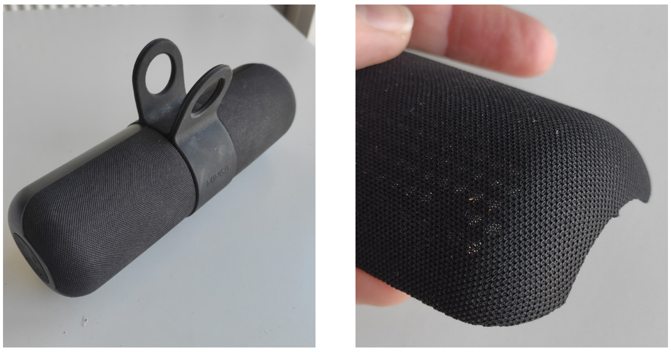


Fig. 3.16: Non-developable surface of the Miniso speaker.

When using stretch fabric it is possible to create non-developable round shapes. This use can be observed in the Miniso speaker on the left.

Fig. 3.17: Sewn sleeve of the leopard speaker. Non-developable surface.

There was one product where the fabric was sewn to create its shape. This was the case for the leopard print speaker in the shape of a non-developable cylinder. There was a slot in the plastic housing underneath to give space to the seam.

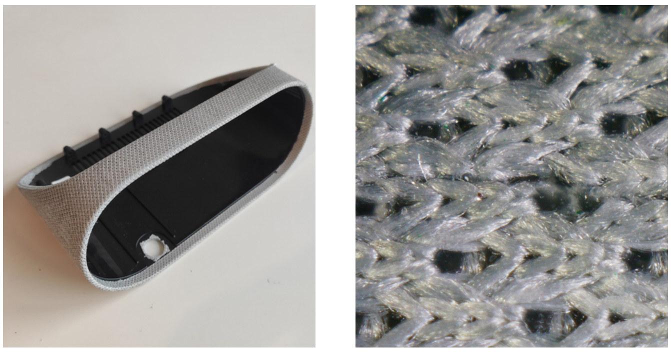


Fig. 3.18: Welded line in the Google Hub. Non-developable surface.

In the Google Nest Hub another fastening method to create a non-developable cylindrical shape could be observed. When looking at the textile under the microscope a welded line can be seen. Here the fabric is ultrasound welded to create an invisible seam. This is a sophisticated method to join the fabric without creating extra thickness at the seam.

Conical

A developable cone shape was not observed during the product disassembly analysis. This non-developable cone was made by knitting the textile in shape. At the top the diameter of the tube is smaller than at the bottom.

Fig. 3.19: Knitted non-developable cone. Edison the Petit lamp with fabric Hoodie.

Spherical

The housing of the Google Nest Mini was made by stretching a knitted fabric around a double curved surface and gluing or welding it to the inside. This shape is non-developable and the limits of curvature of the sphere depend on the stretchability of the fabric.

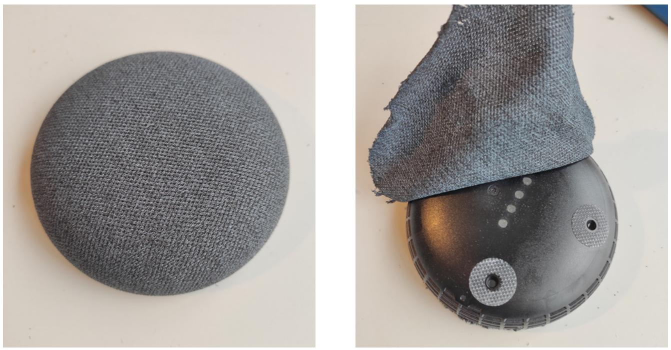


Fig. 3.20: Spherical non-developable surface of the Google Nest Mini.

Rectangular

Fig. 3.21: Sharp edges, developable surface. Fresh 'n Rebel Rockbox Mini.

Block shapes can have varying curvatures at the edges. When the edges are sharp the fabric needs to be thin to prevent the fabric from accumulating on the inner edges. The more curvature there is, the thicker the fabric can be. For this product on the left with relatively sharp edges, a thin fabric was chosen.

Fig. 3.22: Rounded edges, developable surface. Fresh 'n Rebel. Rockbox Bold S.

The Fresh 'n Rebel Rockbox Bold contained double rounded edges. This allowed thick (3mm) spacer fabric to be wrapped around the form without stretching it. Spacer fabric is a type of knitted textile that has some compressibility. Sharp edges would require the fabric to stretch around them which would diminish the compressibility which is so unique for the product experience. This stretching only happens towards the inner edges where the fabric is glued to the inside. These edges are not being touched by the user so compressibility is not required here.

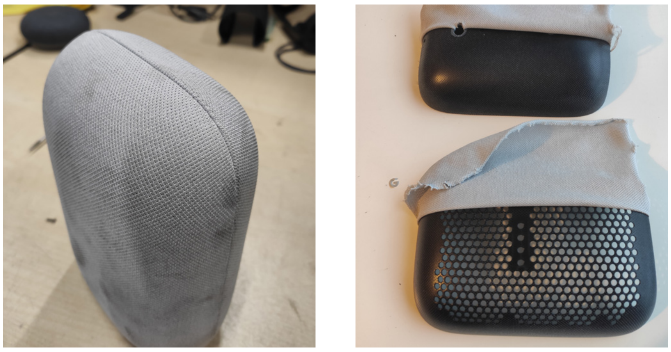


Fig. 3.23: Non-developable surfaces of the Google Nest Audio.

The previous two examples were both developable surfaces where a long strip of fabric is being used to wrap around the housing. In the Google Nest Audio we can see how a block shape with double rounded edges is created by stretching fabric around two non-developable surfaces.

3.2.2 Textiles

The textiles were taken off the housings to examine them under a microscope. Zooming in allowed the weave- or knit patterns and yarn colours to be seen. The main insights of this in-depth textile observation are listed here. More information can be read in appendix E.

Woven textiles

The fabrics of the JBL Flip 4 and brandless grey speaker are similar and have a clearly visible textile appearance because of the thick yarns that are being used. When zooming in, an interwoven second layer of thin plastic yarns can be observed. This structure makes the holes in the weave smaller which lowers the permeability for water. It also creates a weave to lock in the thicker yarns with equal spacing.

Another interesting effect that can be observed under the microscope is the variation in yarn colours of the weave. This can be seen in the JBL Flip 4 and brandless grey speaker. These products appear to have a single coloured textile from a distance, but the textile is built up from two distinctly different coloured yarns in the weft- and warp-direction. This is often done by textile manufacturers to enhance quality perception. It gives the textile a subtle depth perception. Using a single colour yarn would make the fabric look flat and cheaper.

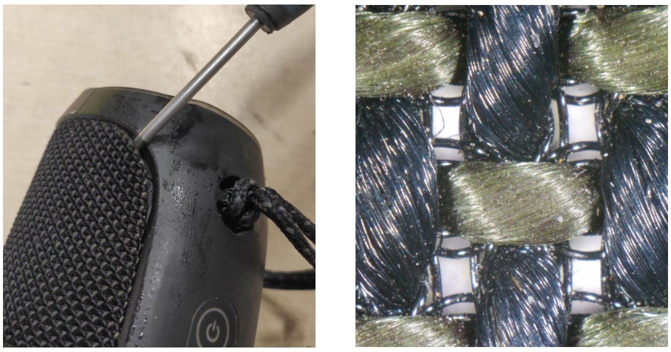


Fig. 3.24: JBL Flip 4 looks black on the outside but the yarns are actually blue and yellow.

Fig. 3.25: The brandless speaker looks grey but zoomed in you can see the yarns differ in grey shades.

Fig. 3.26: Cross-section of the fabric, where the integration of thick and thin yarns can be observed.

Knitted textiles

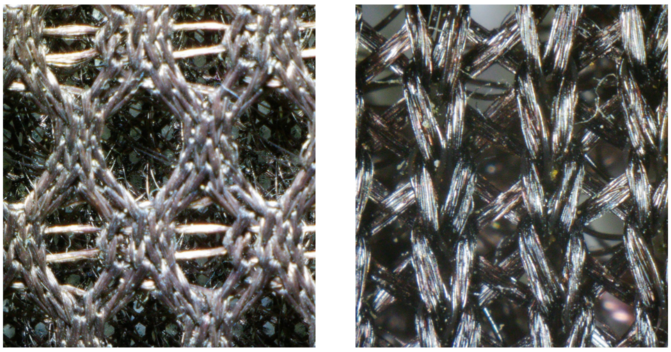


Fig. 3.27: Front- and backside of the spacer fabric in the neck massage pillow.

In the neck massage pillow and Fresh 'n Rebel Rockbox Bold S a fabric with an intriguing touch was observed. This so called "spacer fabric" is a double layer knitted textile. Spacer yarns in between the layer give the fabric its compressibility and soft touch.

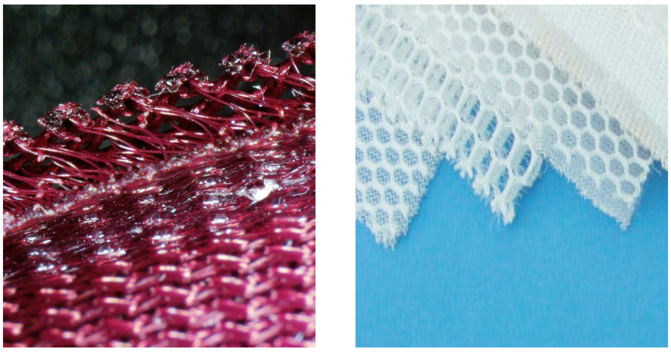


Fig. 3.28: Left: cross-section view of spacer yarns. Right: different patterns in spacer fabrics (Averinox B.V., 2008).

Spacer fabric is usually made from PES. It is suitable to wash and dry. It is made from non-absorbing hydrophobic material, allowing it to dry quickly. This makes spacer fabric highly suitable for consumer product applications like upholstery, back panels of bags or Bluetooth speakers. There are many patterns and thicknesses available. (Averinox B.V., 2008)

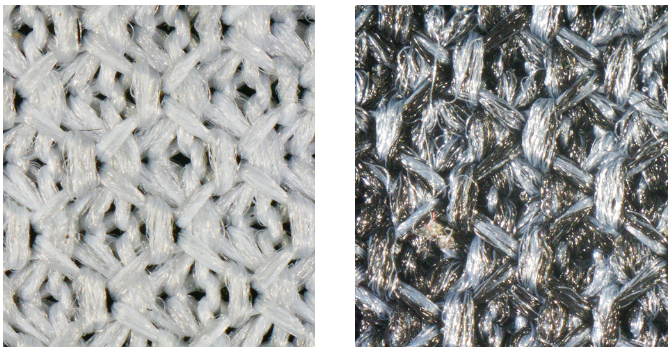


Fig. 3.29: Fabrics from Google Nest products with mixed colour yarns.

Spacer fabrics are a separate category within knits. Ordinary knitted fabrics are very common in consumer products as well. These knitted fabrics from the Google Nest series for instance. To make the fabric more interesting a similar colour variation technique is used as in the woven fabrics described previously. The knit pattern on these google products is the same but the yarns vary in colour. This is especially apparent in the dark grey fabric: here the fabric colour is created by mixing black and white yarns so it looks dark grey to the naked eye. In the white fabric the yarn colours vary only slightly in shade.

3.2.3 Fastening

Textile can be fixed to the inner edges and/or to the surface of a product. This fastening can be used to fix the fabric in place by gluing or welding. It is also possible to use methods where the textile is not fixed thoroughly. Gluing is the most commonly observed method in this disassembly analysis.

Gluing or welding

In the observed products textile is commonly fixed to the housing with adhesives or by ultrasound welding. In the first case adhesives are visible when peeling off the fabric. For ultrasonic welding no adhesives are observable.

Stretchable fabric is movable relative to the housing part underneath if it is not glued to the surface. This could be an undesirable effect in portable products because it lowers the users grip when picking up the product.

To prevent this shifting from happening most portable products have its textile glued to the outer surface. Either over the whole surface or at a few spots. For stationary products the fabric is not always glued to the surface in contrast to portable products. The only exception that was observed was the portable Miniso speaker. The fabric components in this product were such a small part of the cylinder that when picking up the product the user also grips onto the other plastic components.

Fig. 3.30: Glued inner edges (left) and welded edges (right).

Fig. 3.31: Movable fabric over the surface of the Miniso speaker and Bose Soundtouch.

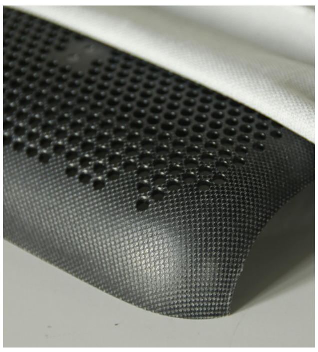


Fig. 3.32: Glued all over the housing surface (Google Nest Audio).

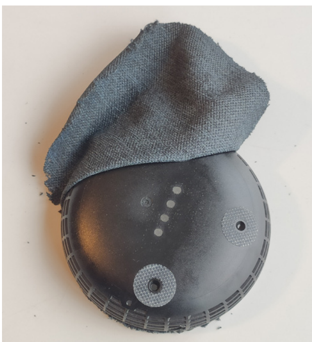


Fig. 3.33: Glued at a three circular spots (Google Nest Mini).

Fig. 3.34: No glue on the surface (JBL CS460 sat).

Sewing

Fig. 3.35: Leopard printed speaker with sewn sleeve: inner housing contains a slot for the seam allowance.

Another way of fastening the fabric over the housing is by creating a sleeve which is pulled over the shape. This is done by joining two edges of a flat sheet of fabric with sewing. During the disassembly analysis this was observed at one product: the leopard printed speaker. The seam-allowance of the fabric required some space in the inner housing for which there was a slot. The textile stays in place because the components at the top and bottom of the product prevent it from being able to slide off.

The advantage of sewing a sleeve is that there is no need to glue the fabric as the non-stretch fabric will stay in place. The disadvantage could be the required extra step of sewing in the production process.

Knitted sleeve

Fig. 3.36: Fatboy Edison Petit lamp with separate sleeve.

This Fatboy Edison Petit lamp can be upgraded with a textile "Hoodie" which was first knitted into a shape and then joined by sewing. The seam that this creates is unfortunately clearly visible especially when the light is on.

This separate sleeve is a great method to add textile to the product appearance in a later stage, without integrating it into the housing. In addition it can be taken off or replaced easily. This is favourable to the customizability and recyclability.

3.2.4 Interface elements

Buttons can be either integrated onto the textile housing parts or on other parts of the housing of a product. The observed methods will be discussed now.

In several of the textile housing products the user interface elements are not integrated into the textile. They are separate buttons on other plastic components.

Fig. 3.37: Buttons on plastic components other than the textile housing.

It is also possible to integrate the buttons onto the textile housing. An interesting method to do this can be observed in the Fresh 'n Rebel Rockbox Bold. On the outside small figures with pins are pushed through the fabric. These pins fall into holes in the housing underneath. These holes are part of movable latches in the plastic housing, which bend inwards if pressure is applied on top. These latches then push onto the buttons on a PCB underneath, activating the corresponding button.

Fig. 3.38: Outside surface of Fresh 'n Rebel Rockbox Bold S: button with pins can be popped off.

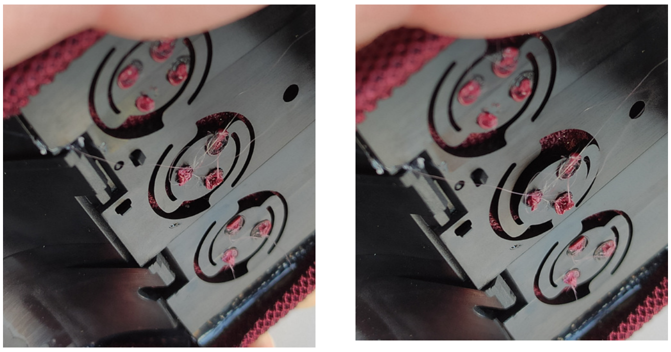


Fig. 3.39: Inside surface of Fresh 'n Rebel Rockbox Bold S: latches that bend inwards when pressure is applied on top.

These smart home hubs from Google can be controlled by a button that is invisible on the textile: capacitive touch. There is a layer of copper on the inside. When the users finger hoovers closely above the product the capacity of the sensor changes and consequently a signal is given to the control of the product.

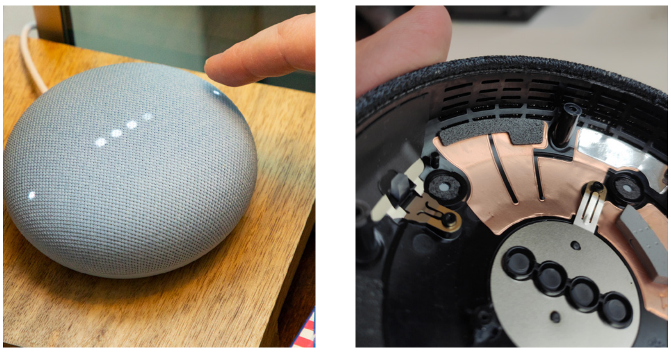


Fig. 3.40: Layer of copper for the capacitive touch sensor inside the Google Nest Mini.

Chapter 4:

Textiles for housings

This chapter will first dive into the basic principles of textiles before elaborating on the possibilities for 3D-knitting shapes. Then, the choice of textile colour in this research will be discussed. Finally, a fabric ideation was done to find textiles with which Signify can differentiate their Philips Hue products from existing textile housing consumer electronics.

All in all this chapter aims to find an answer to the following question:
What kind of textiles can be used for application on product outer housings?

4.1 Basic understanding of textiles

Before we start designing a textile housing we need to dive into the fundamental element of this research: textiles. We need to understand this main ingredient to learn about the possibilities and design limitations for product application.

In this chapter a brief explanation of fabric types will be given. This knowledge will help to gain basic understanding of the three main types: knitted, woven and non-woven textile. This knowledge is crucial in order to fully understand parts of the research of this thesis.

Textile or fabric is a cloth which is built up from yarns. These yarns can be made from natural resources like cotton and wool, or man-made fibres like polyester. Nowadays cloth is often made from a mix of these yarns because both have their own properties and advantages.

Natural fibres like linen or cotton tend to be more absorbent but dyes do not attach so well, causing the colour to fade over time. Man-made fibers like polyesters hold their colour better and can be more durable. In addition, polyester fibers can be tweaked to gain desired properties such as flame retardants.

All textiles can be classified within one of three main categories based on the way that the cloth is built up: knitted textile, woven structures and non-woven fabric. These three categories will be explained next.

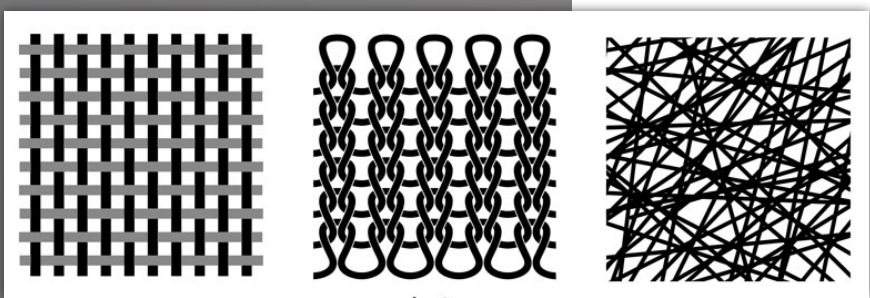


Fig. 4.1: Illustrations of woven, knitted and non-woven textile.

4.1.1 Wovens

Woven fabrics consist of yarns in two directions: the weft- and warp-yarns. The warp yarns are held in a fixed position on one end and lengthwise they are held parallel to each other. The yarns are interlocked by weaving them under and over each other on a weaving loom, creating a non-stretch cloth.

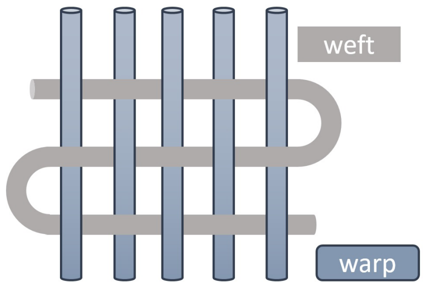


Fig. 4.2: Illustration of weft and warp yarns.

If elastic yarns are used a weave can have stretch. In this report we do not take these stretchable woven fabrics into account. This is done to make a clear distinction between fabrics and their main properties to be used in the DDT.

Many weaving patterns are available. Below are illustrations of the most commonly used patterns. Each weave has their own properties. (Hallet & Johnston, 2016).

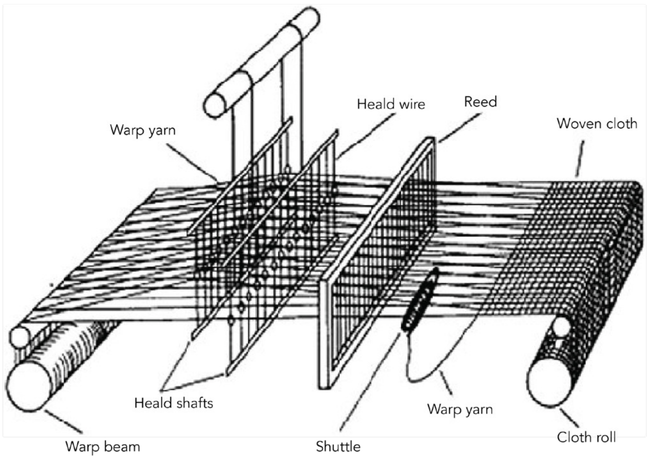


Fig. 4.3: Illustration of weaving loom (Engin, 2009).

A plain weave is the most basic pattern and can be rough or smooth depending on the yarns used.

A twill weave is usually strong and this can be seen in denim fabric for example. In a twill weave there are more touchpoints between the weft- and warp-yarns because they go over and under each other more frequently than in the other patterns. This results in more stiffness.

Contrary, a satin weave is more supple and shiny. In a satin weave the weft-yarns skip more warp-yarns under before going over one resulting in less touchpoints between weft- and warp yarns

In conclusion, the properties of a woven fabric are influenced by its weaving pattern. Desired properties can be gained by choosing a weaving pattern that fits its purpose.

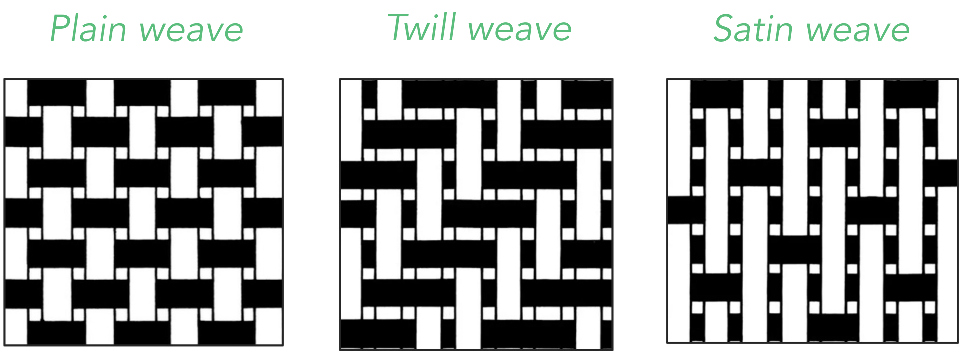


Fig. 4.4: Illustrations of common weaving patterns.

4.1.2 Non-wovens

Non-wovens consist of fibers which are rubbed together. Firstly a web of these fibers is made. With the help of pressure, moisture and soap the fibers interlock in a chaotic way: this is called web consolidation or felting.

Industrially, felting is achieved through a chemical process or with the use of felting needles. In order for the fibers to hold together a minimum of 30% wool yarns is required (Hallet & Johnston, 2016).

A common non-woven fabric is known as "felt" and it can be seen in coats and hats. Because its dense structure water cannot easily penetrate the surface.

Wovens and knits can be stretchable, non-wovens cannot. In addition felt is rather thick which makes it difficult to apply to a surface such as a plastic housing component. This was experimented with in the surface shape experiment which can be read in chapter 5.2. Thin felt would not be a solution because this is fragile and it would not keep its structure well over the long term use of a product. Lastly, it is not possible to create patterns on the surface of felt.

For these reasons it was chosen to not include non-wovens into this research for textile housing application.

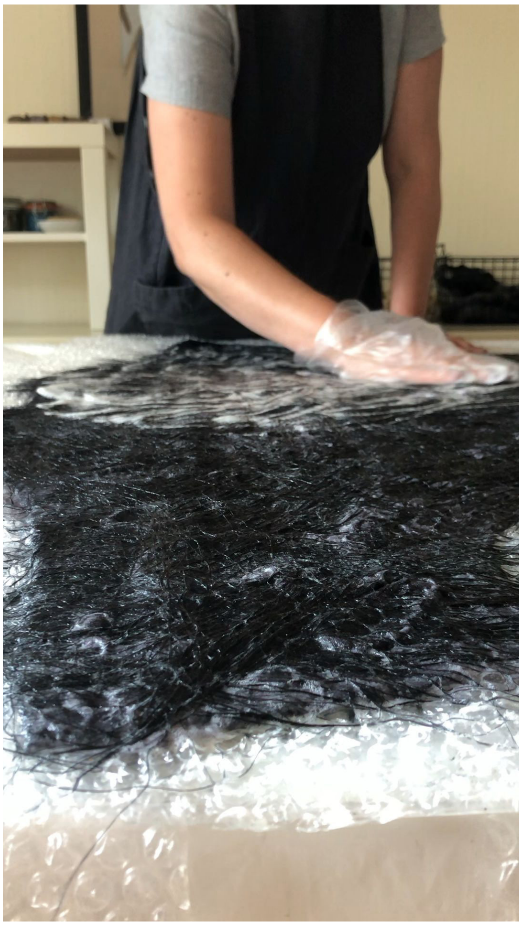
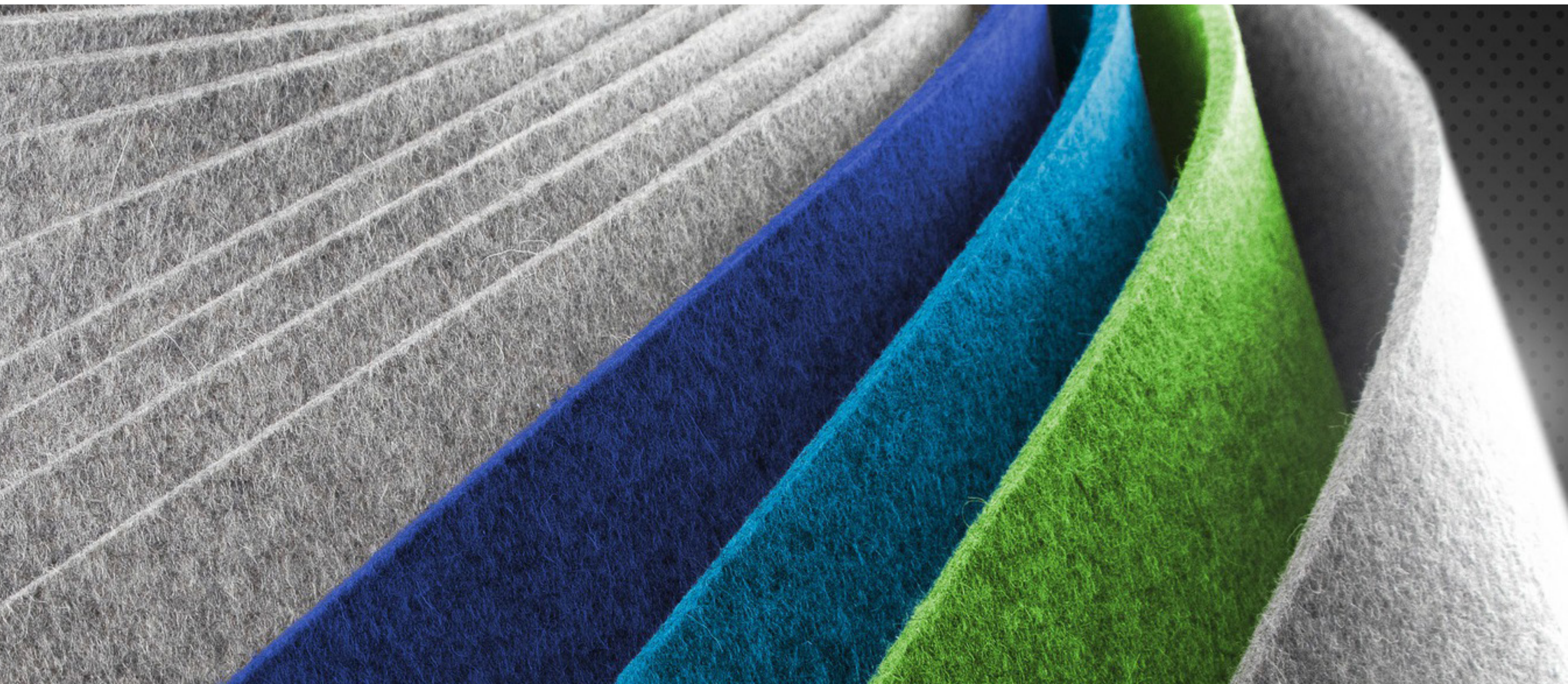


Fig. 4.5: Felting done by hand with the use of soap.

Fig. 4.6: Sheets of felt.



4.1.3 Knits

Knitted fabric is built up by interlocking the yarns through loops. Because of its structure it becomes stretchable: the loops can be compressed when force is applied and this movement allows the fabric to stretch.

When knitting automatically on a machine the fabric can be either weft knitted or warp knitted: illustrated on the right. These are the main two industrial knit patterns. Automatic knitting can be done on a flatbed- or circular knitting machine.

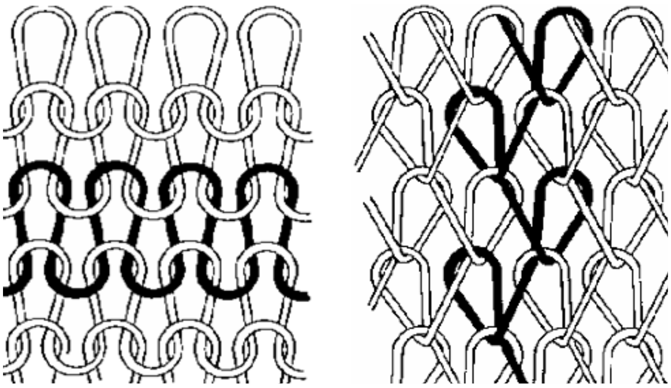


Fig. 4.7: Weft knit (left) and warp knit (right) illustrations.

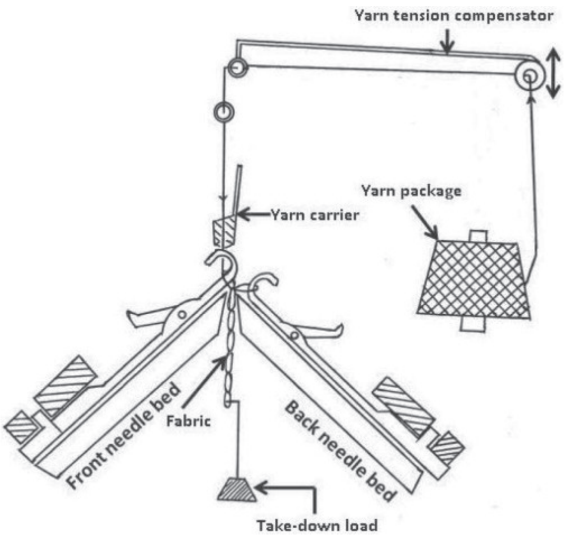


Fig. 4.8: Illustration of a flatbed knitting machine, cross-section (Ray, 2012).

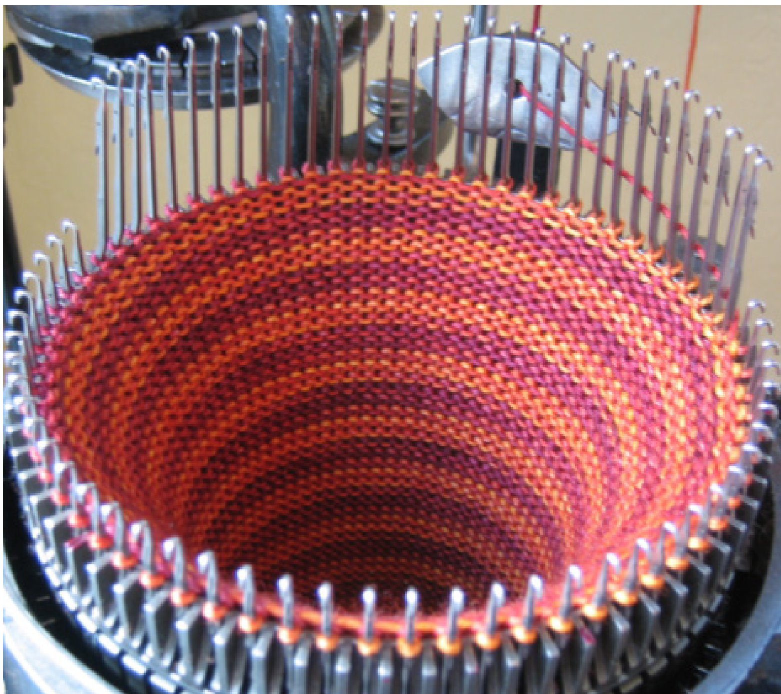
On a flatbed machine there are two beds with knitting needles which are orientated opposite to each other under an angle (see illustration on the left). Needles are pushed upwards to grip and loop the yarns. The knitted cloth is formed and pulled down at the bottom.

Each bed can knit a separate layer of cloth so a two-layer textile can be manufactured. In addition, the needles can also grab onto the loops of the opposite bed, connecting the two layers. This method allows tubular shapes to be knitted, for example seamless sweaters. This technique is elaborated in chapter 4.2.6.

A circular knitting machine can be used to seamlessly knit a cylindrical shape like a sock. The needles are orientated in a circle and they go up and down, grabbing the new yarn which travels around the cylinder. The cylindrical knitted fabric is formed and pulled down the machine. The diameter of the circular knitted fabric is determined by the size of the machine.

This method is quicker than flatbed knitting because the yarn can go around continuously. With flatbed knitting the direction has to switch directions regularly to move back and forth on the beds. Therefor, circular knitting is used to produce large quantities of flat fabric. The cloth is knitted and cut to create a flat piece of textile.

Fig. 4.9: Circular knitting machine.



4.2 3D-knitting literature research

Much research has been conducted to explore the possibilities for 3D-knitting non-developable shapes. This chapter will list the 3D-knitting techniques that were found in the scientific papers read for this thesis.

What is interesting about the technique of knitting is the possibility to create three dimensional shapes without the need of cutting or stitching after production of the cloth. With this method no waste is generated.

Knitting complex shapes is time-consuming. Various research has been conducted exploring the creation of three dimensional shapes on flatbed- or circular knitting machines. In this report these techniques are summarized with the term "3D-knitting".

Automated 3D-knitting is done by pulling yarns through loops with the use of needles. These needles are positioned on a bed and they can move up and down. By opening and closing the needles, yarns can be grabbed and pulled through existing loops. On automated machines this process can be programmed for each individual stitch.

It requires in-depth expertise about knitting patterns and construction to program the machine to knit a novel shape and to set it to the correct settings in order to make a successful knit.

Fig. 4.10: 3D-knitted seat cover by Stoll flatbed knitting machine. Pictures made by the author at TechTextil 2022.

4.2.1 Knit, tuck and miss stitches

The stitching movement of the needle on an automatic knitting machine can be described in five steps. This can be seen in the image below.

Firstly, the needle is positioned inside the existing loop (step a). The needle opens up and moves upwards to catch the yarn (step b). It picks up the yarn (step c) and pulls it through the loop (step d), creating a new loop during this stitch movement (step e).

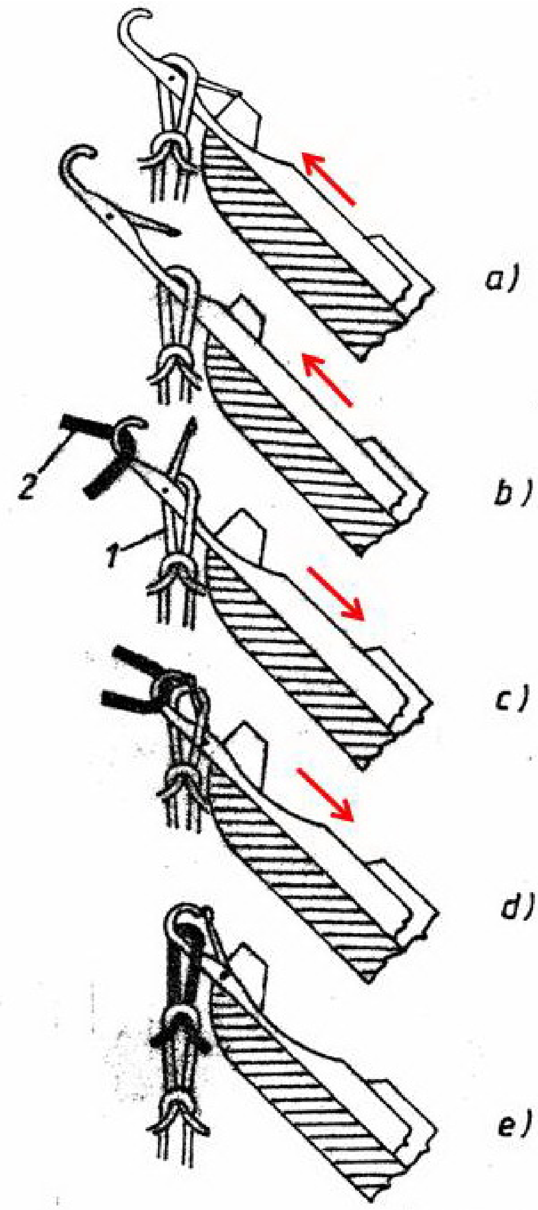


Fig. 4.11: Steps of knitting needle making a stitch to build up a cloth (Loop Formation on V-Bed Flat Knitting Machine, 2018).

The needles on the machine can be controlled individually to skip or alternate a step which results in a varying knitting pattern that can allow the cloth to fall into a certain shape (IIT Delhi, 2019).

- If the needle goes through all the steps normally this makes a regular "knit stitch".
- When the needle does not fully pull the yarn through the loop (step d & e) but collects multiple loops before pulling another yarn through, this creates a "tuck stitch".
- If the needle does not pick up the yarn (skip step c) before pulling it through the loop (step d & e) or if the needle does not move at all this makes a "miss stitch" (also called "float stitch").

With tuck and miss stitches it is possible to create patches in the cloth which are tucked inwards or looser in structure. This method allows the knitted fabric to locally vary in stretchability.

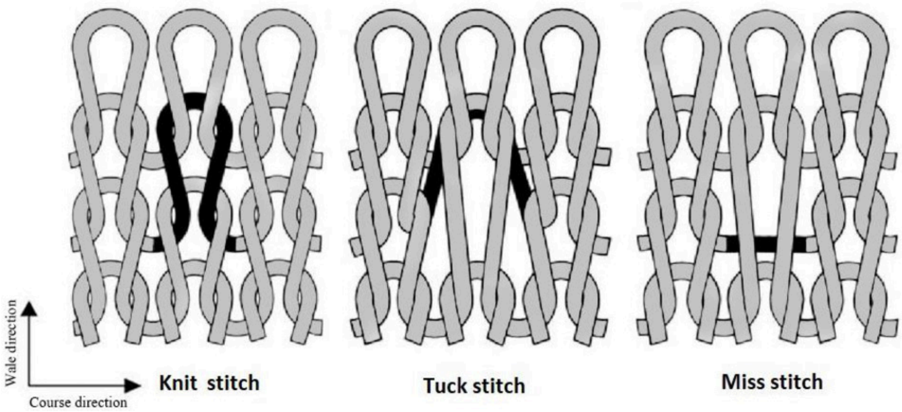


Fig. 4.12: Knit, tuck and miss stitch illustrations (Ziaei et al., 2020).

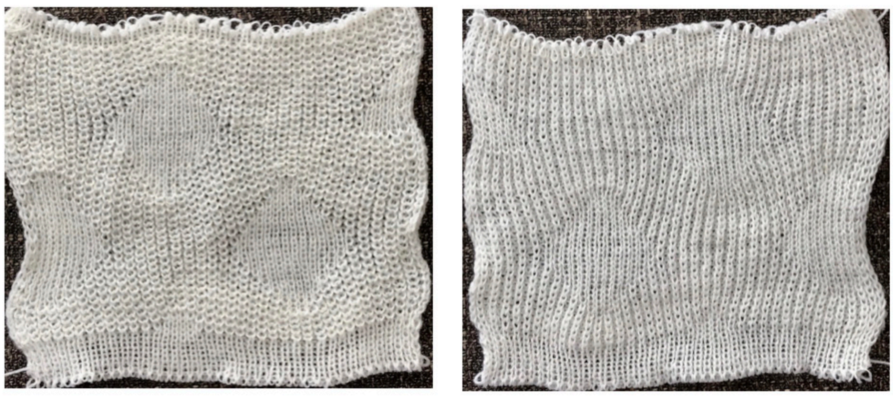


Fig. 4.13: Samples with visible diamond-shaped patches of tuck stiches (Alessindrina, 2019).

4.2.2 Combining rib and purl knit

In one of the papers read for this thesis the researchers used a flatbed knitting machine to create three dimensional shapes by combining rib and purl structures (Choi & Hee Lee, 2010). When these two knit patterns meet they push each other upwards at the joint lines. Rib and purl knits are two patterns that can be made by weft knitting.

This technique allows the creation of spectacularly steep shapes. According to the researchers this technique could create potential benefits for the use of textile in upholstery, medical and other industry branches.

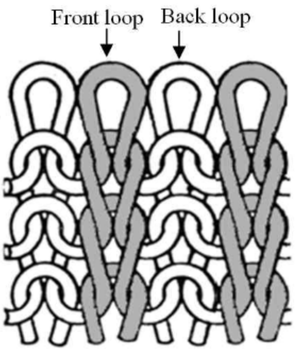


Fig. 4.14: Rib knit structure (Choi & Hee Lee, 2010).

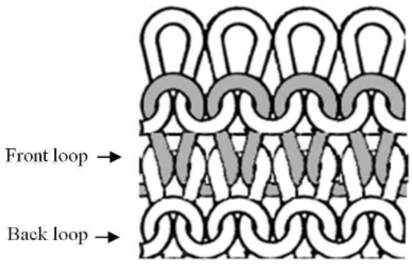


Fig. 4.15: Purl knit structure (Choi & Hee Lee, 2010).

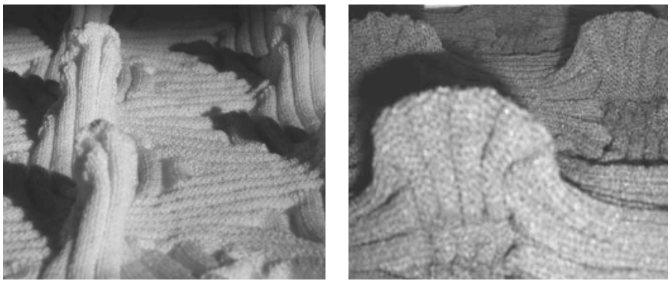


Fig. 4.16: 3D-knit shaped by combining rib and purl (Choi & Hee Lee, 2010).

Fig. 4.17: Structured garment made with rib and purl knit (Choi & Hee Lee, 2010).

The researchers demonstrated this technique by making three dresses, one of them shown on the left. The rib and purl structures are clearly visible and they create a rough surface on the fabric. This makes for a distinctive artistic style. This style does not fit the sleek design language of Philips Hue products, nevertheless the technique could be used to create 3D-shapes for these products. A more refined yarn or structure can be used.

4.2.3 Varying yarn tension and knit density

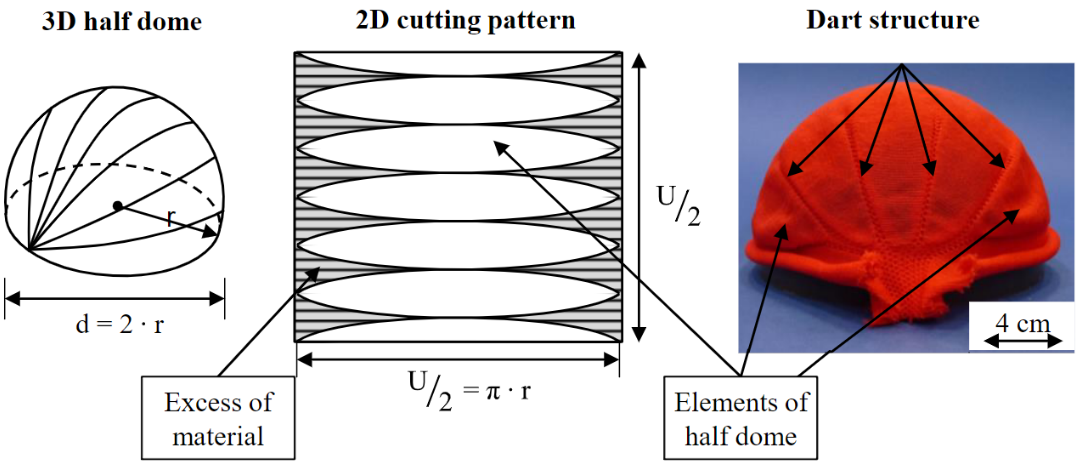


Fig. 4.18: Prototype of a 3D half dome, circular weft knitted (Simonis et al., 2017).

The spherical shape shown above was knitted using a large circular knitting machine. By varying the yarn tension and knit density in the excess of material these parts were reduced in size. The excess material shrinks in size when released from the knitting machine, leaving the fabric in this half dome shape.

This dome was developed using programming solely and no changes were made to the hardware of the circular knitting machine. This method relies on programming the correct instructions for the knitting machine. This is a complex and time-consuming process. Nevertheless the shaping possibilities for this method are extensive.

4.2.4 Varying yarn thickness

If the yarns used in the knit are not consistent in size this allows the shape to widen or narrow in certain areas. If a regular knit pattern is used and the yarns on top are thicker, the total width will be larger than at the bottom.

It is unclear whether this project was made on an automated machine or fabricated by hand. Nevertheless, it visually demonstrates the principle of varying yarn sizes and cloth width which could be useful for 3D-knitting purposes.

Fig. 4.19: Moonbotica by Verena Winkelmann (Bendt, 2016).

4.2.5 Increasing or decreasing stitches

By increasing or decreasing the amount of loops in the horizontal direction the cloth width can be widened or narrowed. Making a short row in the fabric creates a wedge which allows it to bend more easily. This method is used to create the saddle cover that can be seen in the introduction of this chapter (4.2).

These images below illustrate how increasing, decreasing and creating a short row manipulates the knitted structure.

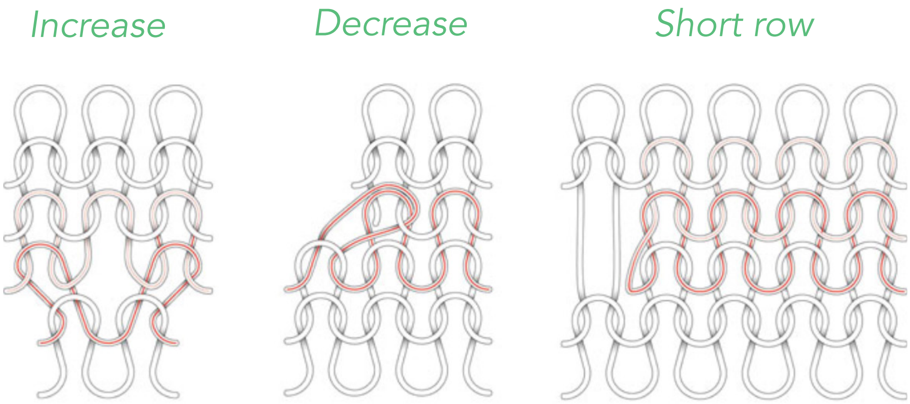


Fig. 4.20: Knit pattern manipulations (Popescu et al., 2018).

Below you see the design of a template for a conical shape. This is done by multiplying a single pattern in which the rows decrease going upwards. To make a 3D shape from this 2D layer of fabric the ends need to be joined by hand knitting them together. With this method, no material is wasted.

In the same fashion corners can be fabricated. What is important to bear in mind when creating corners on a flatbed machine is the careful takedown of the cloth, the stitch length and yarn properties. Large stresses are exerted on the edges when the cloth is attached to the machine. Taking the fabric out of the machine must be done carefully to prevent damage to the textile or the machine.

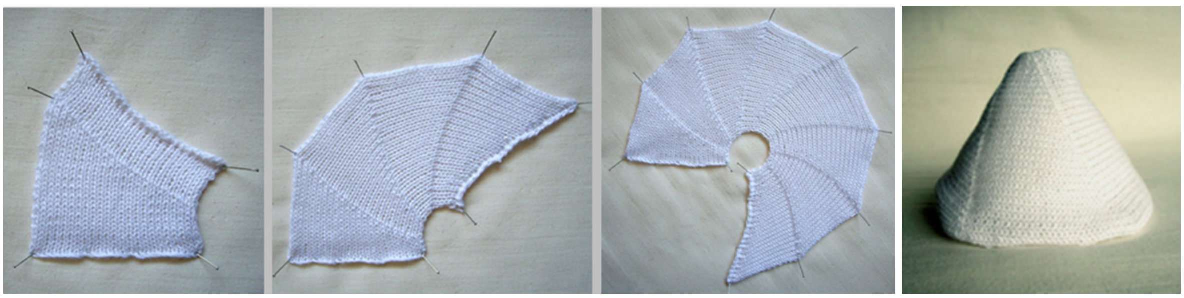
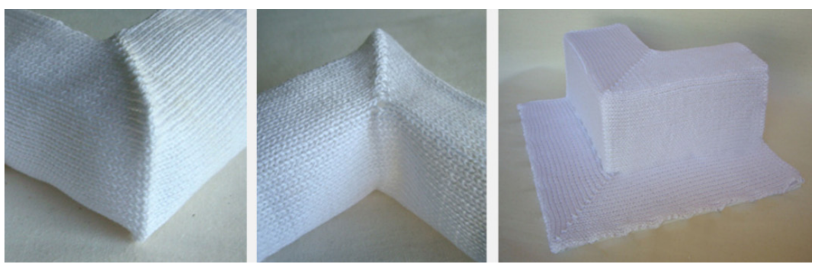


Fig. 4.21: 3D-knitted template for a cone (Underwood, 2009).

Fig. 4.22: Sharp corners, made on a flatbed knitting machine (Underwood, 2009).



4.2.6 Tubular knitting on a flatbed machine

Fig. 4.23: Tube with flange, made on automated flatbed knitting machine (Underwood, 2009).

It is possible to knit tubular shapes on a flatbed machine. The two beds on the machine can create a layer of cloth separately and they can also be joined because the needles on the beds can hook onto the loops of the opposite bed. On the left is an image of a tubular shape with flanges on both sides. It clearly demonstrates how the two layers can be joined or kept separate in one piece of textile.

Flanges are created when multiple rows are connecting both layers of fabric. If only a single row is connected at the edge it is possible to make a seamless tube. Many kinds of interesting tubular shapes can be produced with this method, like the one shown below. This technique allows for broad design freedom in creating textile shapes to cover complex surfaces.

Fig. 4.24: Y-shaped textile, made on automated flatbed knitting machine (Underwood, 2009).

4.3 Colours in textile

For Philips Hue products it is important that the colour of the textile will not influence the light colour from the light source. In the Rotation Lamp product concept made for this project, the light could reflect on the textile elements. If the textile is coloured, the light can be reflected in a different shade. This is an undesired effect. To prevent this from happening it was chosen to use white fabrics in the prototype of the Rotation Lamp.

All experiments in this thesis focus on the use of white textiles. These fabrics influence the light colour minimally in comparison to other colours. In addition, this allows for equal comparison of the fabrics in the experiments.

It is important to take into account the difference in perception that coloured fabrics bring about. On dark colours like black, shadows and highlights are less visible than on bright and white textiles. This makes the darker colours appear flat and less textured. If coloured textiles will be chosen this needs to be taken into account.

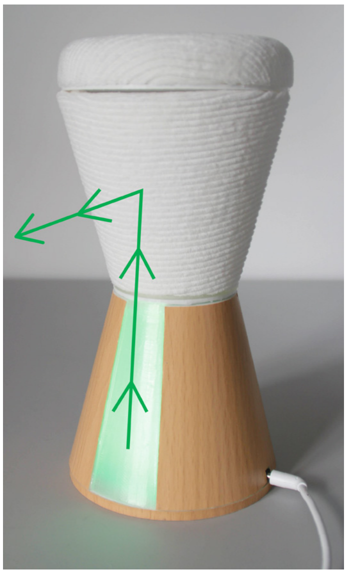


Fig. 4.25: Potential direction of coloured light reflections onto the textile components of the Rotation Lamp.

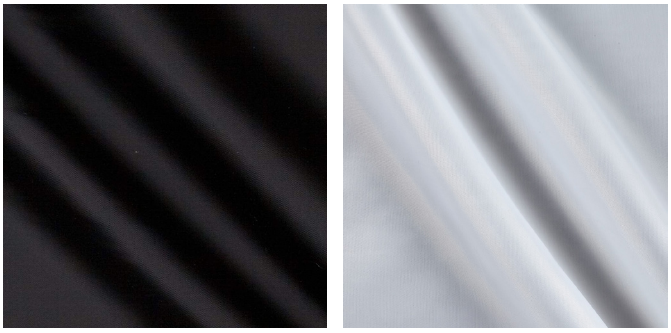


Fig. 4.26: Comparison of black and white fabric. Shadows are more apparent in white fabrics.

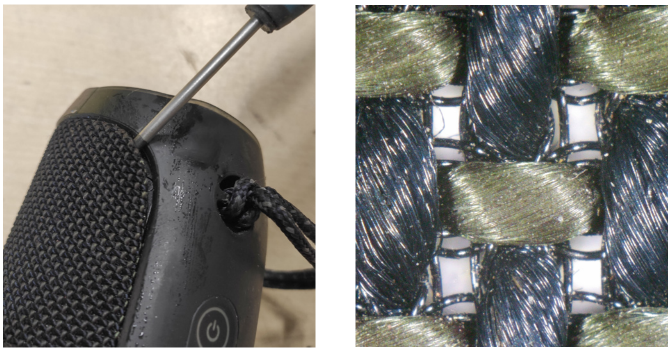


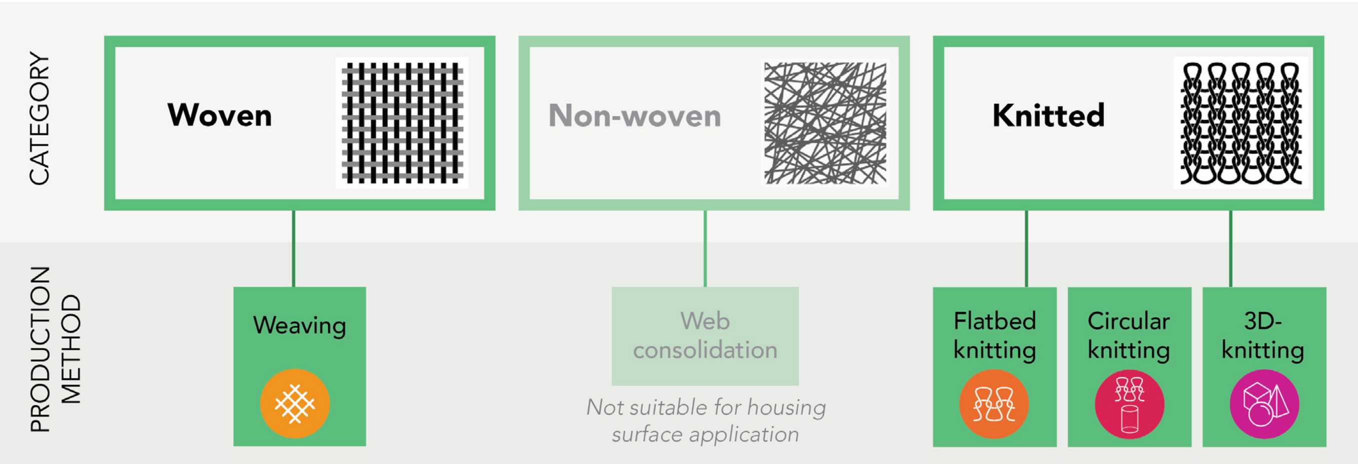
Fig. 4.27: Blue and yellow yarns create a black fabric.

Fig. 4.28: Two different shades of white yarn are used in sock 4 from Esther Jubbega.

A trick to enhance the quality perception of a fabric is to use different coloured yarns. From a distance the colours are visually mixed and the textile is perceived as a single colour. This creates a depth perception and it enhances the perceived fabric quality.

This was clearly visible in the textile of two disassembled products, shown on the left. In addition this technique was used in the circular knitted sock samples from Esther Jubbega. It is advised to use this technique for the textiles used in the product designs of Philips Hue.

Textile types



There are three main types of textiles and these are their typical properties:

Woven fabric:

- Made from yarns that are structurally woven into a pattern.
- Weaving results in a flat sheet of fabric.
- Different weaving patterns are possible.
- Usually non stretch.
  (Woven fabrics can be stretchable if elastic yarns are used.)

Non-woven fabric:

- Made from chaotically interlocked yarns.
- Web consolidation results in flat sheet of fabric.
- Not suitable for housing surface application because of the dense and thick structure and undesired surface look.
- Non-stretch.

Knitted fabric:

- Formed by looped yarns.
- Two production methods:
  - *Flatbed knitting results in a flat sheet of fabric.*
  - *Circular knitting results in a cylindrical textile.*
- 3D-knitting possibilities with both production methods to go beyond flat or cylindrical shapes.
- Stretchable.

Comparison of fabrics:

	Stretch?	Suitable for surface application?	Fabric orientation
Woven fabric	No	Yes	Flat sheet
Non-woven fabric	No	No	Flat sheet
Knitted fabric	Yes	Yes	Flat sheet, cylinder, 3D-shape

4.4 Fabric ideation

A fabric ideation was executed to stimulate outside-of-the-box thinking. This chapter will elaborate on the process towards proposing two new interesting fabrics for the textile building blocks of Philips Hue.

In the product disassembly analysis it was learned that brands apply a distinct type of fabric for each product category and/or their brand (see chapter 3.2). This textile application is new for Philips Hue and a signature fabric has not been chosen yet. This leaves room for competitor differentiation through applying an innovative fabric.

Depending on the product in which textile is being used the requirements will be different. The fabric needs to fit the purpose. For example, it would not make sense to use thin satin fabric in car upholstery or thick woven wool for underwear.

Fig. 4.29: Fabric used for different purposes: garments and upholstery. Left: clothing. Right: Lounge Pug corduroy beanbag.

Requirements for fabrics of consumer electronics vary from those of clothes and upholstery. These textiles must be durable, even more so for products which are regularly touched and picked up. In addition, the fabric must not be too thick since it has to be wrapped around a housing. The specific requirements for durability, waterproofness, thickness, softness etcetera depend on the product application and should be determined according to the requirements of the specific product.

A fabric ideation was conducted and this can be read in appendix F. From this a fabric sample board was created. This board functioned as an inspirational tool during a brainstorm session with the Signify Textile Application team and for the product concept ideation.

Two fabrics that were considered intriguing by the Signify team are spacer fabric and corduroy.

Spacer fabric is found in the products from the brand Fresh 'n Rebel and it has a unique tactile experience because of its foam-like compressibility.

Corduroy is not found in consumer electronics yet but very common in upholstery, for example the blue beanbag shown on the previous page. Both these fabrics could be applied in a Hue luminaire to create an object that is inviting to touch. With corduroy, Signify can differentiate their products from all other existing textile housing consumer electronics.

To see these materials in the intended product context these two fabrics were applied to parts for the Rotation Lamp prototype. See chapter 7.3 for more information on the appearances of these textiles in their intended product context.

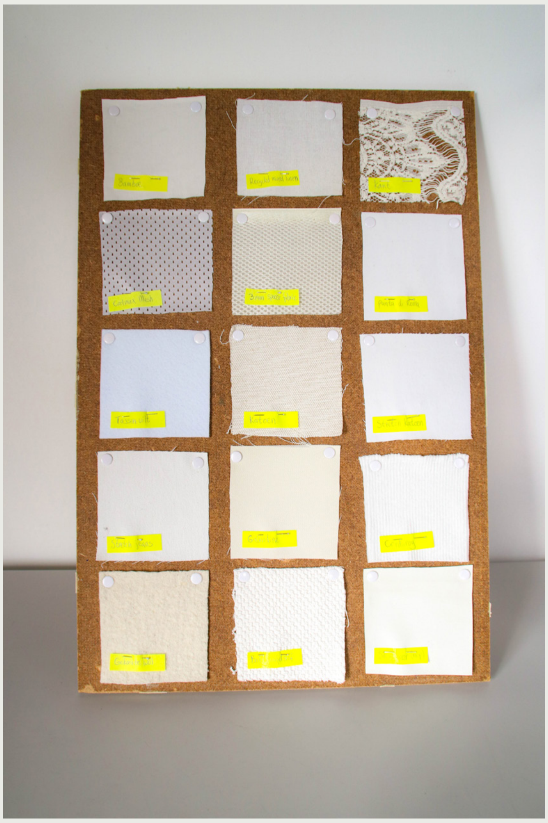


Fig. 4.30: Fabric sample board with 15 pieces of textile.

Fig. 4.31: Corduroy and spacer fabric parts attached to the Rotation Lamp prototype.

Chapter 5:

Shaping possibilities

Fabric can be either produced in a flat sheet of fabric or in a tubular shape. Depending on what fabric you choose the shaping possibilities differ. This chapter will list the research that has been done to discover the possibilities of both ways of covering surfaces with textile. These three experiments will be discussed in this chapter: the surface shape experiment, the cap variations of the Rotation Lamp and the socks & cylinders experiment.

This chapter aims to find an answer to the following question:
What shapes can be achieved with textile when applied to the outer surface of a product?

5.1 Shape index matrix

This chapter will introduce the "shape index matrix" which is a model to which we will apply the insights for flat sheet textile surface coverage in the Design Guidelines. First we need to understand what this model describes.

Researchers developed a method to describe surface shapes and their curvature with two values (Koenderink & van Doorn, 1992). The shape is described by a single number. This model is useful for this research as a tool to group the insights that were gained in this chapter about shaping possibilities for applying textile to surfaces.

The model of Koenderink & Van Doorn describes a surface using two values. The shape index and curvedness. These values indicate the following:

- The shape index is a single number from -1 to 1 which describes the convex or concave curvature of the X- and Z-axis of the surface. At -1 both axis are concavely curved, creating a hollow sphere. At 1 both axis are convex, which results in a convex sphere. At 0 the Y-axis is concave and the X-axis is convex which makes a saddle shape.

- A surface can be laid out into a mesh. The curvedness describes how far points on this mesh are apart from each other: a high number means steeper curves and a low number means a flatter surface.

A matrix was made to visualize the parameters of this model to be used in this research. Important to note is that this model describes surfaces to which textile is applied on top.

This matrix is used on the introductory pages of the Design Decision Tree (chapter 1.3) to group the surfaces into categories for the Design Guidelines.

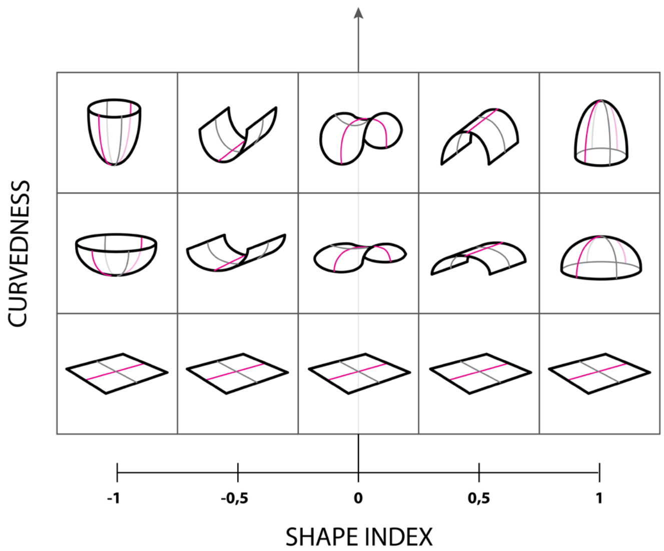


Fig. 5.1: Shape index matrix made to group the insights of this research.

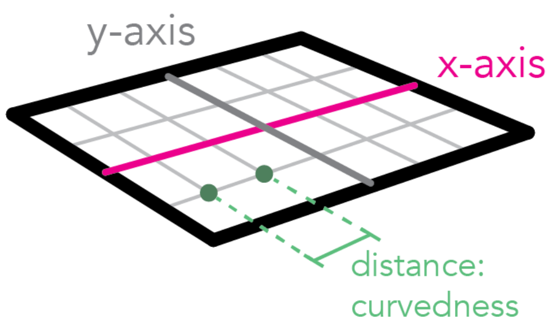


Fig. 5.2: Visualisation of the points on a surface mesh to determine the curvedness.

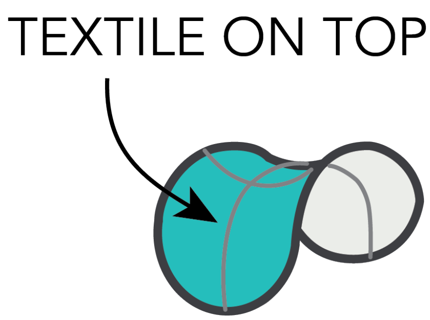


Fig. 5.3: Visualisation to indicate that textile is applied on top of the surfaces in this model.

5.2 Surface shape experiment

From the product disassembly analysis it could not yet be discovered what design limitations come with wrapping textile over a surface. To learn about these a hands-on "surface shape experiment" was conducted.

It was discovered that the products in the portfolio of Philips Hue consist of one of these four basic shapes: cylindrical, conical, spherical or rectangular (see chapter 2.2). For the shape experiment six of each of these shapes were 3D-printed in hand-size and wrapped with six different textiles that could be interesting for Philips Hue. In appendix G you can read the full setup of the surface shape experiment.

Fig. 5.4: All the shapes of the surface shape experiment.

This experiment resulted in a 4×6 matrix. By wrapping the shapes with woven, non-woven and knitted fabrics insights were gained about the shaping behaviour of these textiles. The main insights will be listed in the design guidelines that follow at the end of this chapter.

Fig. 5.5: 4×6 Surface shape experiment matrix.

	Rough woven cotton	Soft knitted bamboo	Spacer fabric	Flocking	Felt	Corduroy
Cylindrical						
Conical						
Spherical						
Rectangular						

5.3 Rotation Lamp caps

For the prototype of the Rotation Lamp variations on the textile top cap were made. This was done to experiment with product appearances and to gain more insights in the textile covering of a double curved surface. This chapter will elaborate on these parts of the prototype.

The original design of the Rotation Lamp contained a flat top to create a symmetrical hourglass-shaped product that could stand on both flat surfaces. When doing a user test with a dummy of the lamp it was discovered that the original diameter of the product was too large for most participants to grab comfortably. This top side was 14 centimetres in diameter. The full test can be read in appendix H.

The final design of the Rotation Lamp has two textile parts to grab. The side cone and top cap. For the top cap multiple designs were made to experiment with the product appearance. Three variations were made and two designs of the caps were designed to be easier to grab than the original flat cap. Three different knitted fabrics were used to give the caps a varying product appearance and to see how these textiles behave around the surfaces.

Fig. 5.6: Participants with small hands (left) and large hands (right) rotating the dummy of the Rotation Lamp.

Fig. 5.7: From left to right: flat cap, spherical cap and easy grip cap.

All caps were covered with stretchable knitted fabric because they are non-developable surfaces and this is a suitable textile for that application. Covering the flat and spherical cap was relatively easy to do because they only contained convex shapes. However, the easy grip cap was challenging to cover with fabric because of its saddle-shaped surface.

The tension of the knitted fabric around the convex shapes caused the textile to pull away from the housing surface. This is an important insight for designing a non-developable shape with convex-concave surfaces: the fabric must be glued thoroughly to the surface in order to stay in place. The glue must be cured while pressing the textile to the surface to prevent air bubbles from forming in between the layers.

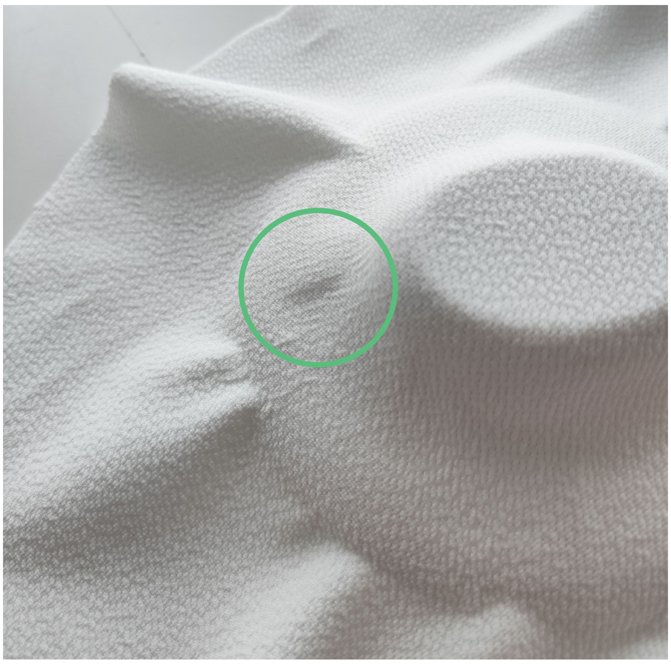


Fig. 5.8: Air bubble in wrapping the easy grip cap with textile.

Covering a surface with a flat sheet of textile

General rules to take into account when wrapping flat sheets of fabric over surfaces.

Pattern placement

When the fabric contains a pattern it is important to make conscious design decisions about how the pattern falls around the shape to make sure that the desired look is created. When patterns or lines are visible it is important that they follow the shape in a visually pleasing way.

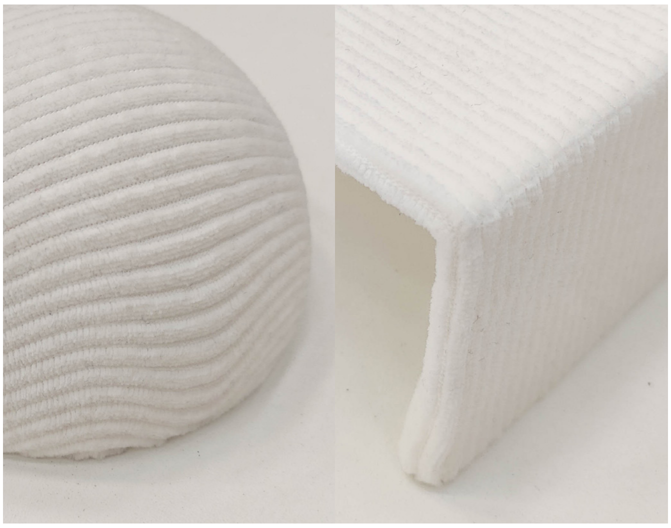


Fig. 5.9: Pattern lines of corduroy on the spherical and rectangular surface shape.

Curvature of edges

The thicker the fabric the more it accumulates on the inner edges. If these corners are sharp, this could cause problems when attaching the textile housing to the inner housing. If that is the case some extra space should be designed in the inner housing for the fabric to fall into.

In general it is advised to give these corners some curvature for the fabric to spread. If the design requires sharp edges it is advised to choose a thin fabric. For rounded edges the fabric can be thicker.

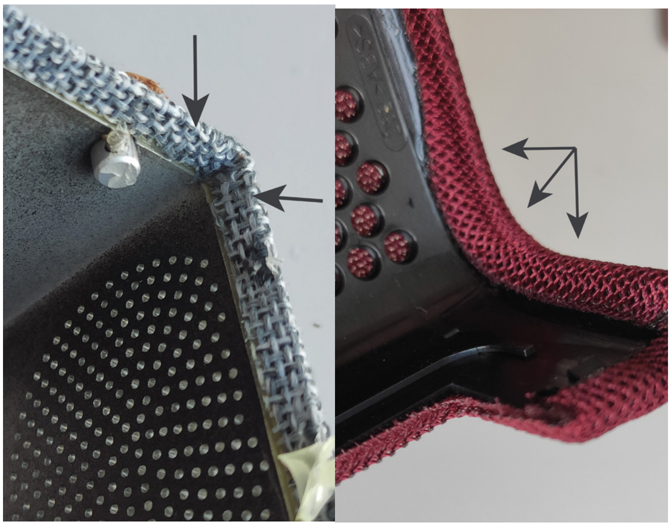


Fig. 5.10: Thin fabric used for sharp edges (left) or thick fabric spread over curved inner edges (right).

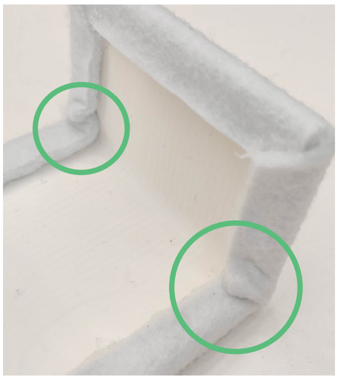
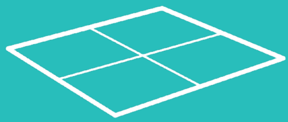


Fig. 5.11: Undesired accumulation of thick felt fabric on the inner edges of the rectangular shape.



Flat surface

Flat surfaces are easiest to cover of all surfaces.

Textile type

Flat sheets of woven or knitted fabric can be used to cover this suface. Shaped textiles are not required.

Fastening method

Both gluing and clamping can be used to fasten textile to this surface.

Fig. 5.12: Example of a flat surface covered with knitted corduroy fabric. This shape is non-developable, however it resembles flat surface coverage as well.

Concave
developable surface

Textile type

Concave developable surfaces can be covered with flat sheets of woven or knitted textile. These surfaces do not require fabric to stretch or to be pre-shaped.

Fastening method

Concave developable surfaces can only be covered with the gluing method, otherwise there would be a hollow space between the housing surface and the textile. This is why the clamping method would not work.

Convex
developable surface

Textile type

All textile types for surfaces can be used. However shaped circular knitted or 3D-knitted fabric is not necessary since the surface can be covered with a flat sheet of textile.

Non-stretch woven fabric is easy to wrap around single-curved surfaces but difficult around double-curved ones. Depending on the slight stretch that the woven cloth allows, a double curved surface can be covered.

Fastening method

All fastening methods for surfaces can be used.

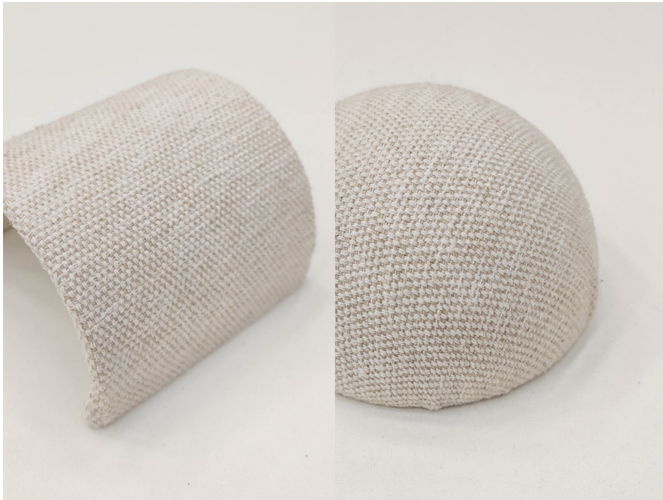


Fig. 5.13: Woven fabric used to cover a developable and a shallow non-developable spherical surface (both surfaces belong to this category).

Convex-concave
developable surface

Textile type

Shallow double-curved surfaces can be covered with flat sheets of woven or knitted fabrics. The slight stretching properties of all fabrics allow a shallow double curve to be made.

A 3D-knitted textile could be made to follow the surface shape.

Fastening method

A convex-concave surface must be glued to stay to the surface. Otherwise a hollow space between the housing surface and the textile can appear. The clamping method would not work.

Fig. 5.14: Shallow saddle shape covered with woven textile. Air bubbles are visible because the textile is not glued to the surface.

Concave
non-developable surface

Textile type

To cover a concave non-developable surface stretchable flat or 3D-knitted fabrics can be used. The textile needs to be shaped according to the surface either by stretching or shaping otherwise.

Fastening method

To cover the hollow shape the textile requires to be glued. Otherwise there would be a hollow space between the housing surface and the textile creating an air chamber. This is why the clamping method would not work either.

Convex
non-developable surface

Textile type

To cover a convex non-developable surface stretchable flat or 3D-knitted fabrics can be used. If the spherical shape is shallow, it could be covered with a woven textile and it would fall into the category of developable surfaces.

Steep spherical shapes must be covered by stretch fabric. The maximum steepness of the surface is determined by the stretch capacity of the fabric.

Fastening method

The textile can both be glued or clamped onto the shape.

Fig. 5.15: Spherical shape covered with knitted stretchable spacer fabric.

Convex-concave
non-developable surface

Textile type

If the shape is convex as well as concave (saddle shape) only stretching flat or 3D-knitted fabrics can be used. Non-stretch woven fabrics can only cover shallow saddle shapes since these are considered developable surfaces.

Fastening method

To cover the hollow parts of the surface the textile requires to be glued. Otherwise there would be a hollow space between the housing surface and the textile. This is why the clamping method would not work either.

Fig. 5.16: Non-developable surface with air bubbles caused by the textile not being glued to the surface sufficiently.

5.4 Socks & cylinders experiment

An experiment was set up to explore the shaping capabilities of circular knitted socks around continuous shapes. This chapter will elaborate on this experiment called "socks & cylinders".

With circular knitting a tube is created which has openings on two ends. The elasticity of the knitted structure allows this tube (or "sock") to be pulled over a continuous tubular surface.

Signify has contacted a supplier which is specialised in circular knitting techniques. They produced 10 sock samples with a diameter of around 16cm to experiment with. Details on these socks can be found in appendix I.

Seven of the ten socks were pulled over six different cylindrical shapes. Four of these shapes were inspired by the shapes of Philips Hue products: cylindrical, conical, rectangular and spherical. Two extra shapes were meant to explore more shaping possibilities. This full "Socks & Cylinders" experiment can be found in appendix J.

The main insights of this experiment will now be discussed in the following Design Guidelines.

Fig. 5.17: Sock samples from Esther Jubbega.

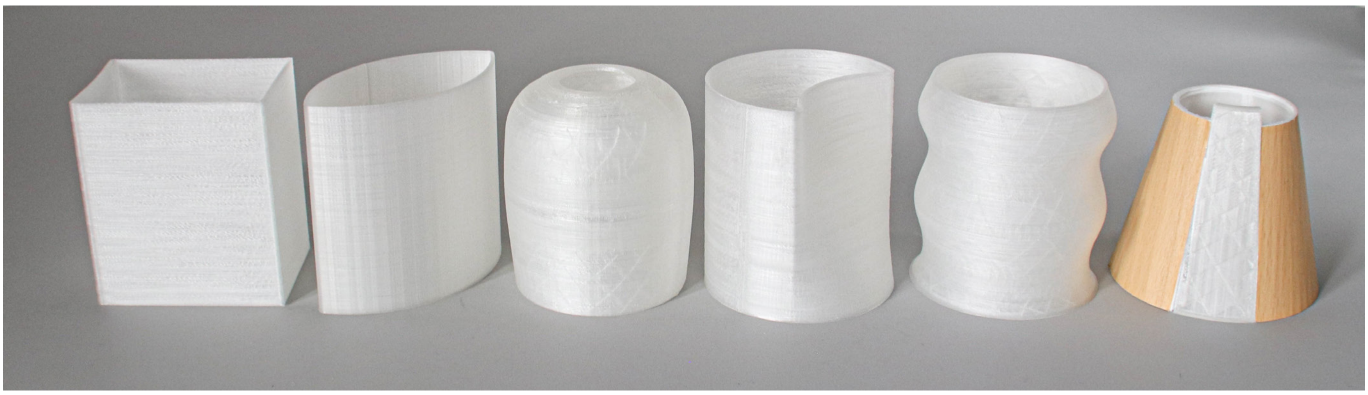


Fig. 5.18: Shapes of the Socks & Cylinders experiment. From left to right: rectangular, flattened cylinder, spherical, convex-concave demo, wobbly and conical shape.

Covering a continuous surface with tubular textile

General rules to take into account when wrapping tubular knitted fabric around continous surfaces.

Circular knit diameter

When using circular knitted fabrics around a continuous surface the fabric should be of accurate diameter. It must be tight enough to cover the shape but not too tight to stretch over the smallest diameters, obstructing it from touching the surface.

Fig. 5.19: On the left: sock 9 is not tight enough around the top of the cone. On the right: sock 1 is too tight and stretches over the smallest diameters.

Pattern lines

Lines in the knit pattern, for example in a rib knit, should be aligned according to the shape. This should be done to acquire a pleasing visual aesthetic appearance.

Fig. 5.20: Unaligned (left) versus aligned lines (right).

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Visible connection lines

Circular knitted pieces might have visible connection lines. Depending on the knit pattern these will be clearly visible or not. If they are highly visible a conscious design decision should be made about where this line is placed over the surface to have minimal impact on the product appearance.

Fig. 5.21: Visible connection lines in sock 9.

Diagonal patterns

Diagonal patterns with no clearly visible horizontal or vertical lines are easy on the eyes from a distance. A distinct horizontal-vertical pattern makes the surface more interesting but also attracts more attention towards the pattern.

A diagonal pattern is advised for creating a sleek design appearance.

Fig. 5.22: Comparison of diagonal and horizontal-vertical patterns on the conical shape.

Shape-knit pattern interaction

The knit pattern can be used to let it interact with the shape. Therefor the knitted piece can be designed with the preferred to-be-covered shape and visual effect in mind.

Fig. 5.23: The pattern of sock 5 interacting with shapes.

Complex
continuous surface

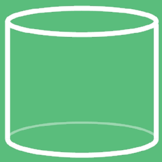
Textile type

A method with many possibilities for covering complex shapes with textile is through 3D-knitting. A tailored textile should be designed for this surface. It is advised to research the possibilities of 3D-knitting for this application preferably with a textile expert.

Fastening method

All fastening methods are possible for complex shapes. Which one is preferred depends on the specific design requirements.

Fig. 5.24: 3D-knitted example of a complex continuous shape that can be made on a flatbed knitting machine.



Cylindrical
rotationally symmetric surface

Textile type

Wrapping a circular knitted piece around a cylinder is not challenging if the diameter of the sock matches the shape. For cylindrical shapes circular or 3D-knitted fabrics can be used.

Fastening method

The sock can be glued to the surface, but this is not necessary if the clamping method is used. The sock can also be used as a sleeve that is not fastened to the surface but rather a separate piece. The sock can also be clamped to the surface.

Conical
rotationally symmetric surface

Textile type

For a cone with shallow angles a sock can be used with a consistent diameter without warping the knit pattern too much. Pay attention to the warp of the pattern when designing the circular knitted fabric. For conical shapes it is also possible to use circular or 3D-knitted fabric.

Fastening method

The sock can be glued to the surface. The sock can also be used as a sleeve, that is not fastened to the surface but rather a separate piece. The sock can also be clamped to the surface.

Fig. 5.25: Visible differences in the pattern at the bottom and top of the conical surface. It is slightly warped.

Curved
rotationally symmetric surface

Textile type

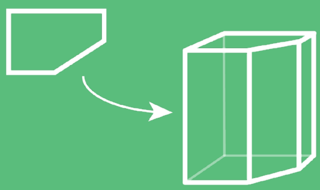
For cylindrical shapes circular or 3D-knitted fabric can be used.

For the fabric to tuck inwards, this movement must be allowed. If the knit is too dense or too thick this becomes difficult. Open knit structures and loose knits allow the textile to bend inwards enough to cover the spherical shape without folding.
In conclusion: choose the knit pattern for this application strategically.

Fastening method

All fastening methods can be used.

Fig. 5.26: Not all socks allow tucking wards without folding. The sock on the right works because of its open knit structure.



Profile
continuous surface

Edges

Profile shapes are likely to contain edges. At the sharp corners (0,0 and 0,1cm fillet) knitted structures are spread open. This creates a possibly undesired effect on the appearance of a product. It is therefor advised to give sharp corners fillets of minimally 0,2cm.

The exact minimally required fillets could vary depending on the pattern and thickness of the knitted fabric.

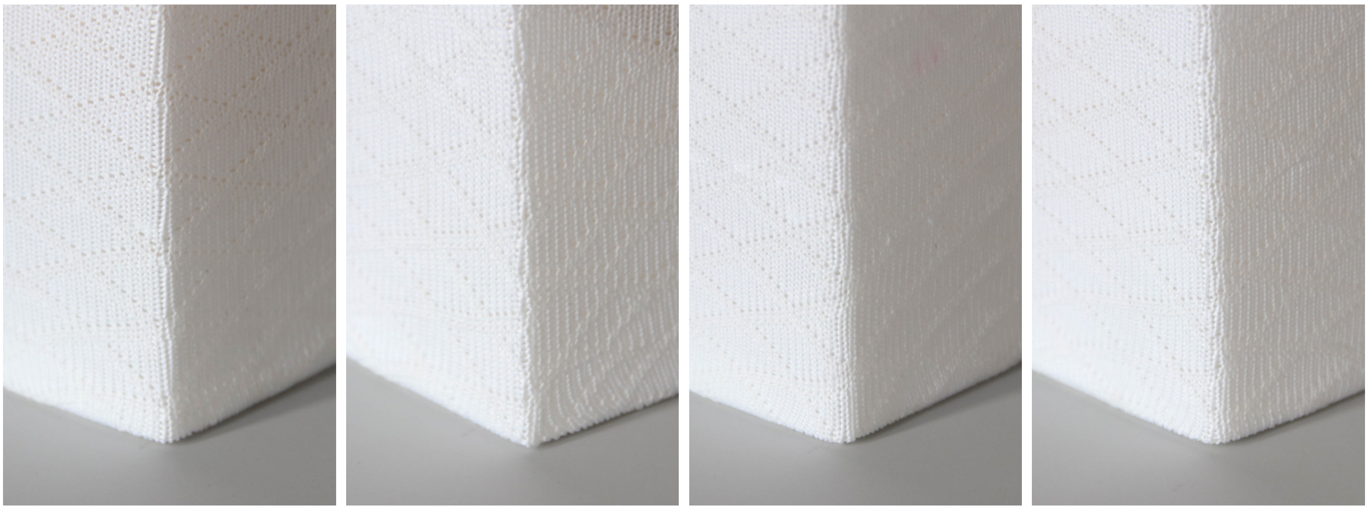
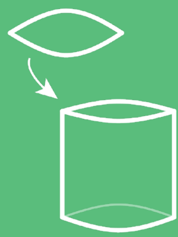


Fig. 5.27: Fillets of 0,0; 0,1; 0.2; 0,3cm (left to right). For the fillets of 0,0 and 0,1 the knit structure is spread open. Higher fillets are advised.

Convex
continuous profile surface



Textile type

Circular or 3D-knitted fabrics can be used to cover these profile shapes without hollow curves.

Fastening method

All fastening methods can be used to fix the textile to the surface.

Fig. 5.28: Example of a profile shape with only convex curves.

Convex-concave
continuous profile surface

Textile type

Circular or 3D-knitted fabrics can be used to cover these profile shapes with concave curves. The tightness of the textiles will determine how far they pull inwards.

Fastening method

The clamping method cannot be used because of the convex curves. The fabric requires to be glued to the surface to prevent air chambers from existing between the textile layer and surface.

Fig. 5.29: Socks with different tightness pull inwards at the concave parts of this concave-convex demonstration shape.

Chapter 6:

Fastening methods

In the previous chapters we have seen methods with which textile is currently being fastened onto a housing element: gluing or welding to the surface and inner edges of the component. There are also products with a separate sleeve which is pulled over the product.

This chapter will list the pros and cons of these two methods. In addition, a novel sustainable alternative to the gluing method will be introduced: a disassembly-friendly method described as "clamping".

This chapter aims to find an answer to the following question:
How can textile be fastened in a way that it can be taken off easily for repairing or recycling?

Fig. 6.1: Google Nest Audio with textile glued to the outer- and inner surface.

6.1 Gluing and welding

Most portable consumer electronics with textile housing parts that were disassembled for this project had their textiles glued to a plastic housing. This is the most common way to fasten textile for application on a housing surface.

To learn more about this procedure the company "Roma Strickstoffe" was contacted. They are specialised in gluing and welding textile applications for consumer products. In appendix K the notes of a digital meeting with the company can be read. For this report the insights of Roma are used to describe the gluing and welding processes.

Textiles can be glued to different types of housings like wood, plastic or metal. Wood is often used in high-end products. For plastic materials like PS, ABS or PC are suitable for textile coverage. Silicon, PP or greasy materials are not suitable.

The fabric is fastened on two sides: the outer surface and the inner edges. The housing components and textile are both sprayed with a component of an adhesive. Then the fabric is wrapped over the surface of the component, by hand. The fabric is folded inwards over the edges and more adhesive is used to glue the fabric to the inside. The glue is thermally cured with a lamp. Finally, the remaining fabric is cut off with a hot knife.

Roma uses varying types of adhesives for each purpose: adhesives for the automotive industry are usually tough, but water based glues for other products are easier to pull off.

A variation on this method of gluing is ultrasonic welding. This method only works for fabrics with synthetic fibers because the fastening relies on melting the fabric with the plastic of the housing. This is not possible with natural fibers like cotton or wool.

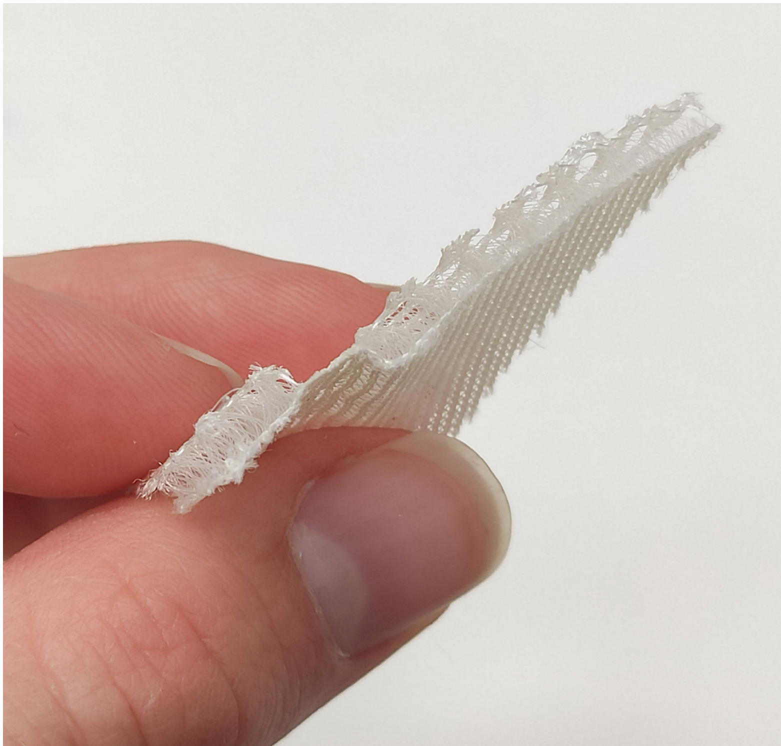
Roma Strickstoffe is able to use ultrasonic welding for large quantities. If the batch size is large enough this method is cheaper per piece than gluing.


Fig. 6.2: Glued textile housing with visible glue (left) and welded part with no observable glue (right).

The ultrasound welding properties of textiles were experimented with on a machine in the lab of the University. Indeed synthetic fabrics allowed to be welded, whilst other textiles would not. Spacer fabrics were highly suitable to be welded, however they lose their compressibility at the welding lines. See the images below. Considering these will be at the inside of the product this will cause no problems.

A serious issue of using either of these fastening methods is the recyclability. When textile housing products are disposed at the end of their lives, they end up in recycling facilities. The textiles are fixed to the surface and it requires too much effort to separate the materials. In addition, even if the materials would be separated the glue would contaminate the waste streams. Therefor these methods are not ideal from a circular economy perspective.

Fig. 6.3: Ultrasound welded pieces of spacer fabric, joined together.

6.2 Sustainable alternative: clamping

Clamping the fabric onto the surface of the housing could be a novel solution for creating a circular textile housing product. Allowing the fabric to be easily disassembled stimulates repairing and recycling. This chapter will elaborate on this new design solution. Several easy-disassembly methods were prototyped and clamping was chosen as the most viable method. The method will be elaborated in this chapter.

Signify is a market leader in the business of luminaire products. In addition, they have high ambitions when it comes to sustainability (see chapter 2.1). These ambitions should ideally be translated into the new textile luminaire product. We just learned that gluing textile to a component ruins the recyclability: so how can we design a more sustainable textile housing?

Imagine a scenario in which the textile is damaged by a sharp object, causing a hole to form on the surface of the product. The consumer could want to demand a replacement product: ideally Signify would take back the product and repair it, or they could provide replacement parts to the consumer. If the textile cannot be replaced by either the consumer of the company the product is likely to be discarded since a damaged-looking but functioning product loses its value.

In an ideal circular economy products are kept in the loop for as long as possible before the materials are being recycled into another product. Designing the textile components in such a way that they can be repaired easily will elongate the products life span and thus contribute to a more circular approach of product use.

In conclusion, the product should be designed so the textile can easily be separated from the product. This is not only great for the recyclability for separate waste streams, it also enhances the repairability in the stages before recycling. Easy disassembly contributes to the product life cycle phases of maintaining, reusing, refurbishing and recycling and therefor enhances the circularity of a textile housing product.

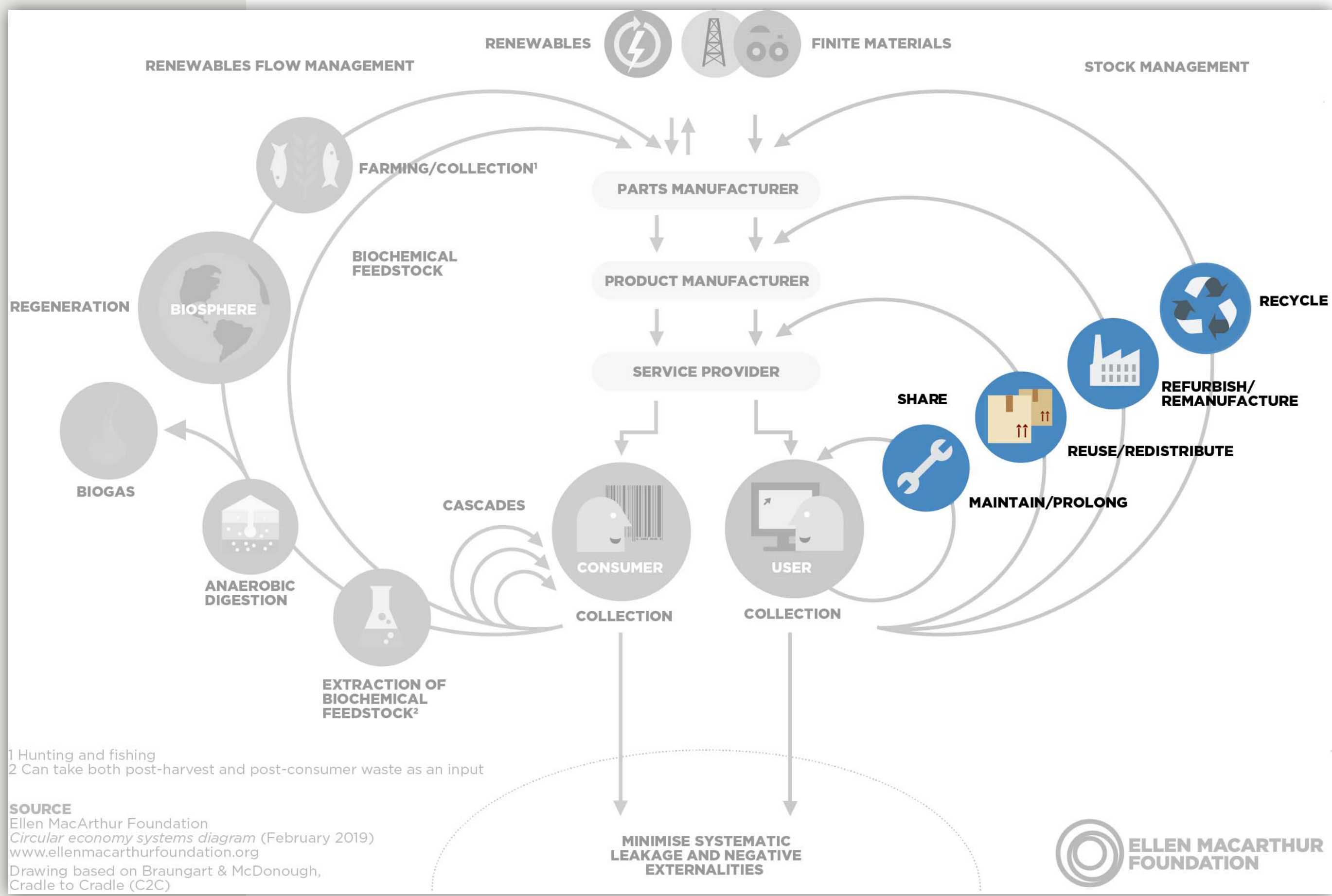


Fig. 6.4: Parts of the Butterfly Diagram to which easy disassembly contributes: maintain, reuse, refurbish and recycle.

6.2.1 Requirements for circular textile housing

In a circular economy, materials should be kept in the loop as long as possible. Downcycling should be avoided to make sure the materials stay of the highest quality for as long as possible. To design a circular textile housing, the requirements below should be met.

It is not enough to develop a more sustainable gluing or welding method. Easy-to-peel off glues or non-toxic sustainable glues will still result in textile housings that look like the fabric is fixated. This does not give the recycling facilities clear use cues on how to separate the materials, like for instance screws or snap hooks would. In addition, adhesives contaminate the waste streams of fabric and housing material (plastic, wood, metal). This would result in downcycling the materials.

A list of requirements for fixating textile to a housing component in a circular way:

- Clear use cues for separating textile from housing components.
- No contamination of adhesives in the waste streams of the textile or housing component materials.
- Fixating the fabric over the housing surface without glue to prevent it from shifting when touched.

6.2.2 Omitting glue for surface fixture

Glue is used to fix the fabric over the whole surface of a product to prevent it from shifting. For small parts like in the speaker shown on the right it is not a problem if the fabric is not fixed. However you can imagine that a fully textile covered product could slip out of your hands when you try to pick it up if the fabric stretches at the touchpoints between the hand and product. The fabric is able to shift when the underlying housing surface is smooth.

Fig. 6.5: Miniso speaker with fabric that can shift over its surface.

The use of glue to fix fabric over the top surface can be eliminated if the surface of the underlying housing is rough. This was experimented with by rubbing textiles over 3D-printed surfaces. These FDM 3D-prints were made from PLA filament with a layer height of 0.3mm. The untreated surfaces were smooth, causing the fabric to glide over the surface. After the prints are sanded the fine rough structure is enough to prevent the fabric from shifting. When the 3D-printed parts are put under a microscope the working principle can be observed.

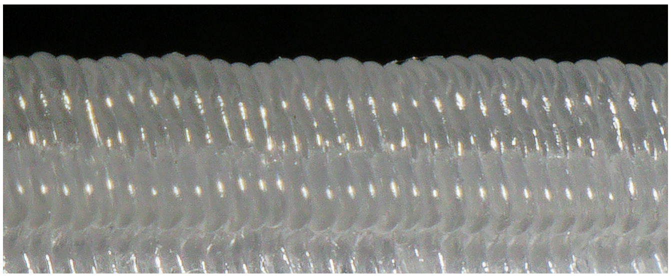


Fig. 6.6: Non-sanded 3D-print, sideview.

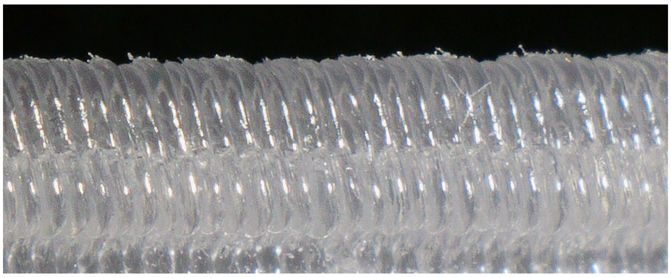


Fig. 6.7: Sanded 3D-print, sideview.

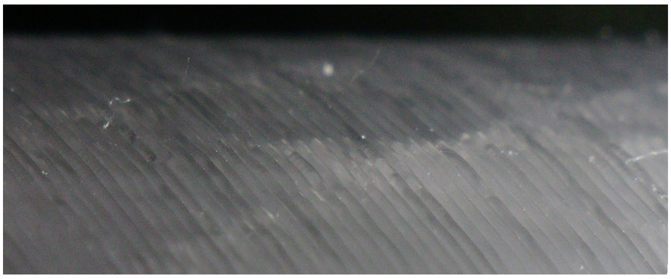


Fig. 6.8: Non-sanded 3D-print, surface view.

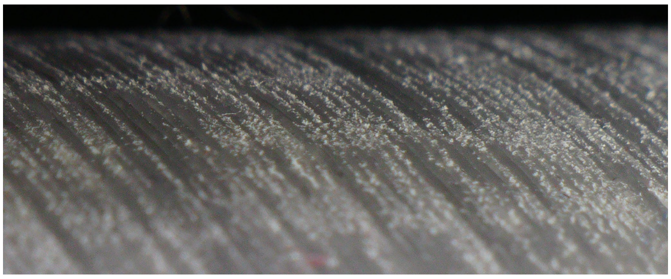
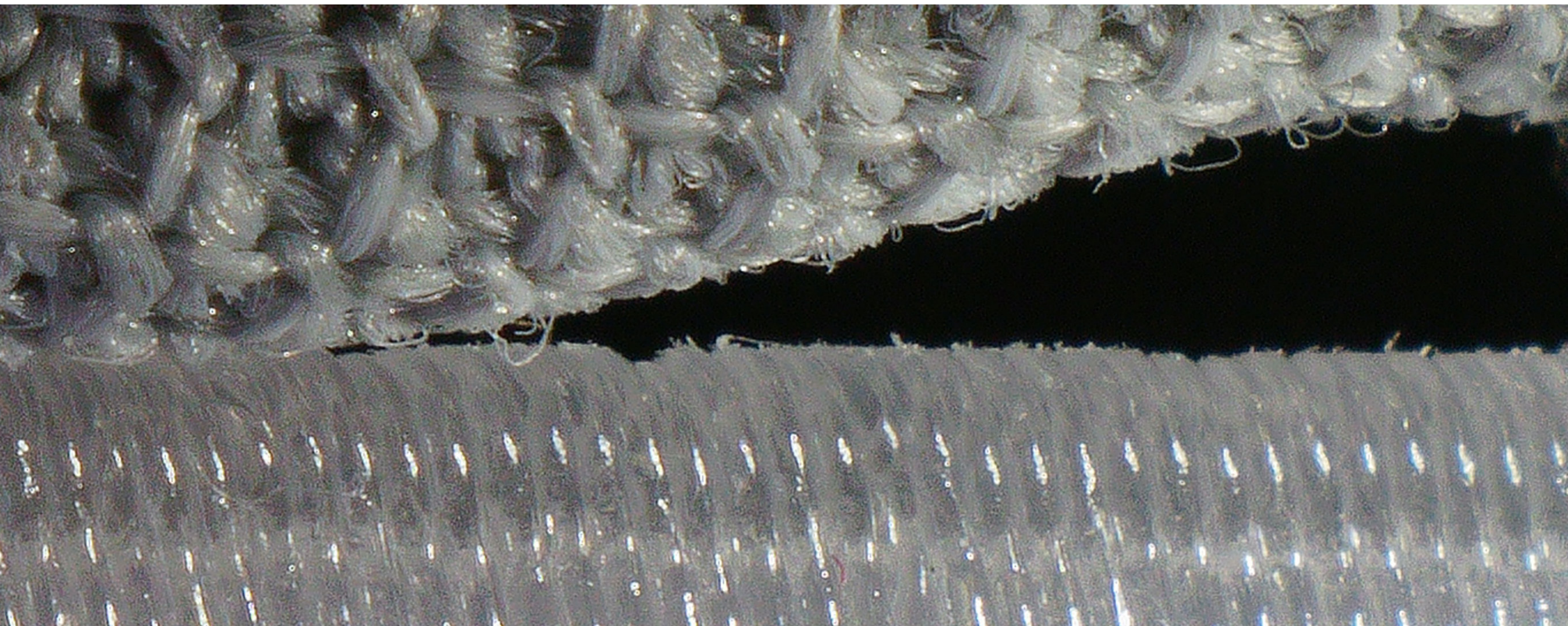


Fig. 6.9: Sanded 3D-print, surface view.

If the print is not sanded the surface consists of smooth layers of plastic. The sanded surface is damaged which creates small hooks. These hooks grab onto loops on the bottom of the textile. This hook and loop effect is well-known to be used in Velcro: a type of band that is used to create non-permanent bonding between textile layers.

Fig. 6.10: Piece of Velcro band.

Fig. 6.11: Sanded 3D-printed surface with textile on top.



The pictures below demonstrate that this principle works for other materials than 3D-printed parts too. A wooden part was lightly sanded in the same way and this created small hooks for the fabric to interlock into.

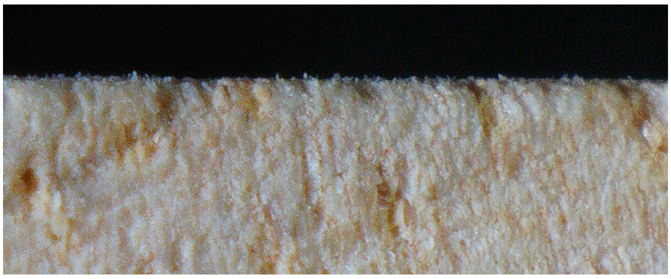


Fig. 6.12: Sanded wooden block, sideview.

Fig. 6.13: Hook and loop effect in the wooden block.

The surface of for example an injection moulded part is never perfectly smooth. The surface roughness can be described through the parameter ***Ra***, which is the average deviation from the ideal height of the surface. The higher this deviation the rougher the surface and the other way around.

Surface roughness can be measured with a device that has a stylus which is dragged across the surface. The ***Ra*** is then automatically calculated and displayed on the device.

However this method is not sufficient to describe the required roughness for the hook and loop effect. The surface roughness can be high but if the structure consists of rounded curves like the 3D-print the hook and loop effect will not occur. The surface structure should be spiky. To determine if the surface of a plastic housing is suitable it should be analysed under a microscope.

To industrialize this hook and loop effect there are two options for plastic housings. For injection moulding the inside of the mould can be roughened to achieve the desired surface finish. Another option is to create surface roughness by sandblasting, chemical etching or laser texturing the parts in a post-process step. These methods can also be applied to manufacturing methods for wooden or metal housings. A more in-depth analysis is required to analyse the fabrication of rough surfaces on an industrial scale.

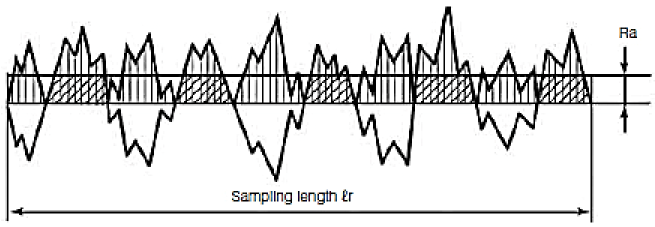


Fig. 6.14: Illustration of deviations in surface height.

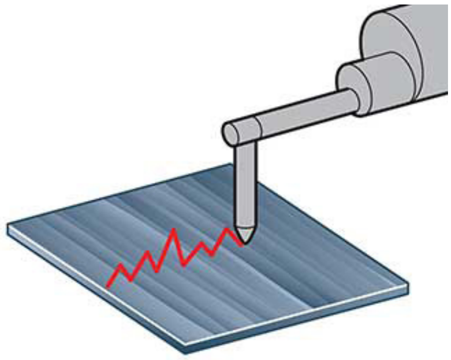


Fig. 6.15: Illustration of surface roughness measuring method.

6.2.3 Inner edge fastening solutions

Several clamping solutions for fastening the fabric to the inside were designed and prototyped with 3D-printing. It is important to notice that these methods focus on clamping the fabric onto housing components, not on the attachment of the housing element to the rest of the product.

These methods were designed with easy disassembly in mind and without the use of any glue. All prototypes have a rough surface on the outside for the textile to attach to and a different inside fastening method.

These four prototypes are variations on the conical housing part of the Rotation Lamp and they fit into the prototype of the product. Placing these parts in the Rotation Lamp allowed to check if the prototypes would create the desired outer finish when applied onto a product, which they all did.

Fig. 6.16: a) Hook; b) Clamp; c) Cover; d) Hook and clamp.

On the following pages these prototypes will be explained in more detail.

a) Hook

This housing part has a single hook in the middle on the inside. A piece of fabric is cut to fit around the housing. Four holes in the fabric are cut to wrap around the hook and to fasten the textile in a few simple steps. By executing these steps in reverse order the fabric can be taken off.

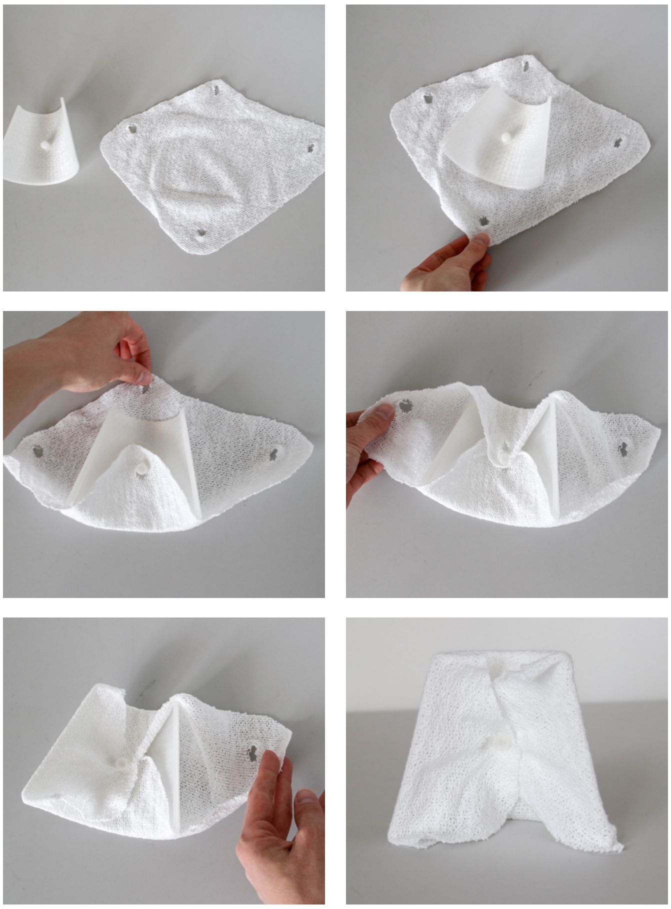


Fig. 6.17: Assembly steps of the hook system.

b) Clamp

This prototype consists of two plastic pieces: the housing and a clamp. The fabric is wrapped around the housing and the clamp is pushed between the ribs on the housing, locking the fabric in position. A small knob is visible on the clamp, meant to indicate to the user that the clamp can be taken off by pulling or dragging onto the knob. This action results in the easy release of the fabric from the housing.

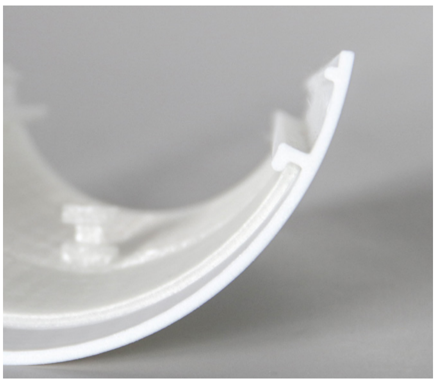


Fig. 6.18: Closeup of the clamp system.

Fig. 6.19: Assembly steps of the clamp system.

c) Cover

Similar to a duvet cover this fabric uses elastic to stay in place around the shape. The cover is sewn to fit the conical housing part and an extra elastic band was added to help keep the fabric in place. The cover can be taken on or off by wrapping it over the corners of the housing component.

Fig. 6.20: Assembly steps of the cover system.

d) Hook and clamp

This prototype combines the methods of prototype a and b. For prototype b it was a hassle to wrap the fabric onto the housing. Prototype d consists of the same parts as prototype b but it divides the assembly process in two steps. Firstly the sides of the fabric are wrapped around and clamped. Then the flaps of fabric at the top and bottom are wrapped around the hook on the clamp. These steps executed in reverse order will result in the release of the fabric.

Fig. 6.21: Assembly steps of the clamp and hook system.

6.2.4 Validation of easy disassembly methods

To validate these intuitive understanding of these novel design solutions a user test was set up. Prototypes a, b and c were used to validate the three different methods. Prototype d was left out of the test because this method is a combination of prototype a and b. The full setup, results and conclusion of the experiment can be read in appendix L.

The goal of the experiment was to test if people who had never seen the housings before would understand how the textile can be taken off. Intuitive understanding of their disassembly is important for consumers or recycling facilities who do not get any instructions when disassembling products. The better they understand this, the higher the chance that the materials will be separated and repaired or recycled accordingly.

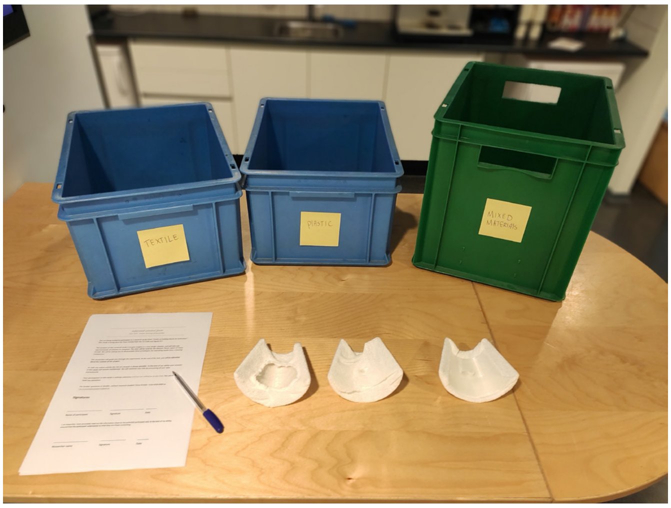


Fig. 6.22: Setup of the user test.

Validation was required to answer the following questions:

- Do people intuitively understand that the fabric can be taken off?
- Are people willing to put in the effort to disassemble the textile housing?

Five participants took part in this user test. It was found that the prototype with a textile cover (c) and with the single hook (a) were easily understood, but the clamp (b) was not. However, the clamp is considered the most viable solution for two reasons: the (dis)assembly process is executed in a single step which saves time in the process and the fabric is not likely to deform plastically because the stretching forces are divided over the whole surface of the textile.

If the clamping method is improved by adding use cues for the assembly, this method will become suitable for industrial application to create a circular textile housing.

The clamp of prototype b was redesigned to improve the intuitive understanding. The hook was replaced with an arrow. This figure points towards the direction in which the user can slide it to release the clamp. The arrow figure has some thickness which allows the user to get grip on when sliding the clamp in the correct direction....

Fig. 6.23: Redesign of the clamping method with arrow.

6.2.5 Clamping scenario

The scenario in this chapters illustrates how the clamping system can be used for easily separating the textile from the housing for repairing or recycling.

The textile housing is removed from the product.

The user is provided with a use cue for the disassembly: an arrow indicates how the clamp can be removed.

The clamp is removed by pushing it into the direction of the arrow.

The textile is unclamped from the housing.

The textile and housing materials are separated for accurate recycling of separate waste streams.

6.2.6 Clamping textile onto a continuous shape

The previously described prototypes focused on clamping a flat sheet of fabric onto a surface. These prototypes are part of the design of the Rotation Lamp concept. The clamping method can also be translated to textiles covering continuous shapes. Cylindrical knitted textiles are suitable to be clamped at the open ends. The pictures on the right show how clamping can be used for continuous surfaces as well.

Depending on the desired design of the product this clamp can fall either into the shape or be laid on top. When designing the clamping caps, tolerances need to be added between the surface and the cap to account for the thickness of the textile.

To prevent the caps from popping off when the product falls onto the ground, the design of these caps should be improved. With the use of snap hooks or a screw-system inside, this clamping system can become more robust.

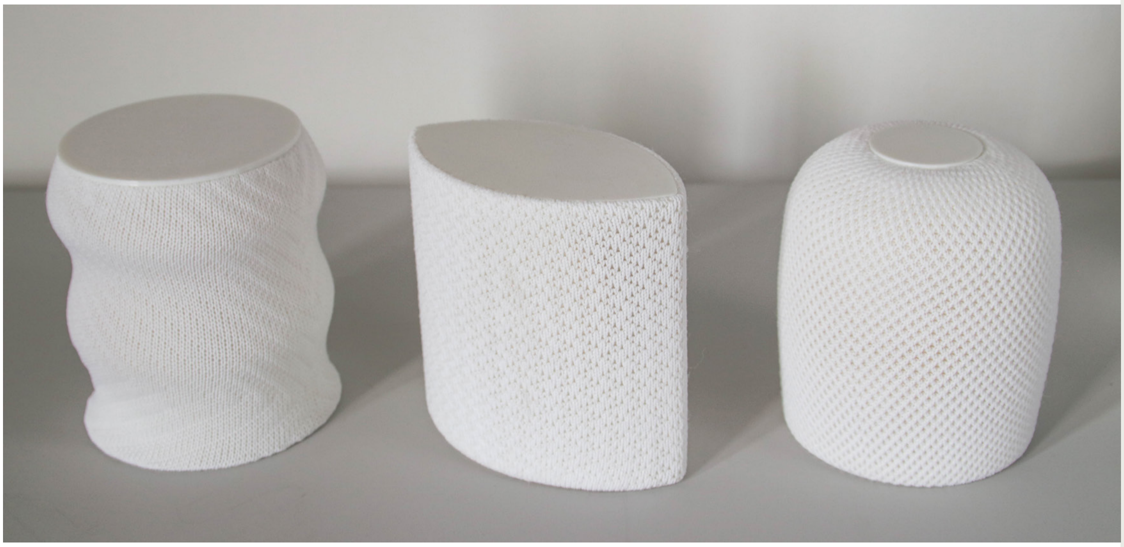


Fig. 6.24: Continuous surfaces with socks clamped to the shape.

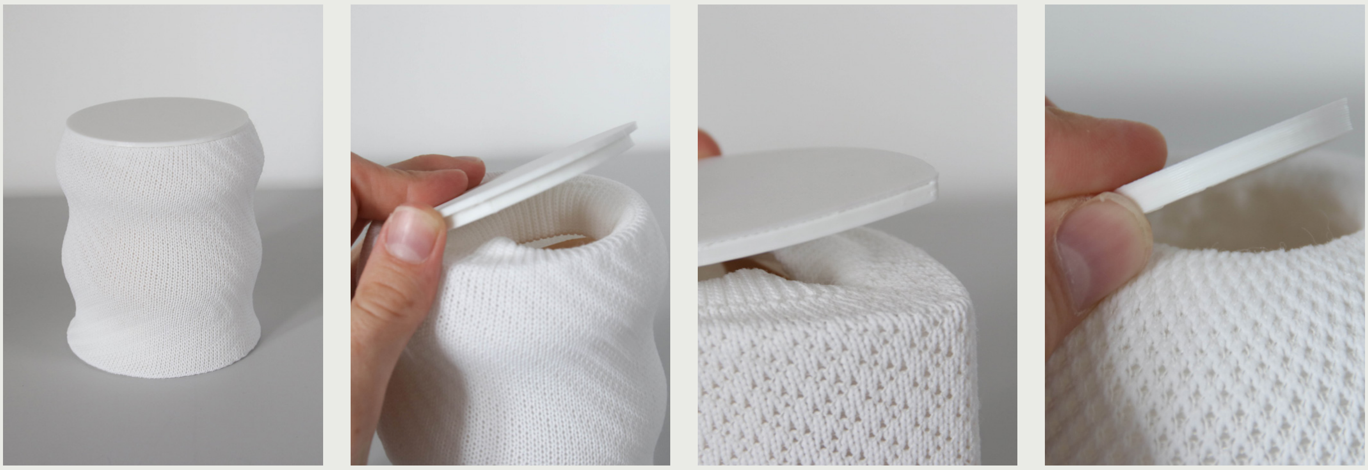


Fig. 6.25: Clamping caps for the wobbly shape, flattened cylinder and spherical surface.

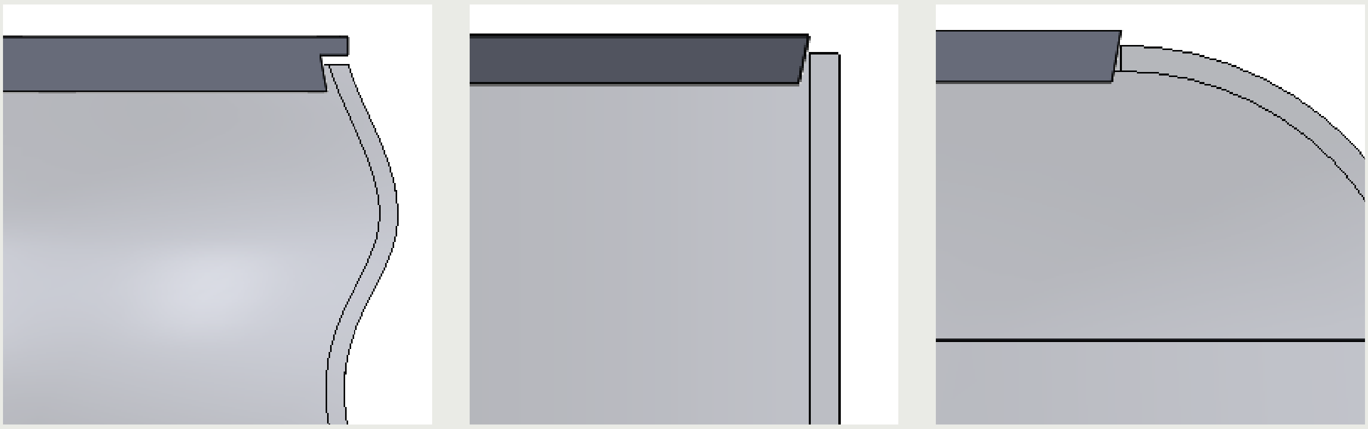


Fig. 6.26: Cross-sections of the clamping caps.

6.3 Sleeve

An easy way to cover a product with a textile look is with a sleeve. The look of the product can immediately be transformed without having to take it apart. The user can pick a colour that fits their interior and the sleeve can be changed anytime. By supplying these sleeves separately the user has to fit it over the product themselves, automatically informing them about the possibility of taking it off at the end of the products life span. This enhances the accurate recycling of the textile.

Stretchable knitted fabric suits this application. To follow the shape of the product accuratly 3D-knitting techniques can be used (see chapter 4.2).

This method can be observed in consumer electronic products. In the product detail photos of the Sonos Soundskin and Edison Petit Hoodie the changes in knit pattern can be seen in the places where 3D-shapes are formed. This method does not create a seamless product: the 3D knitted shape might require some stitching like is the case with the Edison The Petit Hoodie (see picturs on the right). This technique has a unique look with visible knitted structures and lines which should fit with the desired product appearance.

The products of Philips Hue consist of basic shapes which are highly suitable for a sleeve. Complex shapes would result in complex 3D-knitting processes.

3D-knitted shapes could be created with the help of textile engineers for example at the TextielMuseum in Tilburg. These experts helped with the development of the Sonos Soundskin. Depending on the desired optical properties the knitted textile can be tweaked to achieve a desired light effect or light transmission as was done for the Edison the Petit Hoodie.

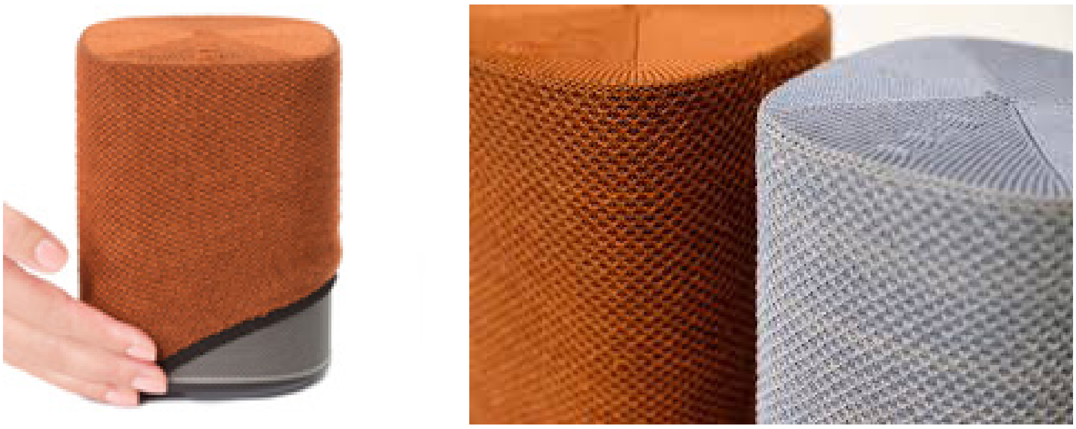


Fig. 6.27: Sonos Soundskin.

Fig. 6.28: Edison the Petit with Hoodie.

To demonstrate the use of a sleeve for a Philips Hue product, one was made for the Hue Go. For the purpose of the prototype this sleeve was sewn. For large-scale production this sleeve can be 3D-knitted in one piece. 3D-knitting is a highly suitable method to create a sleeve without generating textile waste as a result of cutting or sewing.

Fig. 6.29: Sew sleeve prototype for the Hue Go.

6.4 Comparison of fastening methods

Each fastening method has their own (dis) advantages. Here we will compare the methods on three topics: sustainability, design freedom, textile use and ease of implementation.

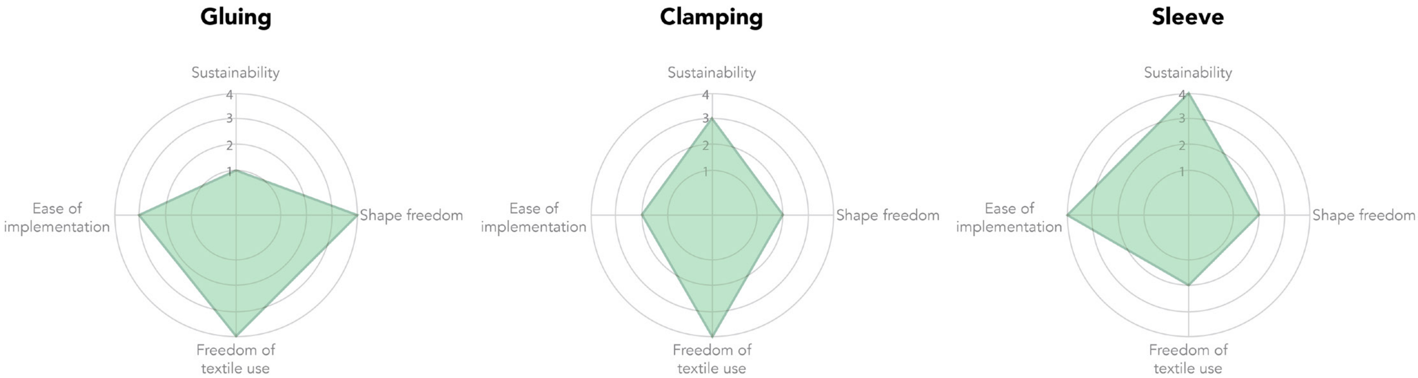


Fig. 6.30: Radar chart to compare the three fastening methods.

In the radar charts above the methods are visually compared. The scale for each axis goes from 1 to 4, where 1 means the worst and 4 the best properties.

A brief explanation of the comparison topics:

- **Sustainability:** the potential to easily disassemble the product for repairing or recycling. 1 means that the textile cannot be detached from the housing and 4 means it can be separated easily.
- **Shape freedom:** the design freedom of different shapes that can be made. At 4 all surfaces and tubular shapes can be made, convex or concave. At 1 only a few of these can be realised.
- **Freedom of textile use:** the possibility to use this method for woven, non-woven, flat knitted and circular knitted fabrics. For each textile type the method scores 1 point.
- **Ease of implementation:** how easily this method can be applied in the near future. 1 means new product development and additions to the supply base need to be realised. 4 means that the product design does not need to be adjusted and only one supplier is needed to create an add-on to the product.

From this comparison it was learned that if sustainability is not an issue the gluing method is most suitable. It has the most design freedom for shape and textile types and it can be easily implemented by a slight change to the product design and the addition of one textile application company.

However if Signify wants to take sustainability into account, it is wise to consider the clamping and sleeve method. These might have some disadvantages when it comes to design freedom and depending on the method it will take some investments to implement the textile integration but their disassembly potential is much higher.

Fastening methods

This report distinguishes the following three fastening methods to apply textile to the surface of a housing:

Gluing / welding:

Textile is glued over the surface and on the inner edges using an adhesive or ultrasonic welding.

The latter is only possible for synthetic textiles on plastic housings.

Clamping:

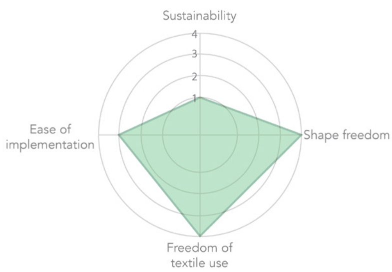
Sustainable alternative to gluing. Fabric is clamped onto the surface. A rough outer housing surface eliminates the use of glue for surface attachment.

This method creates a circular textile housing that is easy to disassemble, repair and recycle.

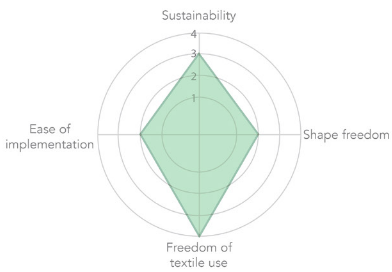
Sleeve:

A separate sleeve is (3D-)knitted and pulled over the outer housing of the product. It is not fixated to the housing.

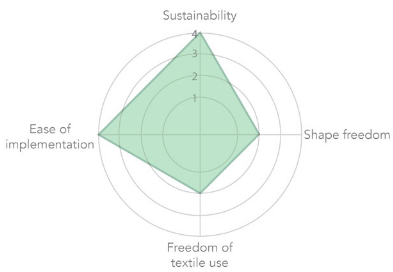
Gluing



Clamping



Sleeve



Comparing the methods:

Explanation of the assigned values in the radar charts above:

	Sustainability	Shape freedom	Freedom of textile use	Ease of implementation
Gluing method	1	4	4	3
	Gluing ruins the recyclability of the housing part, because it would require too much effort to separate the textile from the housing. Especially when the component is ultrasonic welded.	Gluing allows all shapes to be made, convex or concave. It is the only method for attaching fabrics to hollow shapes.	All textile can be used for this method: woven, non-woven, flat knitted and circular knitted.	The design needs to be tweaked slightly to give space to the thickness of the fabric. The textile can be applied with one supplier that glues it to the housing.
Clamping method	3	2	4	2
	Clamping allows the textile to be take off easily. The only obstruction for this to happen might be lack of knowledge or time to do this at the recycling facility.	Only convex shapes can be made with this method, since it relies on the stretching over a surface. This does not allow hollow shapes.	All textile can be used for this method: woven, non-woven, flat knitted and circular knitted.	The design of the housing needs to be changed to add a clamping component. A new application method should be designed to attach the fabric since.
Separate sleeve	4	2	2	4
	A sleeve can be easily detached: this can even be done by the consumers if clear instructions are included with the product.	Only shapes that are rotationally symmetrical or extrudable from a profile can be made	Ideally circular knitted fabrics are used. (Non-) wovens would require a visible seam. 3D-knitted fabrics could be an interesting option too.	The product design does not need to change. A knitting supplier can help with the design of a sleeve.

Chapter 7:

Product application

A new product concept was designed to demonstrate this application in the context of a Philips Hue luminaire. The design of this “Rotation Lamp” and the process towards creating this and four other product concepts will be explained in this chapter.

7.1 Design vision and requirements

Textile surface application is novel to the products of Philips Hue. It fits well with a new product category that Signify is planning to release. These products will focus on enhancing the users well-being. A touchable, warm textile luminaire would differentiate from the current portfolio of sleek yet cold looking products and fits well with this well-being proposition.

During a team brainstorm with Signify (see appendix M) it was discovered what elements should be incorporated in the new textile luminaire design. These are the following qualities:

- High quality
- Beautiful
- Unique user experience
- Easy to use
- Useful
- Want to touch it
- Fit with interior

To help define the purpose of this new luminaire a product vision was formulated. This product vision captures the qualities that the design needs to have in order to differentiate from existing luminaires and textile housing products and it was inspired on the employers answers during the brainstorm.

Through the research that was conducted in the discovery phase of this thesis it was found that taking into account sustainability is crucial in order for this product to be further developed and produced. This is important for the brand image as well as for the designers who wish to make a product with as little environmental impact as possible. In addition, a personal concern of the author for the environmental impact of a potential new product led to the inclusion of sustainability in the product vision.

The aim of the new product concept is captured in the following design vision:

"

Design a playful smart home luminaire that intrigues the user through a unique tactile experience and which can be recycled efficiently.

"

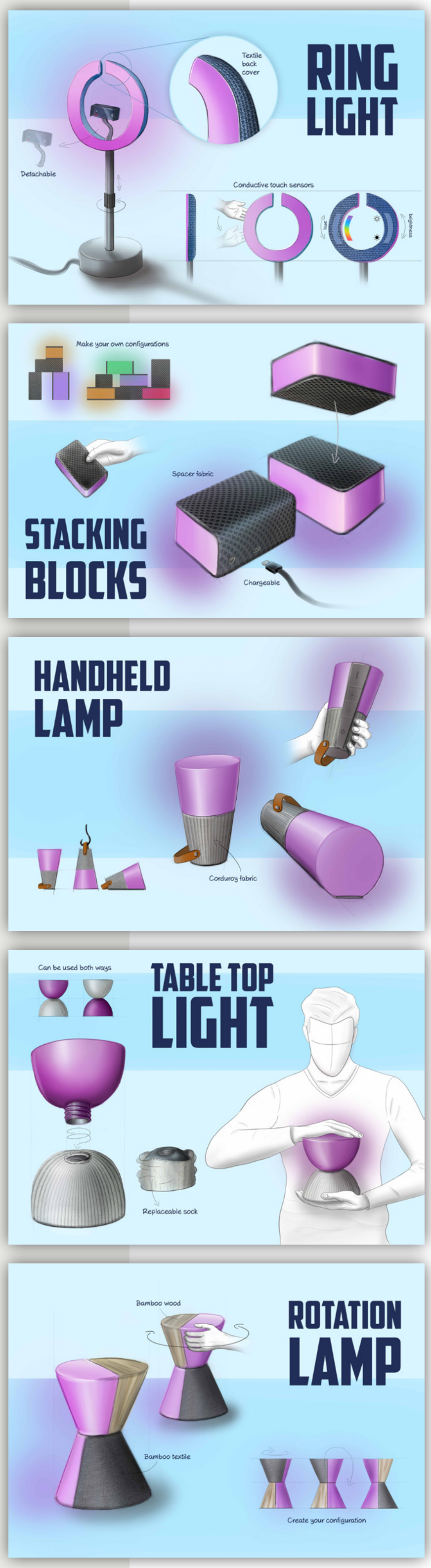


Fig. 7.1: Sketches of five product concepts.

7.2 Product concepts

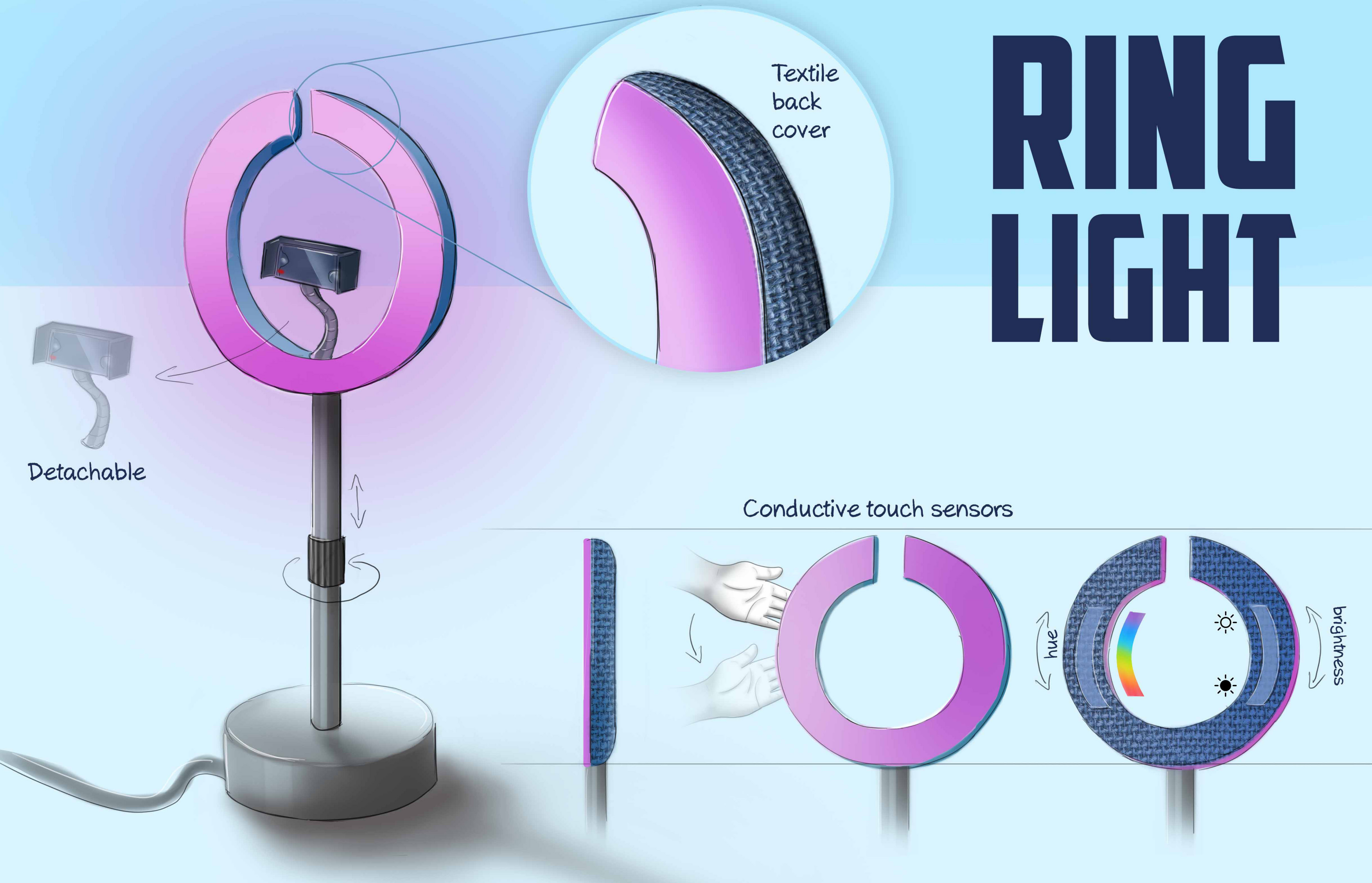
Five concepts were created. They were inspired on ideas from a brainstorm that was held with the Signify Textile Application Team (see appendix M). Larger images of these product concepts can be seen on the following pages.

During the midterm presentation it was unanimously chosen that the Rotation Lamp concept suits best with the expectations for a Philips Hue textile luminaire.

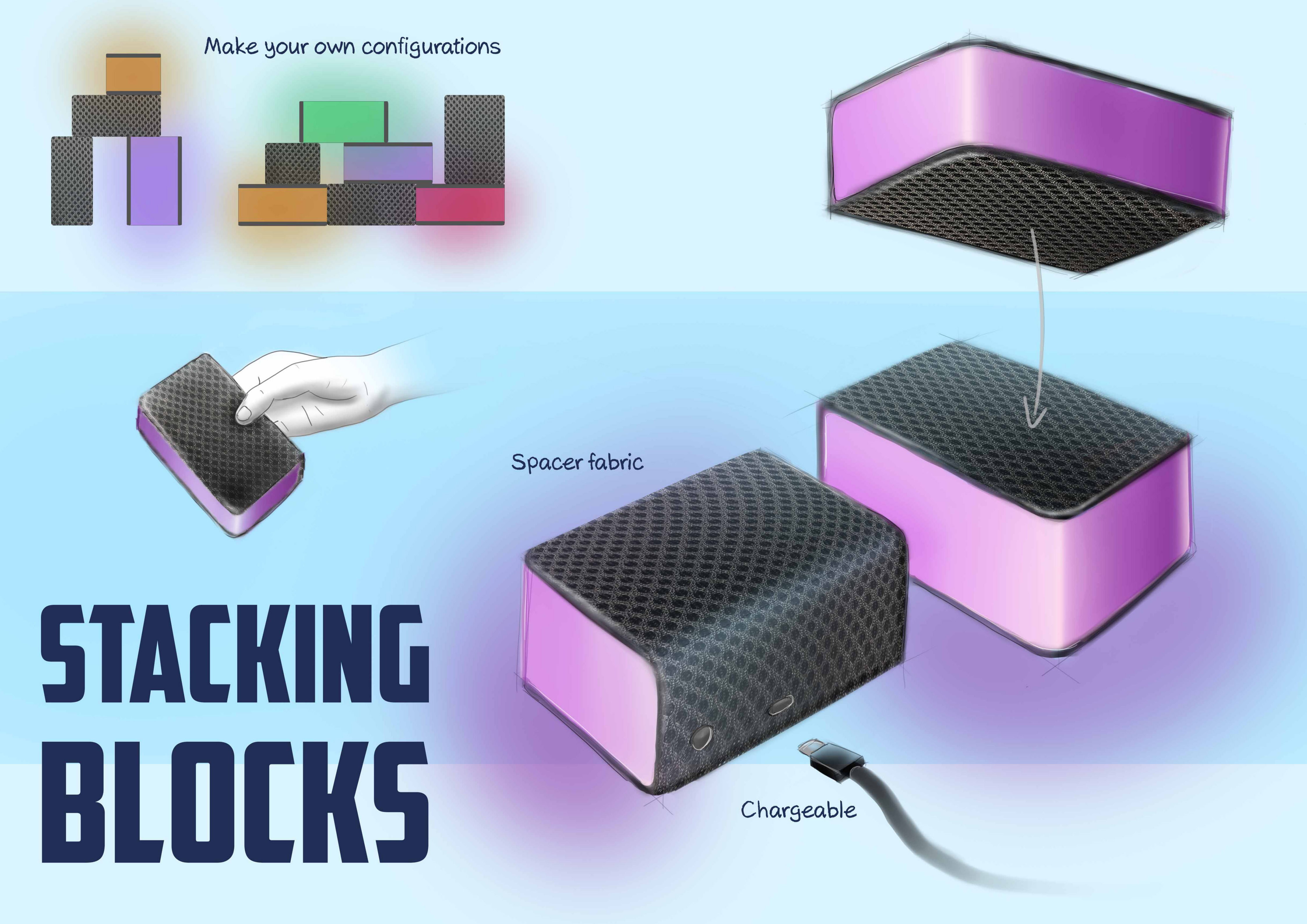
The combination of textile and wood creates a natural aesthetic. The rotation interaction allows the user to set the light to the orientation of their liking. This product is inviting to touch and the textile elements stimulate user interaction. Therefor the product can be kept close to the user to enhance their well-being.

This product was chosen to elaborate on and to use as an explorative tool throughout this thesis. It was chosen to focus on elaborating on the textile building blocks for the Rotation Lamp.

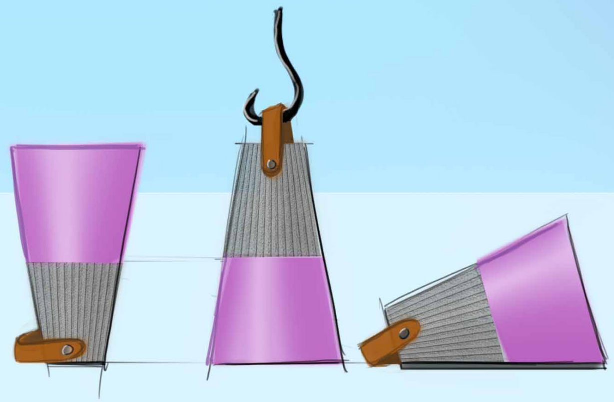
RING LIGHT

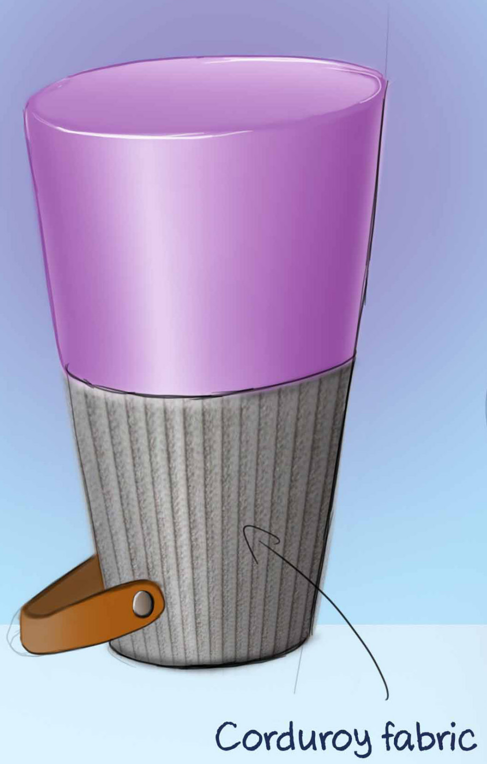


Textile back cover
Detachable
Conductive touch sensors
hue
brightness


Make your own configurations
Spacer fabric
Chargeable
STACKING
BLOCKS

HANDHELD LAMP





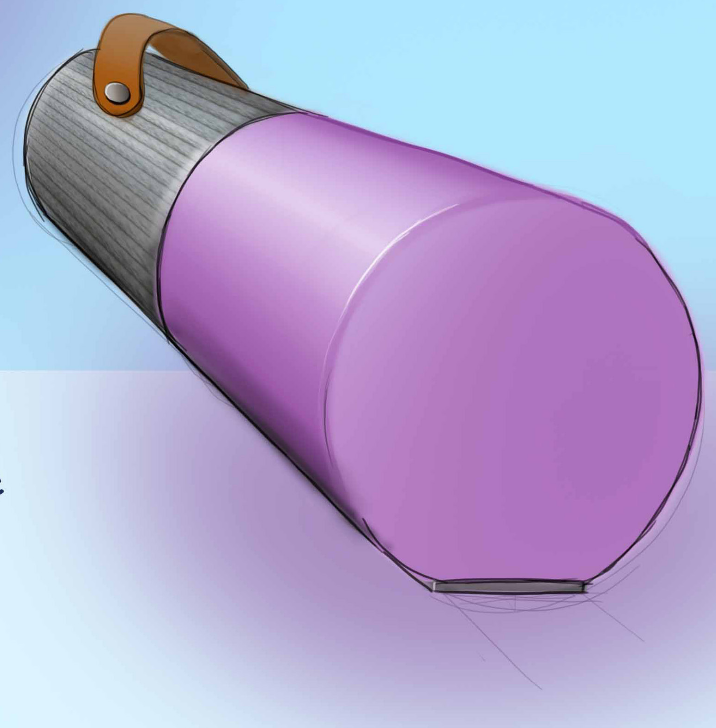
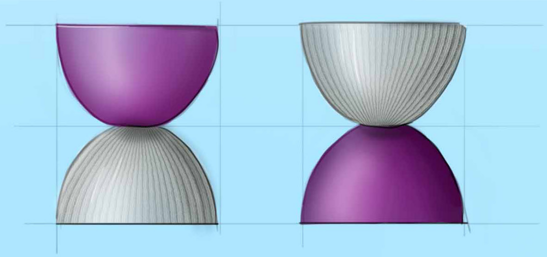
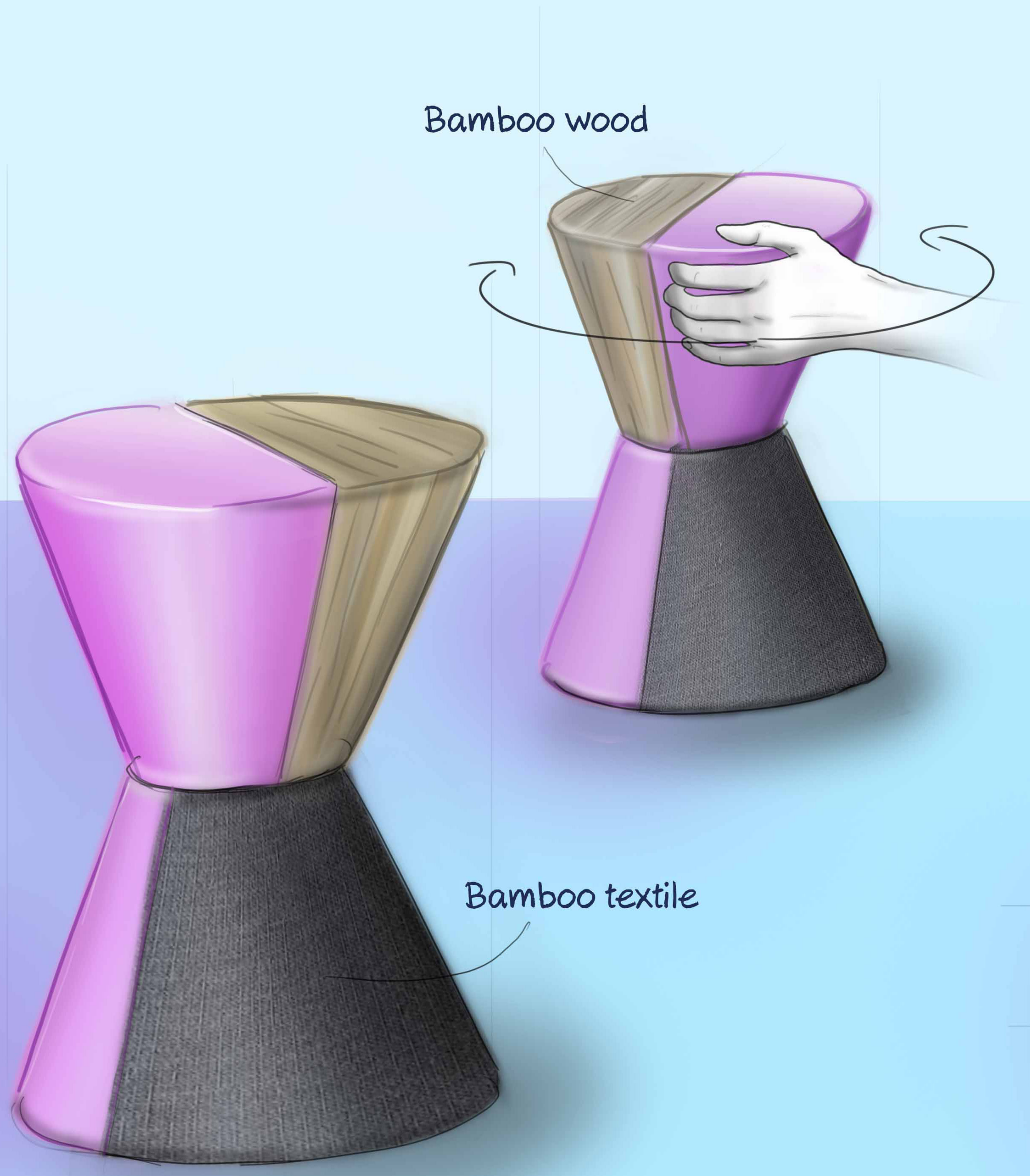
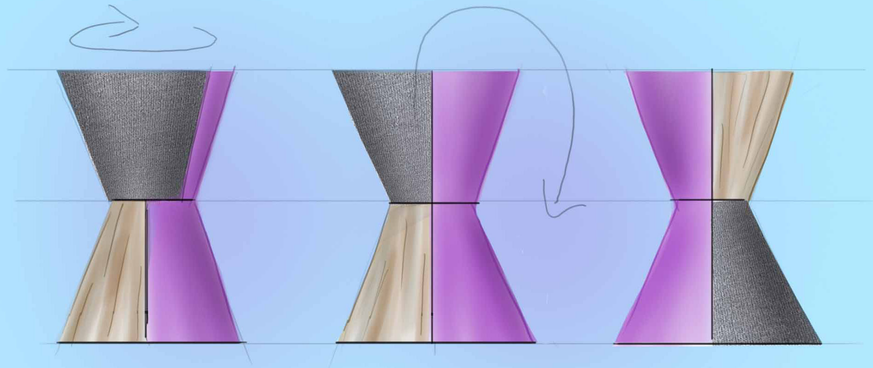


TABLE TOP LIGHT



ROTATION LAMP





Create your configuration

7.3 Rotation Lamp

From these five concepts the Rotation Lamp was chosen. This product suits best with the intention of Signify to create a Philips Hue product that has a natural appearance. This chapter will explain the product concept in further detail and describe the prototype that was built.

7.3.1 The concept explained

The rotation lamp concept was meant as a playful product that is inviting to touch because of its soft-looking textile components. The top and bottom part of the hourglass-shaped product can be rotated relative to each other. This rotation user interaction is evoked through the textile appearance of the top cap and side conical part. In future versions of the product this rotation movement might even be used to dim or brighten the light to provoke even more user interaction.

This luminaire can be kept closer to the user than other light sources such as ceiling- or wall-fixtures. The table-top lamp will enhance the users well-being through providing them with the customizability of room ambience and desired light levels.

The top and bottom contain a separate light source and this allows the user to direct the light on two surfaces. Both light sources will contain a White and Colour Ambiance (RGBW) LED board. This is a design rule that was set by the Philips Hue brand to create consistency in their product appearances. It is not possible to integrate two different light sources in one product. With the Hue app both light sources will be separately controllable with the Hue app to emit different colours of light.

The bottom part can be directed towards a wall to create reflected ambient lighting. To achieve this effect only one tenth of the cone consists of a light emitting element. This small ambient light source will not be visible when directed away from the user towards for instance a wall, preventing glare from happening.

The top diffuser can shine on a working surface like a desk. Half of the cone consists of a diffusing material to let light pass through. This creates a large luminous surface for shining light on the users workspace.

Fig. 7.2: Render of the Rotation Lamp.

Fig. 7.3: Prototype of the Rotation Lamp with three sets of textile housings.

7.3.2 Prototype of Rotation Lamp

The focus of this product concept is to develop the textile housing components. Therefor a prototype was made of the Rotation Lamp with two components which are covered with textile.

This prototype is 80% of the size of the intended product to speed up the prototyping process. All housing components are 3D-printed and reducing the size allowed for quicker printing of the elements for iterating. The size was large enough to realistically assess the qualities of the product.

The side cone and top cap are made easily detachable from the prototype. This way they can be interchanged to see the difference varying shapes and textiles can make to the overall product appearance. These different cap shapes were used to analyse the surface coverage limitations of textile.

To cover both top cap and side cone with textile 0,1m2 of fabric is needed. Through conversations with a suitable textile supplier it was discovered that for luxury fabric the costs are €25/m2 (textile supplier: Kvadrat). This means that the textile for a single product would cost €2,50. However there are many cheaper alternatives available.
To get more insights into the costs for industrial application the fastening method should be chosen and suppliers should be acquired.

Light was integrated into the bottom part to make a functional prototype. This allowed the textile components to be experienced in their real context.

The bottom diffuser is directed towards the textile housing. As a result, the light shines on the top side cone. For this reason it was decided to use white textiles that do not influence the colour perception caused by colourful reflections.

Fig. 7.4: Light in the bottom of the Rotation Lamp prototype.

The shape of the top cap in these extra components varies to create caps which are easier to grab. For more information about this, see chapter 5.3. There are three shapes: a flat cap, spherical cap and the easy grip cap. The latter two caps are designed to be comfortable to grab with one hand. The prototype is 80% the size of the intended product and the caps for the full-size product are expected to be easier to grab as well.

The prototype was made with three sets of textile housings. These textile building blocks can be interchanged in the prototype so different overall aesthetics can be created. All building blocks succeeded in creating the soft natural, inviting-to-touch appearance that was required. The easy grip cap helps to visualise the expansion towards more organic shapes besides the basic four shapes that were identified for Philips Hue products (cylindrical, conical, spherical, rectangular).

This prototype can be used to kickstart the next step of the design phase. With this prototype Signify can research the behaviours and expectations of a consumer on textile surface finishes for a Philips Hue luminaire to identify how this can be used to design a desirable new product.

Corduroy with flat cap:

Spacer fabric with spherical cap:

Knitted fabric with easy grip cap:

7.3.3 Textile-wood combinations

The natural appearance of this product is defined by the wooden and textile elements. In this research all textiles are white in order to make equal comparisons. However, different shades of white are used because it was not possible to acquire fabrics in the exact same colour.

Through experimentation with wood-look panels and fabric, inspiration was gained for the design of the rotation lamp. The fabrics and woods were also placed next to a plastic material, because the diffuser of the new luminaire is likely to be made of plastic.

The following things were learned from this experimentation:

- Shiny plastic does not match the matte look of the textile. The textile creates a homely, warm feeling and high-gloss materials do not fit this look.
- The plastic should not have too much visible structure when the fabric also has a defined texture. This creates too much texture to have a minimalistic sleek-looking product.
- Warm colours are more beautiful with wood than crisp white fabric and plastic.
- Dark coloured wood creates a deep contrast with crisp white textile.

If a wooden textile luminaire would be developed for Philips Hue, further experimentation with the combination of these materials is required.

Fig. 7.5: Colour combinations with textile, wood and plastic.

Chapter 8: Roadmap for future application

This chapter contains a roadmap for the near future application of textile in Philips Hue luminaires which can start immediately after this thesis has ended.

This thesis explored many facets of textile application for implementation to housing of products. The designers of Signify are provided with a tool, the Design Decision Tree, which guides them through the most important insights about textile, shape and fastening. They are also provided with the tangible prototype of the Rotation Lamp to explore user interaction.

At the end of this project the following steps can be taken to realize textile application for use in Philips Hue products. These steps are visualized here.

End of this thesis.

- Decide on Philips Hue product design for textile application.
- Define the envisioned textile look that the product is supposed to have.

2023

- Use Design Decision Tree to discover how textile can be used for the application.
- Get in touch with textile experts.
- Explore the optical properties of textiles for using textile as diffuser material.
- Invest in the development of the design of the desired fastening method.
- Prototype textile housing building block for new product design.
- User testing with the prototypes.

2024

- Iterate on the design to improve.
- Finalize the textile luminaire design.
- Acquire the supply base for industrialization of the design.

2025

- Produce first batch of new textile luminaire.
- Collect consumer reviews on the new product.
- Improve product if necessary.
- Start applying textile surface finish building block to more Hue products.

Implementation of textile building block.

Chapter 9: Conclusion

This chapter will answer the main research questions and sub-questions. The main question that this thesis is aiming to find an answer to is:

> ***"What design guidelines should be taken into account when textile is applied as a finish to the outer housing of a Philips Hue luminaire?"***

The main question was subdivided in three categories which each contain a specific area of textile surface application: textiles, shape and fastening. For each category a sub-question was formulated. By answering these sub-questions the main question is answered in the process.

- *Textiles: chapter 4*

  What kind of textiles can be used for application on product outer housings?

Woven and knitted textiles are suitable for application on surfaces of products. Non-wovens are not suitable because of their appearance and required minimal thickness.

Woven fabrics can be applied to developable surfaces because no stretch is required. Non-developable surfaces require stretchable knitted textiles or post-processed textiles. Knitting can also be used to produce tailored 3D-pieces that do not require cutting the textile before application.

- *Shape: chapter 5*

  What shapes can be achieved with textile when applied to the outer surface of a product?

The shaping possibilities of textiles can be divided in two categories: covering surfaces with flat sheets of textile or circular knitted pieces.

Depending on the shape of a surface, different textiles are required. The Design Decision Tree can be used to get an in-depth overview on the design considerations for each type of surface. (See chapter 1.3.)

- ## *Fastening: chapter 6*
  How can textile be fastened in a way that it can be taken off easily for repairing or recycling?

Currently most textile housings are produced by gluing or welding the fabric to the surface of the component. This however obstructs disassembly and therefor easy repairing or correct recycling. This thesis proposes an alternative solution. Clamping the fabric onto a housing component facilitates easy disassembly and it omits the use of glues that would contaminate the material waste streams. The clamping system contains clear use cues to be disassembled without any instructions.

Another method to cover a product with textile without mechanical fastening is to create a 3D-knitted sleeve. This is a separate textile layer which does not require alterations to be made to the design of the product.

The three methods discussed in this thesis are compared on three areas. If this application is to be executed in the short-term, gluing is advised. For sustainability purposes it is advised to further develop the clamping method or to create a separate sleeve for existing Philips Hue products.

All in all, this thesis elaborated on the design guidelines that need to be taken into account when applying textile as a surface finish to product housings. The research was focused on the use of textiles, shaping possibilities and fastening methods. The Design Decision Tree can be used to guide the reader of this report through the most important insights for textile applications. This tool will help the designers of Signify to kickstart the design phase of developing a textile housing luminaire for Philips Hue, preferably in a more sustainable way than is currently being done.

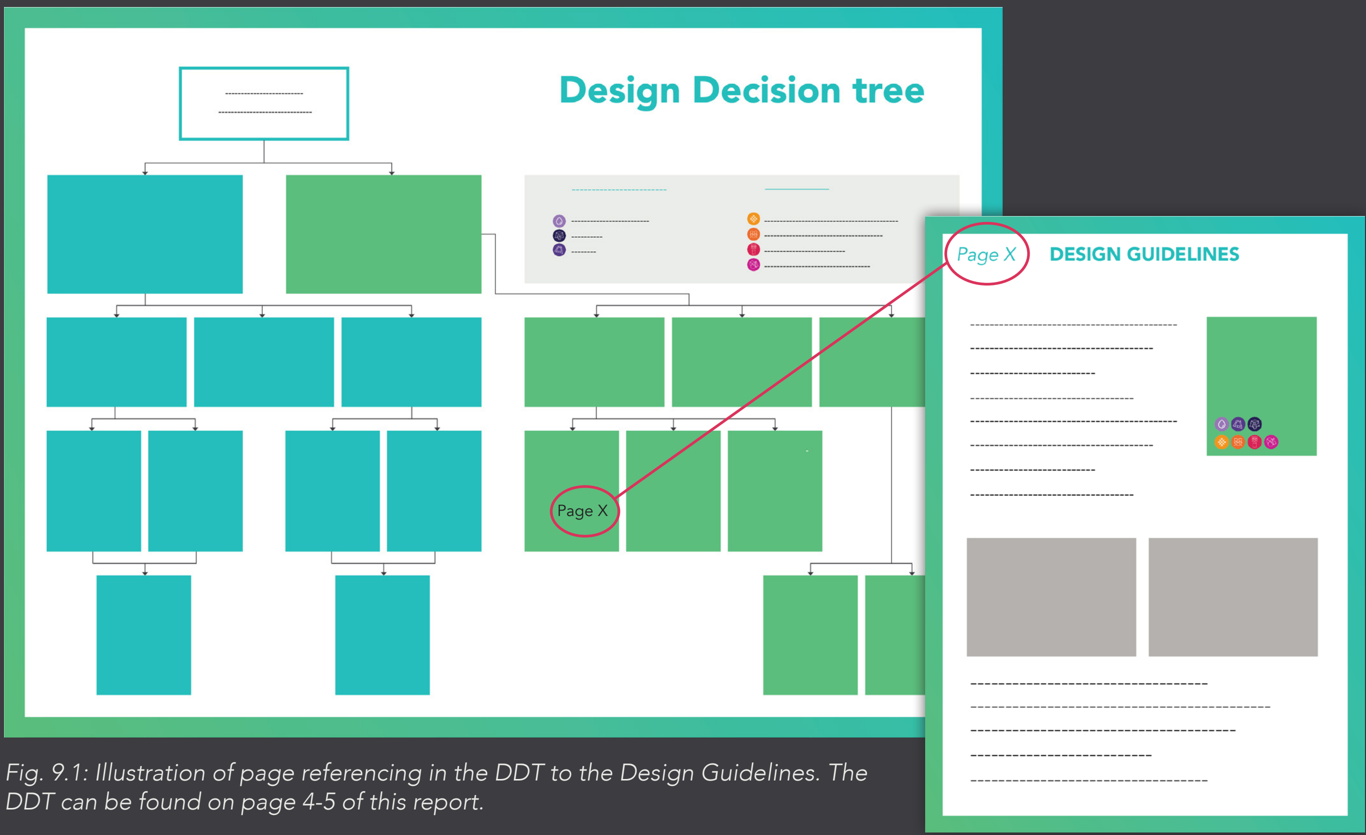


Fig. 9.1: Illustration of page referencing in the DDT to the Design Guidelines. The DDT can be found on page 4-5 of this report.

Chapter 10: Discussion

The sub-topics of this report explored the main areas of knowledge required to start designing a textile housing luminaire. The project was able to make a valuable contribution to the start of the design process for Signify by exploring the first crucial elements. A designer from Signify who was involved in the team meetings of this project confirmed that the Design Decision Tree will be of great use in the design process that will follow after this thesis.

Sustainability was initially not raised as a focus point in the project proposal. During the research sustainability issues with the current production methods for textile housing were addressed. This project was able to propose a circular alternative fastening method which can be implemented in the design process at an early stage, namely by clamping the fabric to the housing. Considering the environmental awareness of consumers and rise in demand for sustainable products, this would be a strategical step for Signify to take.

Besides the added marketing value of the sustainable fastening method there is another increasingly important incentive for Signify to start designing circularly: worldwide governments are developing policies and legislation for the transition into a circular economy.

An example of such a policy is the Extended Producer Responsibility which stimulates packaging producers to take responsibility for post-consumer waste (Extended Producer Responsibility, n.d.). In the Netherlands this policy among others has led to a law that allows consumers to receive a deposit on small PET bottles in 2021 and at the end of this year (2022) for cans as well. This has resulted in the increase of the collected amount of small PET bottles from 20% in 2010 (Stichting Ons Statiegeld, 2010) to 80% in 2022 (NOS, 2022). It is likely that this deposit system is translated to consumer products in the future, considering its effectiveness for recycling purposes.

Another law that will influence the product designs of Philips Hue in the near future is the Right To Repair. The European Parliament is planning to introduce proposals for this legislation in the third quarter of 2022 (Šajn, 2022). Governments on several continents are working on similar legislations which will stimulate companies to design products in a way so users can replace broken parts themselves, or they are facilitated with services which can do that for them. (Camberlain, 2022). Signify should not wait until these legislations are executed: circular design thinking should immediately become an important part of the design process of each component of their luminaires.

The circularity of the design of the clamping method is an immediate step forward into the right direction for these legislations. Signify will set a great example for other industries which use textile as a surface finish such as producers of Bluetooth speakers or car upholstery panels. Signify can become a pioneer in the field of sustainable textile housing products by integrating this novel method into their products and setting a great example for other companies.

Chapter 11: Recommendations

This research laid the foundation for a more sustainable of way of incorporating fabrics in product designs. The first results are promising and additional research can focus on validating and improving the design of the clamping method. It can be evaluated in collaboration with refurbishment or recycling facilities.

The Design Decision Tree can be validated with the designers of Signify and complemented with newly acquired information in further stages of the design process. The DDT can also be used by other designers who want to apply fabrics as a surface finish. Ideally the knowledge will be shared with others to allow them to learn about the application and ideally to incorporate sustainability in their design processed as well.

More research can be conducted to determine what housing surface structures can be produced industrially to create the hook and loop effect used in the clamping method. How can this effect be created in injection moulded parts for instance? Or should the part be treated afterwards with brushing, sanding or another surface treatment method? This knowledge will help to develop this method for industrialization.

For application in luminous textile housing element, the clamping mechanism should be adjusted. The current mechanism does not allow light to pass through without showing the clamp and folds in fabric. These issues can be resolved through a different design of the clamping system.

This research summed up different fastening methods that can be used. With this knowledge Signify can make an informed decision on what method to apply to their products. This choice determines which suppliers should be acquired in their network. For example if the sleeve method is chosen, Signify can start a collaboration with textile experts to design a fitting 3D-knitted product. If the clamping method is chosen investments can be made into the design and development of this system. This is highly advised, considering the novelty and competitive marketing advantage that Signify gains when consumers understand the added sustainable value of easy disassembly.

Besides the three main fastening categories discussed in this report there could be more ways to go about. An example that was not broadly described was the use of sewing as used in the leopard speaker. This method was not elaborated on because of the visible seam that it creates which results in an undesired surface appearance. If ultrasound welding is used to create an invisible seam like used in the Google Hub, this method could broaden the possibilities for using non-stretch fabrics to create non-developable surfaces. Lastly, pre-shaping methods for fabrics such as thermoforming to create more shape freedom could be interesting to explore.

Fig. 11.1: Sewn sleeve of the leopard speaker with visible seam.

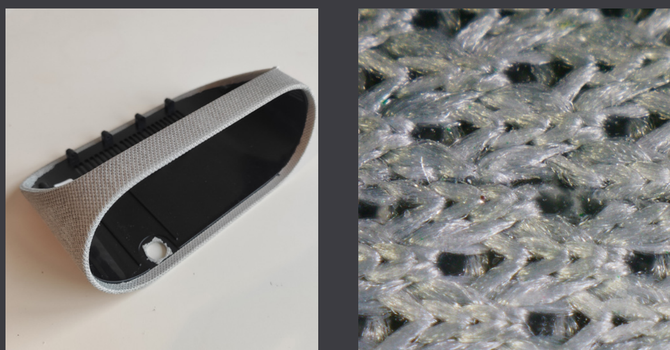


Fig. 11.2: Invisible welded line in the Google Hub.

More types of fabrics are suitable for surface application than were discussed in this thesis. One type that was left out of this report are stretchable woven fabrics. More elaborate research on textile types could be executed, preferably with a textile expert. This is a type of expertise that Signify is lacking at the moment. This becomes even more relevant when the next step towards translucent fabrics will be taken.

Besides textile types, more research could be conducted on the properties of textiles. The fabrics observed in the product disassembly analysis were mainly used in speakers and chosen because of their acoustical properties. These textiles have different requirements than those used in housings which do not let music pass such as for luminaires. Translucent fabrics for light diffusion are considered the next step by Signify. Finding fabrics with great optical properties will be a challenge in this following process. The use of coatings or additives in the textile manufacturing process could be explored thoroughly.

A logical next step to take by Signify is to decide on a product for the textile application. Considering the many possibilities for this application a concrete product design will help in narrowing the research. A concise design proposal will help to gain focus on the requirements for the desired luminaire design. This will help to realize textile application in the near future.

The sustainable clamping method discussed in this report focusses on enhancing easy disassembly for efficient recycling. It could be interesting to consider the possibilities for recycling the textile and plastic housing at the same time. There might be textile types available that are recyclable in the same waste stream as certain housing materials, omitting the need for disassembling the housing.

Specific requirements for the textile should be set. This will allow for exploration of textile with suitable properties like waterproofness, fire resistance, tear resistance and durability. The validation engineers of Signify can be contacted for gaining insights in these requirements.

The shapes of the Socks & Cylinders experiment were 3D-printed with transparent PLA filament. This allowed experimentation with light. When discussing these cylindrical shapes with others it visibly sparked attention. This is a type of curiosity that Signify would like to evoke at users of Philips Hue products. Exploring light through textile components was purposely left out of the scope of this project. After this project it is likely to be explored next because there is much curiosity for this topic within Signify.

Fig. 11.3: Shapes of the socks & cylinders experiment that allow light to pass through. This creates interesting optical effects on the textile patterns.

The current design of the Rotation Lamp allows control of the light via the Hue app. Hue products can be combined with a physical dimmer switch to control the products without a smartphone. In future research the addition of interfaces on the product itself can be explored so the user can control the lamp with a physical controlas well. In the disassembly analysis we observed buttons in the textile housing and these can also be applied to the Rotation Lamp. Further research can focus on investigating buttons and control elements, placement and overall integration into the textile housing elements.

Fig. 11.4: Outside surface of Fresh 'n Rebel Rockbox Bold S: button with pins can be popped off.

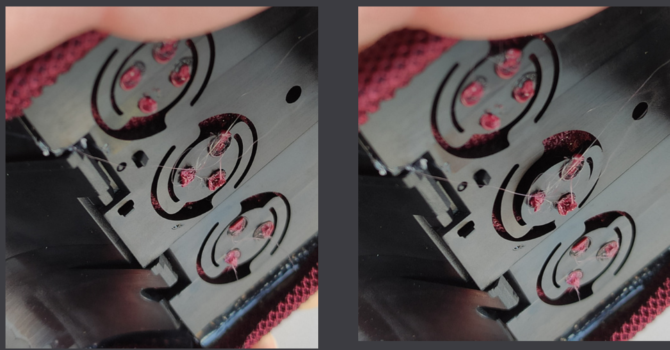


Fig. 11.5: Inside surface of Fresh 'n Rebel Rockbox Bold S: latches that bend inwards when pressure is applied on top.

The Design Decision Tree currently functions as a guidance throughout this report. To make the DDT more user friendly it can be digitalised. By creating a digital platform for this tool the user could be able to click the shape category boxes and be forwarded to the Design Guideline pages. In addition, a digital version of the DDT can be regularly complemented with newly gathered information. This would allow the DDT and Design Guidelines to be kept up-to-date over time as this textile application is further explored.

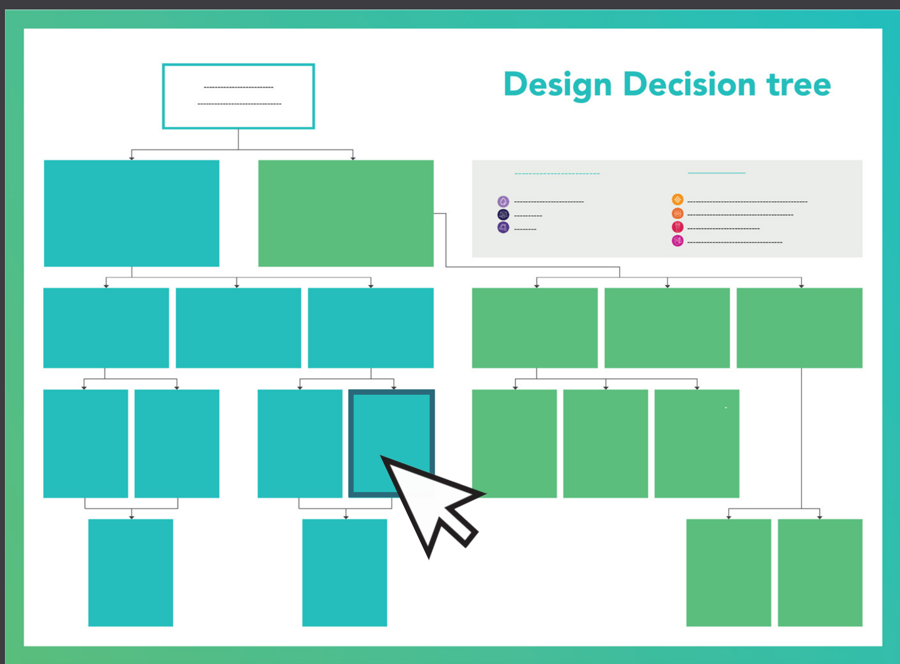


Fig. 11.6: Illustration of clickable content on a digitalized DDT.

Chapter 12: Reflection

This reflection was written by the author of this thesis, Tessa Arnold. It reflects on this graduation internship at Signify and this research that was conducted for the University.

A challenge during this thesis was to align the expectations of Signify and the TU Delft. The commercial motives of Signify did not always align with the research perspective from the University. Signify wanted to learn about concrete production implications such as costs and cycle time. This does not fully comply with the research-based approach of the University which stimulates out-of-the-box thinking for innovative design and which usually takes places in early stages of the design process.

What made this expectation management especially difficult was the composition of the Signify textile application team. This consisted of a project manager, designers, mechanical engineers, procurement engineer and an additive manufacturing and textile researcher. Each colleague had a different view on the priorities for this project. It was a challenging yet educational experience. I believe I managed to take the priorities of all stakeholders into account as far as possible. Most focus was naturally put on the design perspective of the project.

I discovered in an early stage of the project that textile application is a broad field of design. I chose to focus on textiles, shaping and fastening and this helped me to communicate my priorities and project boundaries to the Signify team.

At the start of this project I communicated that I wanted to focus on the embodiment of the design. I planned to do this by creating concepts and choosing one to focus on after the midterm. After the midterm presentation Signify indicated that they felt that focusing on this one concept would result in leaving too much unexplored about the general principles needed for textile surface application. Especially for more organic product shapes: my concepts were namely based on the basic shapes of existing Philips Hue products. Therefor I decided to shift focus from the design of the Rotation Lamp to creating an overview of possibilities. This resulted in the Design Decision Tree and the addition of the Socks & Cylinders experiment.

I believe it was a wise decision to change the focus of the project. It has helped to create a more complete understanding of the design possibilities for products that differentiate from the existing Hue portfolio. In addition it helped me to focus less on design implications which will become relevant in a later stadium of the design process (such as costs and industrial implementation).
It has created more room to innovate on sustainability by creating the clamping method to design a circular housing. I am proud of this sustainability contribution that I was able to make with my project and I hope that Signify will take on this circular design mindset for all of the coming Philips Hue products.

In this project I have been assertive in contacting suppliers and other companies to retrieve information. I believe that this has helped me to get a great view on the field of textile housing design. Lastly, I had much fun at Road2Work where I was warmly welcomed and where I could disassemble as many products as I wanted.

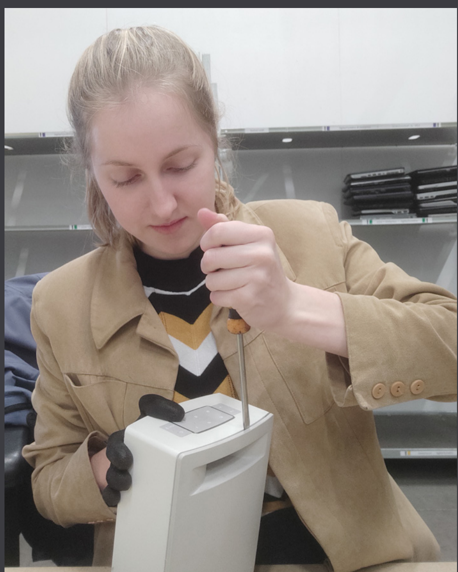


Fig. 12.1: The author of this report disassembling a product for the disassembly analysis.

References

Aaron O'Maley. (2018, July 7). *This thing sucks!!! - Philips Hue Wellness Table Lamp Review.* YouTube. https://www.youtube.com/watch?v=4dj5h7YysD4

Alessindrina. (2019, February 5). *Geometric shapes on ribber fabrics with tuck stitches 1*. https://alessandrina.com/2019/02/05/geometric-shapes-on-ribber-fabrics-with-tuck-stitches-1/

Amazon.nl. (n.d.). *Tiny Love Boho Chic Tiny Dreamer, Baby Starlight Projector Mobile.* Amazon. Retrieved April 29, 2022, from amazon.com

Annual Report 2020. (2020). In *Signify*.

Averinox B.V. (2008). *Knitted Spacer Fabric.* http://averinox.nl/images_up/averinox.nl/downloads/knitted_spacer_fabric_cd.pdf

Bendt, E. (2016). Shape and Surface: The challenges and advantages of 3D techniques in innovative fashion, knitwear and product design. *IOP Conference Series: Materials Science and Engineering, 141,* 12016. https://doi.org/10.1088/1757-899x/141/1/012016

Camberlain, E. (2022, January 19). *2022 Should Be a Landmark Year for Right to Repair.* IFIXIT.

Choi, W.-S., & Hee Lee, Y. (2010). Development of Three-Dimensional Knit Models through Rib & Purl Structures. In *The Potential of Knitting for Engineering Composites: a Review* (Vol. 16, Issue 2).

Engin, A. (2009). Comparative analysis for periodical and random servicing systems considering different working circumstances: A textile application. *Journal of Manufacturing Systems - J MANUF SYST, 28*, 89–97. https://doi.org/10.1016/j.jmsy.2010.04.001

Extended producer responsibility. (n.d.). OECD. Retrieved July 1, 2022, from https://www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm

Farshad, M. (1992). Introduction to Shells. In *Design and Analysis of Shell Structures.* Springer Science & Business Media Dordrecht.

Hallet, C., & Johnston, A. (2016). *Fabric for fashion : the swatch book : with 125 sample fabrics.* Laurence King Publishing.

IIT Delhi. (2019, August 16). *Weft Knit Stitches (Loop, Tuck and Float).* Youtube. https://www.youtube.com/watch?v=8ZFeXjwNhLQ

Justin_Tech. (2020, December 8). *Philips Hue Iris Review - A Work of Light.* Youtube. https://www.youtube.com/watch?v=pZtSzr17SPY&t=1s

Koenderink, J. J., & van Doorn, A. J. (1992). Surface shape and curvature scales. I*mage and Vision Computing,* 10(8), 557–564. https://doi.org/https://doi.org/10.1016/0262-8856(92)90076-F

Loom. (n.d.). Wikipedia. Retrieved May 29, 2022, from https://en.wikipedia.org/wiki/Loom

Loop formation on V-bed flat knitting machine. (2018, January 22). Wikipedia. https://commons.wikimedia.org/wiki/File:Loop_formation_on_V-bed_flat_knitting_machine.jpg

NOS. (2022, July 1). Na jaar statiegeld op flesjes: 80 procent ingeleverd, doel nog niet gehaald. *NOS.* https://nos.nl/artikel/2434807-na-jaar-statiegeld-op-flesjes-80-procent-ingeleverd-doel-nog-niet-gehaald

Popescu, M., Rippmann, M., Mele, T., & Block, P. (2018). *Automated Generation of Knit Patterns for Non-developable Surfaces* (pp. 271–284). https://doi.org/10.1007/978-981-10-6611-5_24

Ray, S. C. (2012). Flat bed knitting. *Fundamentals and Advances in Knitting Technology,* 101–116. https://doi.org/10.1533/9780857095558.101

Rehan Ashraf, M. (2014, August 9). *Weft knitting.* Textile Insights. https://textileinsight.blogspot.com/2014/08/weft-knitting.html

Šajn, N. (2022, May 20). *Right to repair.* Legislative Train Schedule - European Parliament. https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-right-to-repair

Signify. (2021, May 18). Signify 2020 - *Innovations for brighter lives and a better world.* YouTube. https://www.youtube.com/watch?v=jJOjxNrVzJM

Signify.com. (n.d.). *About.* Retrieved April 29, 2022, from https://www.signify.com/en-pk/about#:~:text=Signify%20employs%2032%2C000%20people%20in,%2C%20Lamps%2C%20Professional%20and%20Home.

Signify.com. (2019, October 29). *Introducing Philips hue: the world's smartest LED bulb, marking a new era in home lighting.* https://www.signify.com/en-gb/our-company/news/press-release-archive/2012/hue-launch

Simonis, K., Gloy, Y.-S., & Gries, T. (2017). 3D knitting using large circular knitting machines. IOP Conference Series: *Materials Science and Engineering,* 254(9), 92004. https://doi.org/10.1088/1757-899x/254/9/092004

Stichting Ons Statiegeld. (2010). *Milieu-impact: Percentage recycling.* Stichting Ons Statiegeld. http://www.echteheld.nl/milieu-impact/329/percentage_recycling#:~:text=Het%20huidige%20statiegeldsysteem%20resulteert%20in,van%20deze%20flesjes%20worden%20gerecycled.

The butterfly diagram: visualising the circular economy. (2017). The Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org/circular-economy-diagram

Underwood, J. (2009). *The Design of 3D Shape Knitted Preforms.* RMIT University.

Ziaei, M., Ghane, M. R., Hasani, H., & Saboonchi, A. (2020). Investigation into the effect of fabric structure on surface temperature distribution in weft-knitted fabrics using thermal imaging technique. *Thermal Science,* 24, 1991–1998.

Appendices

A. Project brief
B. Project proposal from Signify
C. Observational analysis: desk & field research
D. Visit to Road2Work
E. Disassembly analysis
F. Fabric ideation
G. Surface shape experiment
H. Ergonomics test with cardboard prototype
I. Sock samples from Esther Jubbega
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M. Team brainstorm
N. Product ideation

Appendix A: Project brief

Personal Project Brief - IDE Master Graduation

TU Delft

Textile as building block for luminaires — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 24 - 01 - 2022 — 15 - 07 - 2022 end date

INTRODUCTION **
Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Signify wants to develop a new type of luminaire. Their current products consist mainly of metal and plastic parts. To differentiate from their current portfolio they want to expand their knowledge towards the possibilities of integrating automated knitted textile into a consumer electronic product. The digitalization of the textile industry provides more design freedom in the production of textile and therefor creates new opportunities for innovative products.

Textile is suitable for Signify as a building block for a luminaire because of its modern and natural look & feel. Use of textile housing in consumer electronics is becoming more common: examples can be found in sound & music products from Bang & Olufsen or Google Nest (see pictures on the next page), however not yet as much in lighting.

I am asked to advise Signify on what path they should take to enter the market of luminaire products with textile components. They give me great freedom to explore this field of design and to expand their network of suppliers and partners. My interest as a designers lies in the field of consumer products with textile parts: this project allows me to learn how I can integrate my favorite material into electronic consumer products.

I will be an intern at the research & development department of Signify for six months. This department is lead by Joris Hagelaar. I will mainly collaborate with Matthijs Vreeman, who is the mechanical engineer of this team. I will experiment with knitted textile types, production methods and creating fastening connections between textile and housing parts. By proposing a new luminaire design, I will be able to connect stakeholders inside and outside of Signify. This will help them to create the required supply base for this product category.

Signify has recently collaborated with the Saxion University textile department to create knitted textile samples which will be presented at the beginning of March and these can function as a starting point for my exploration. Signify has an employer, Koen Van Os, who is specialized in textile production methods. Besides these stakeholders, I will also communicate with the designers, mechanical engineers and employers from other disciplines at Signify. Connecting with these people will allow me to broaden my knowledge of textile integration and luminaire design, as well as to learn to collaborate within a multidisciplinary team in order to realize an industrial design process. This way, I get the chance to develop myself as an industrial design engineer in a business environment.

space available for images / figures on next page

Initials & Name TWN Arnold Student number 4457838

Title of Project Textile as building block for luminaires

Personal Project Brief - IDE Master Graduation

introduction (continued): space for images

image / figure 1: Textile used in the housing of a Bang & Olufsen speaker.

image / figure 2: Google Nest with knitted textile around housing, allowing lights to pass through.

Personal Project Brief - IDE Master Graduation

TUDelft

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Signify does not yet have knowledge of how to integrate knitted textile with housing components nor the supply base to realize this into a luminaire. They have to know the production possibilities before they can decide if it's worth it to invest in setting up a costly process for a new product. It would also mean a shift of focus within the company and its expansion into expertise from metal and plastic products to textile building blocks.

Signify is wondering what product market specifically would be strategical to enter. My analysis of competitor products will help them find what products could give Signify competitive advantage in this growing business of products with textile housing.

They want to create an electronic consumer good that fits in their current product portfolio. The product is expected to be touched and must fit a specific user context which I can choose, for example a bedside light, table lights or wall panels: either for indoor or outdoor use. Depending on this context, the material must be dirt resistant, durable, waterproof and affordable to stay within the price range of other Signify products.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I will analyze the possibilities of integrating or fastening knitted textile onto housing components.
I will deliver a working prototype of a new luminaire product design with textile components.
I will create a roadmap for Signify for future implementation of this and/or other products in this category.

I will analyze the right textile materials, patterns, shapes, colors, look-and-feel, design constraints, mass production limitations and product application possibilities. I will do this by looking at current and new technologies.

With the design constraints in mind, I will create novel product concepts for Signify. In collaboration with the company I will choose and elaborate on the most viable concept. I will deliver a working prototype of this product, that I will use for user testing. Feedback from this evaluation will be processed in at least one iteration step to improve the design.

During the process I will collect insights from stakeholders inside Signify (employers from different disciplines and departments) and outside (Saxion University, partner companies, suppliers) in order to create the right supply base for entering this new product market.

I will NOT look into the industrialization of the knitted textile components, fabric manufacturing methods or the optical properties of light transmission and color shift on the surface of textile components in the luminaire.

The deliverables of my thesis will consist of: an analysis of the opportunities of using textile building blocks for the purpose of luminaire design, as well as a working prototype of a luminaire. I will also advise Signify on which steps to take for future industrialization of this product (roadmap) or other viable options.

Initials & Name TWN Arnold Student number 4457838

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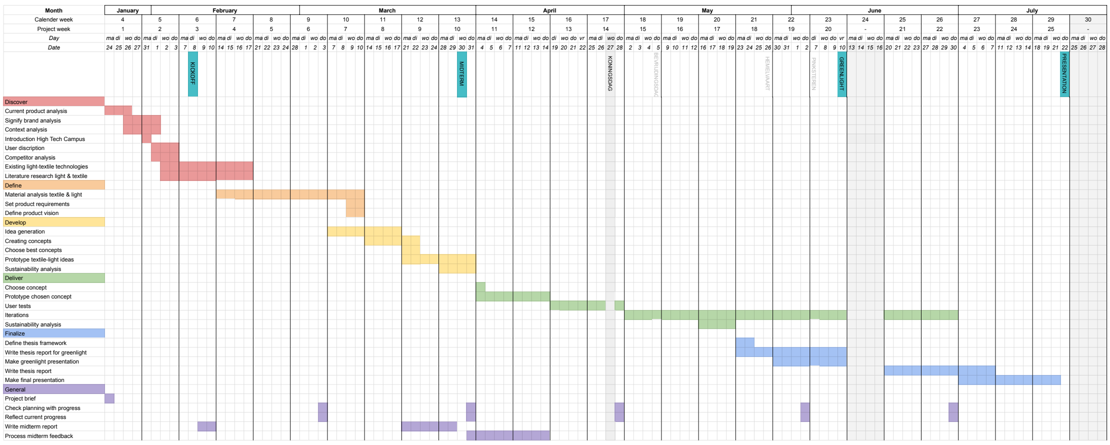
PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 24 - 1 - 2022 | 15 - 7 - 2022 end date



I will work 4 days a week, so the total duration will be 25 weeks.

I set up my planning following the double diamond design process. I plan a break of one week after the greenlight.

DISCOVER
I begin my project by analyzing the current product portfolio and users of Signify products. I will also look at competitors and novel textile integration technologies, in order to find viable market opportunities.
DEFINE
During this phase I'll set the design requirements. These will be influenced by how far into the future Signify would want to implement this product. I will already start some experimenting to get a good feel of the textile materials and some possible production processes.
DEVELOP
When I have a good view of the market opportunities, current product portfolio and users as well as hands-on experience with the materials, I will start designing concepts. I will choose the most viable concept to elaborate on immediately after the midterm presentation.
DELIVER
As an IPD student I am drawn towards the embodiment design part of the of the design process. It's what I enjoy the most and where I see myself working in after I graduate. Therefor I put emphasis on this phase during this graduation project. The largest part of my process purposely consists of developing, testing and iterating on a luminaire design.

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TU Delft

Personal Project Brief - IDE Master Graduation

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I am very grateful for this opportunity to graduate at Signify. The topic of integrating textile into a product design suits my interests as an industrial designer very well. I have 10+ years of experience with using textile to make clothing as a hobby and during my studies I always looked for opportunities to involve textile into my designs and research:

- For the course Advanced Concept Design I designed and fully prototyped an innovative food delivery backpack.
- During my internship last year I improved the production process of sustainable bags for which I created instruction manuals. I also visited multiple sewing workshops to educate myself about clothing production in the Netherlands.
- While following the elective course Lighting Design I researched the influence of retail lighting on the perception of fabric quality through literature as well as experimenting.
- For the Research elective course prior to this graduation I analyzed the possibilities of integrating optical fibers in fabric to create luminous cloth. The acquired knowledge of textile production methods will be very useful.

This project at Signify offers me the ultimate opportunity to use my knowledge of textiles and implement this in an industrial product design. The challenge for me lies in the integration of textile with components from rigid materials: contrary to the projects stated above, this luminaire will consist of more than only textile parts. I have gained extensive experience in designing rigid components with CAD software during my Bachelor and Master, so I believe that this project will be the logical next step towards integrating my design engineering skills with my interest in textile components. Therefor, I put the focus on the embodiment design phase.

I believe I can differentiate myself from other IPD students that graduate because I have specific knowledge about textile that help me make realistic choices during the design process, based on experience with the material as well as some knowledge on the production processes. During my graduation I will be able to learn in greater detail how I would like to use my skills in my future career: where my strengths and weaknesses as a designer lie.

My ambitions during this graduation course, are as follows:

- Learn to work with and communicate my ideas in a professional multidisciplinary design team at Signify.
- Gain more experience with 3D modeling programs (SolidWorks & NX Edge) to communicate my ideas.
- Focus on the embodiment design of the luminaire product by prototyping and iterating on a working model. To achieve this, I need to lower the threshold for myself to start prototyping. I tend to wait until I fully understand the methods and materials. I want to use the facilities at my University as well as at Signify.
- Learn how to take a product design past the concept phase. When a certain level of embodiment is achieved I can say something about the costs, manufacturing and mass-production. This is important information for Signify.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Depending on the Corona measurements, I will work remotely as well as at the office. Ideally I work 1 or 2 days at the High Tech Campus in Eindhoven and the other days at the University in Delft or at home.

Appendix B: Project proposal from Signify

One-slide project proposal

Textile as building block for luminaires

Which needs are we addressing

1. *As leader in lighting it is our ambition to innovate in different materials & finishes in luminaire designs. Textile has special attention, because of the soft natural appearance.*
2. *Luminaire development teams, who are currently not able to realize a design based on textile, as throughput time, required effort and risk are too high to handle in an NPDL.*

Business motivation

- *Digitalization of the textile industry provides more design freedom in textile, eg by different knitting patterns and shapes.*
- *Use of textile in housings of consumer electronics products is becoming more common. Examples can be found in B&O products, Google Nest, etc. But not yet in lighting*

Problem statement

- *The wish to use textiles as material & finishing for luminaires is already present for some years, but we don't have the supply base and the knowledge on the critical aspects for a successful application in luminaire products.*
- *Next to look-and-feel, aspects considered to be important are strength, mechanical interfacing, dirt resistance/cleanability and resistance to discoloring*
- *Due to all these uncertainties, use of textile never fits in the scope of a luminaire development, throughput time is considered too long, and risk too high.*

Where will the results land, E2E Landing spot:

Hue luminaires that are in reach of the end-user and expected to be touched / handled eg bedside light (2023/24), table lights or Spring panels

Main deliverables

Enable textile to be used in luminaire designs by:

- *Benchmarking of competitor articles with textile in consumer appliances. Focus on mechanical interfaces, applied materials and fabric (knitting) patterns.*
- *Explore the design possibilities and limitations of automated knitting (e.g. CMS ADF by Stoll) and define design guidelines*
    - *Finding the right materials / treatments that enable handling / dirt resistance / cleaning*
    - *Understand aging mechanisms and temperature application limits*
    - *Mechanical interfacing towards luminaire*
    - *Shape, patterns and size limitations (use mock-ups to demonstrate possibilities).*
    - *Costs / Cycle times*
    - *Define possible application range (indoor/outdoor/bathroom..) and check for future applications in the roadmap*
- *Definition of lead carrier project for textile introduction. In consultation with Design (Lieven)*

Out of scope

- *Industrialization and release of the knitted physical building block*
- *Optical properties, such as light transmission and color shift in case textile is used on the light emitting surface of the luminaire.*
- *Processing of other fabric manufacturing methods*

I2M Process type: Advanced development / Architecture & Platform creation

Timeline: 2021-H2 & 2022- Q1

Stakeholders: Joris Hagelaar (R&D lead), Lieven Verdin (Design), Ronald Wienia (Procurement), Hidde Schipper (Product Manager), Koen van Os (Lead Development Engineer)

Project lead: Matthijs Vreeman

signify

Appendix C: Observational analysis: desk & field research

C.1 Desk research

A visual overview of the textile products which were found online. The products which were later observed in the field research are omitted to prevent redundancy.

Amazon Echo dot 4th gen

Amazo Echo Dot 3rd gen

Amazon Echo plus

JBL Link Portable

askdjsads,mf

JBL Link Music

JBL Playlist

Apple Home Pod Mini

Apple Home Pod speaker

Acer Halo

Bang & Olufsen Beosound Balance

Bang & Olufsen Beoplay

Bang & Olufsen Emerge

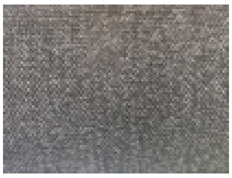
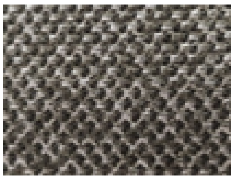
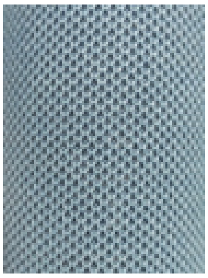
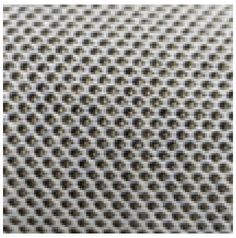
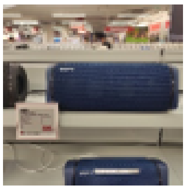
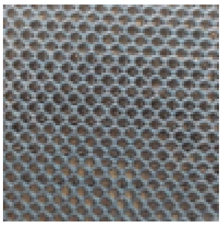
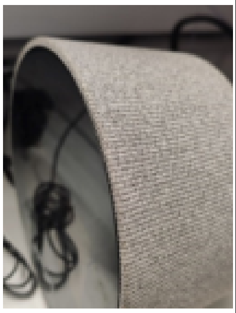
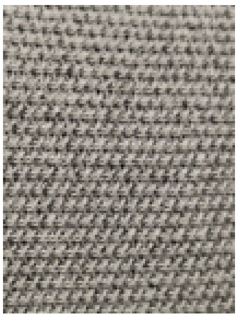
UE Hyperboom

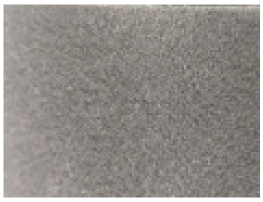
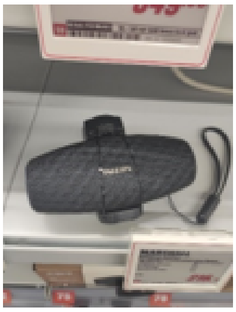
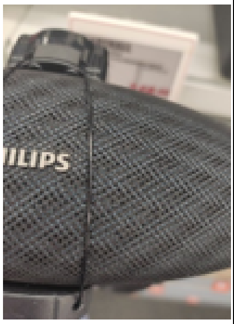
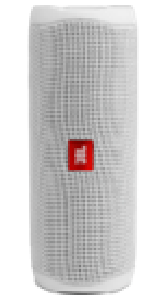
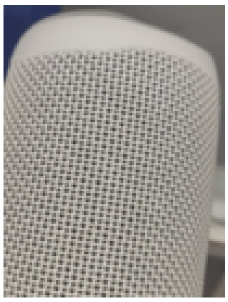
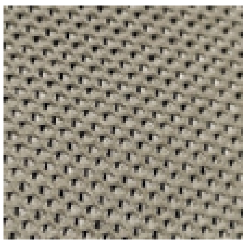
Handheld children's projector, Amazon

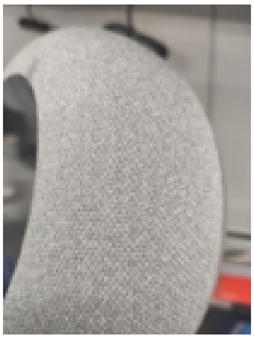
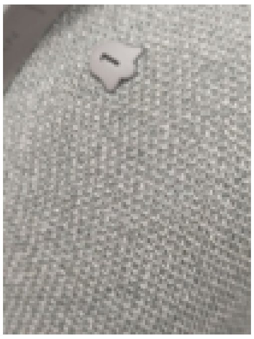
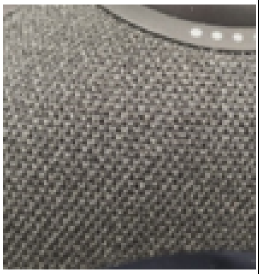
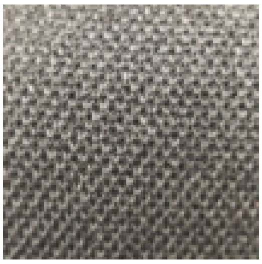
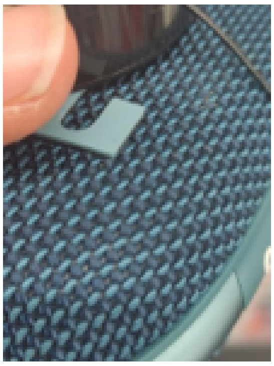
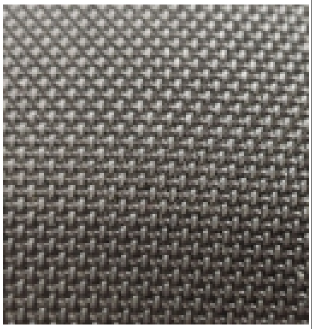
Edison the Petit Hoodie

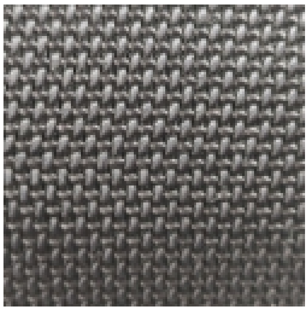
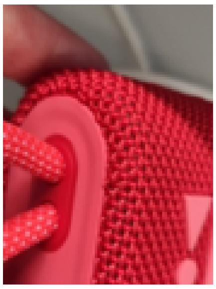
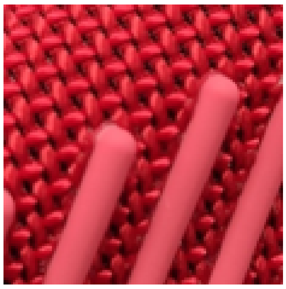
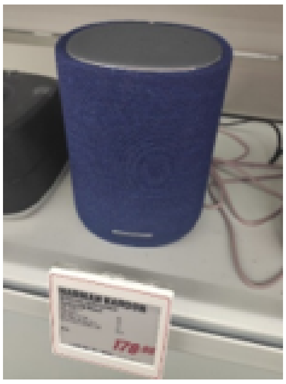
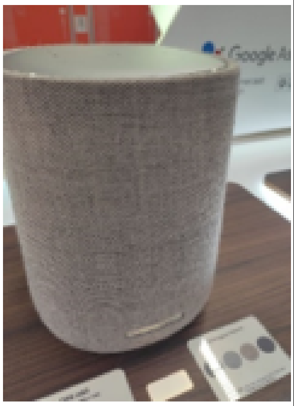
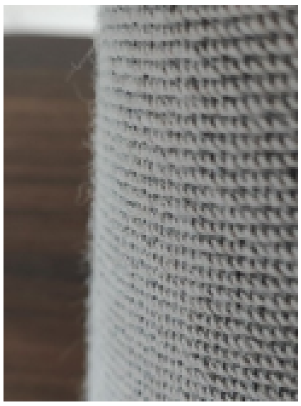
C.2 Field research

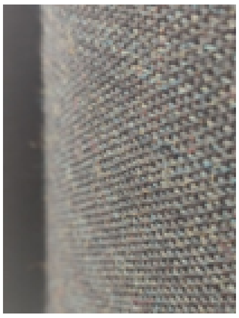
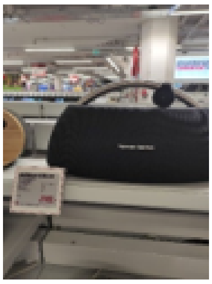
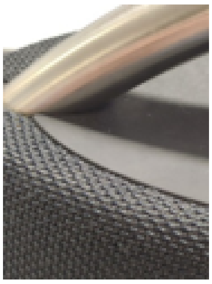
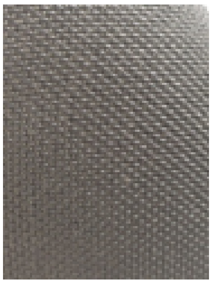
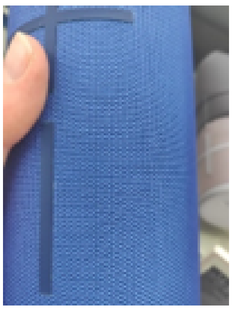
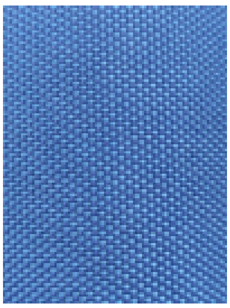
This appendix provides an overview of all the textile housing products that were displayed in March 2022 at the MediaMarkt Rotterdam Zuid and MediaMarkt Utrecht.

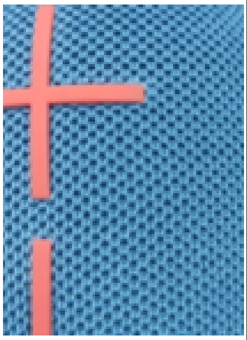
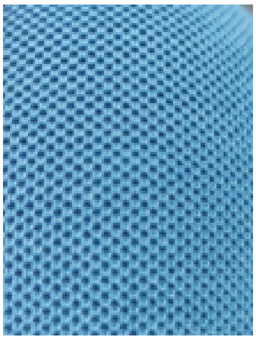
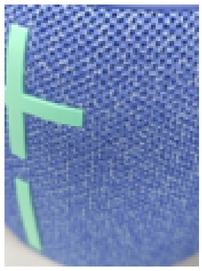
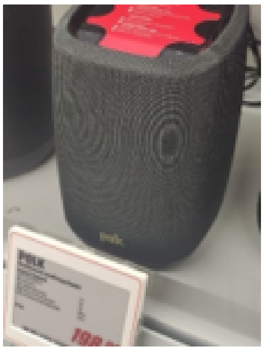
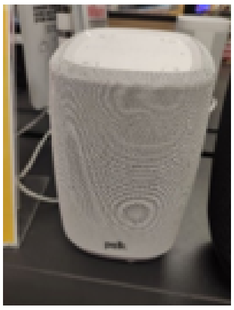
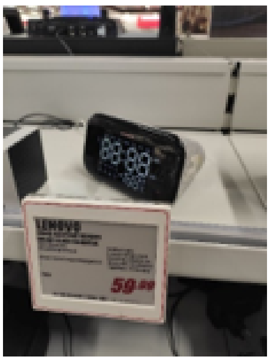
Product	**Shape**	**Zoomed in picture**	**Textile close-up**	**Remarks**
SONY				
Sony SRS-XG500 Partybox €319				Mixed colour.
Sony SRS-XB23 Bluetooth draadloze speaker €81,99				Thick and thin yarns are visible.
Sony SRS-XB33 €139				Extra visible inner structure.
PHILIPS				
Philips TADR402/13 wekkerradio €49,99				Jersey knit backside.

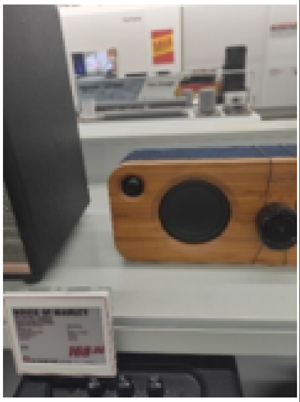
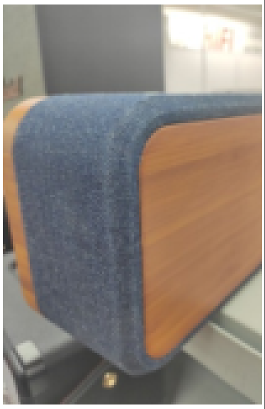
Philips wekkerradio TAPR702/12 €55,99				Circular pattern visible in the textile.
Philips Multiroom audiosysteem TAW6205/10 €178,98				Rough woven textile.
Philips Everyplay €129,98				Several layers of fabric with a plastic cage on top.
JBL				
JBL Flip 5 €119,99				Woven structure.
JBL Horizon wekkerradio €119,99				Knitted structure.

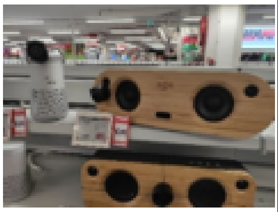
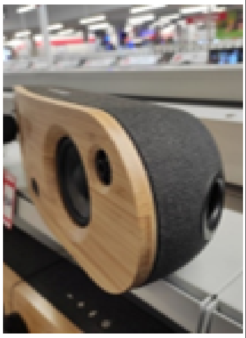
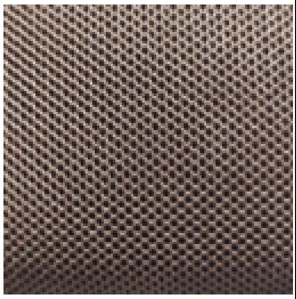
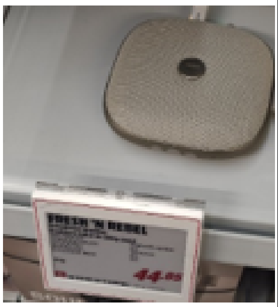
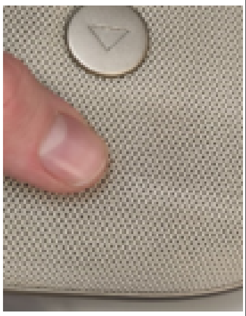
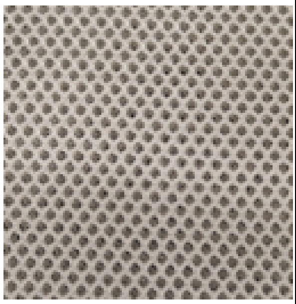
JBL Wekkerradio Horizon 2 €108				Jersey knit front.
JBL Wekkerradio Horizon 2 zwart €109				Mixed yarn colour.
JBL Clip 4 €59,95				Two distinct different colours.
JBL Boombox 2 zwart €379				Woven structure.
JBL Boombox 2 Camouflage €379				Fabric is printed.

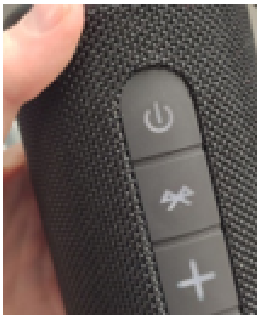
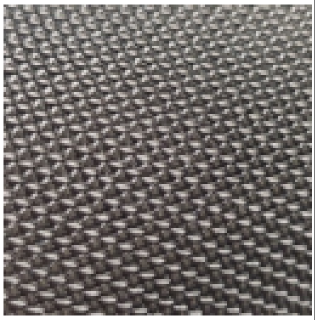
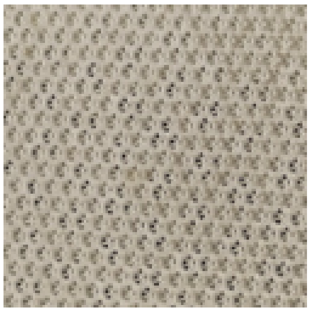
JBL charge 5 €154				Embossing effect on the JBL logo.
JBL Go 3 €39,99				Antislip rubber is glued to the textile. The finish at the rounded edges does not look good.
harman/kardon®				
Harman Kardon Citation ONE €178,98				Yarns are not homogeneously coloured.
Harman Kardon Citation One grijs				Fabric is a bit fluffy.

Harman Kardon Citation oasis				Clear visible dividing seam visible at the backside.
Harman Kardon Citation 500 €648,98				Little fluffy, slight variation in yarns visible.
Harman Kardon Go + Play €249				Same fabric als the JBL flip 5.
Harman Kardon Onyx studio 7 €299				Same buttons as on the JBL Flip 5. Turns out Harman Kardon and JBL are related brands.
		ue ultimate ears		
Ultimate Ears Boom 3 €125,99				Finer woven structure than JBL Flip 5.

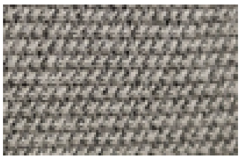
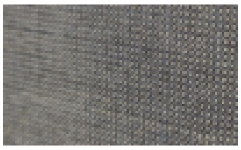
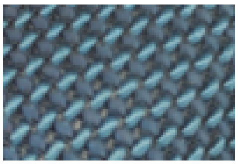
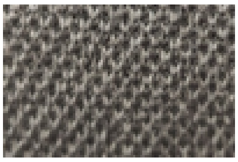
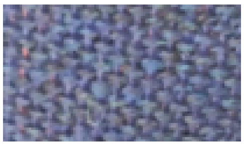
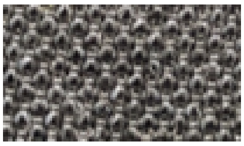
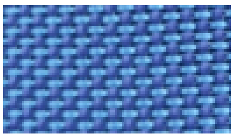
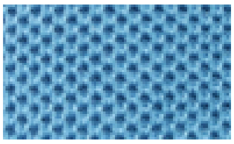
Ultimate Ears Wonderboom €59,99				 Mixed version.
polkaudio				
Polk Assist €198,98				Fine woven structure.
Polk assist wit				Knitted fabric.
Lenovo				
Lenovo voice assitant smart clock assential € 59,99				Same buttons as on the JBL Flip 5.

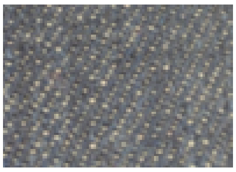
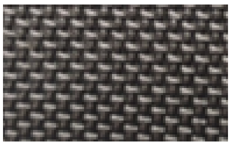
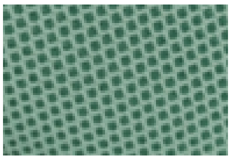
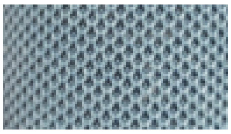
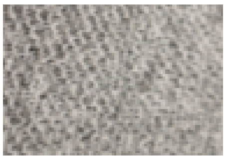
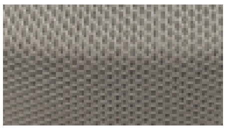
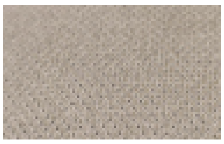
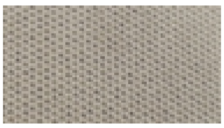
Google				
Google Nest audio mini				Knitted fabric.
MARLEY				
House of Marley Get Together €168,88				Looks like ordinary denim fabric. Buttons are thin layers, glued to the fabric.
House of Marley Signature Black				Less visible denim structure than the previous speaker.

House of Marley bag of riddim II €187 aanbieding				Interesting round shape of denim fabric.
FRESH 'N REBEL				
Fresh 'N Rebel Rockbock €49,99				Buttons are sunken a bit into the fabric, due to its thickness. Squishy spacer fabric.
Fresh 'n Rebel SOUL storm, draadloze speaker €129,99				Spacer fabric, metallic colours.
Fresh 'n Rebel Rockbox bold XS Silky Sand €44,95				Spacer fabric.
PEAQ				

PEAQ PPA301BT bluetooth speaker				Same fabric as JBL flip 5.
JAM AUDIO hang tight €34,99				Fine knitted structure.

Type of fabric per brand and product category:

PHILIPS Radio alarm clocks		Knitted: jersey Mixed colour yarns
PHILIPS Multiroom audio		Woven Mono colour yarns
JBL Flip		Woven Mono colour yarns
JBL Horizon		Knitted Mixed colour yarns
harman/kardon® Citation		Woven Mixed colour yarns
harman/kardon® Go		Woven Mono colour yarns
harman/kardon® Onyx		Knitted Mixed colour yarns
ue ultimate ears Boom		Woven Mono colour yarns
ue ultimate ears Wonderboom		Knitted Mono or mixed colour yarns

MARLEY		Woven Mono colour yarn
PEAQ		Woven Mono colour yarn
FRESH 'N REBEL		Knitted Mono colour yarn
SONY		Knitted Mono colour yarns
Lenovo		Knitted Mixed colour yarns
polkaudio		Knitted Mono or mixed colour yarns
Google		Knitted Mono colour yarn
JAM		Knitted Mono colour yarn

Appendix D: Visit to Road2Work

On the 10th of February (2022) Road2Work was visited: a social enterprise in Ede, the Netherlands. This company disassembles discarded consumer electronics to recyle its components and to research the disassembly potential of these products.

A part of the products that they receive are discarded by consumers in the recycling centre of recycle boxes in supermarkets (from WeCycle). They also receive many retour sent products from webshops such as bol.com. They test these products to see if they still function: if they do Road2Work resells them, if they are broken they will be disassembled.

Because Road2Work is a centre for knowledge on disassembling and recycling product, they regularly invite companies and policy makes for a tour around the recycling facility. They can tell a lot about the recyclability of many different types of products. At the moment, they were disassembling old laptops to retrieve the laptopscreens which can be resold as refurbishment components.

Some components are not allowed to leave the building after disassembly, without taking strict precautions into account. These are mainly batteries which can explode if damaged, or Google chips with personal data of users.

Outside the facility there is a truck where all the disassembled batteries are kept. Not all batteries have a rigid housing but only consist of a vulnerable aluminum-covered pack. This can explode if it is damadged. Next to the truck, also outside, there is a box flame retardant wood chips where the most dangerous batteries are stored. They once had a battery fire, which is extremely difficult to extinquish.

Together with the team leader, we scanned trough a few boxes of discarded products to look for textile housing products. Between the spectacular high stacks of boxes with broken products, we managed to find a few. I was allowed to disassemble the products at the recycling facility, with the agreement to not take any product containing batteries or Google chips home.

Considering the textile housings, they are not disassembled at Road2Work. These products usually contain batteries and are sent to another company that is specialized in recycling battery-containing products in a safe way (Peperzeel, Lelystad). Road2Work has experimented with disassembling these products, but it is too time consuming to do this diligently.

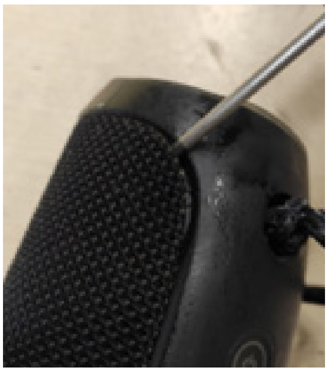
Appendix E: Disassembly analysis

Fourteen products with textile housing elements were disassembled. Nine were retrieved from Road2Work, the other five were bought.
This appendix will provide the step-by-step disassembly up until the textile housing. At the end of the appendix, the fabrics observed under a microscope will be shown.

E.1 Step-by-step disassembly

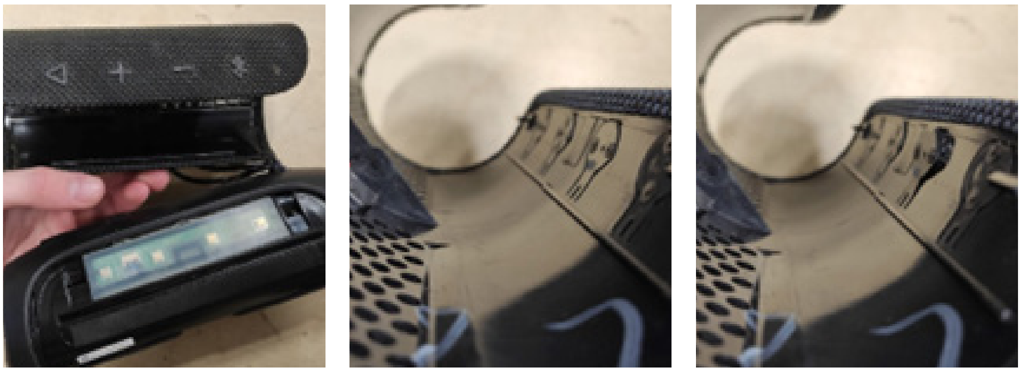
This appendix provides an overview of all the textile housing products that were displayed in March 2022 at the MediaMarkt Rotterdam Zuid and MediaMarkt Utrecht.

JBL Flip 4

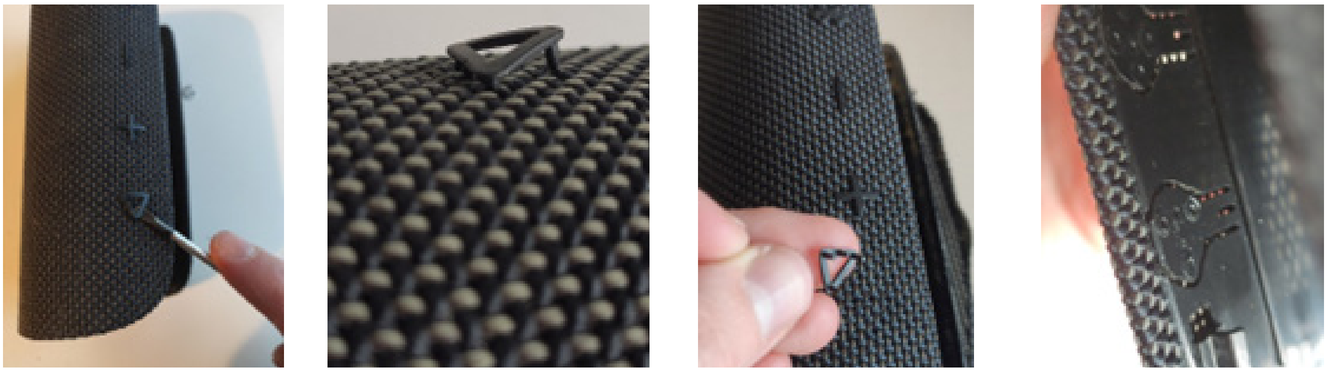


The textile cover was easy to remove with a screwdriver. This cover consists of a black plastic base, with textile glued onto the surface and around the edges. The parts of the housing where the speaker is underneath, contains a grid of holes to allow the music to pass through. The whole surface of this housing part is covered with textile, creating a homogeneous look on the outside. This textile is thick and waterproof (IPX7 waterproofness). Therefor it's easy to clean with a damp cloth.

In the other non-textile parts of the housing, there are slots in at the edges that allow the thickness of the textile housing to fall into.

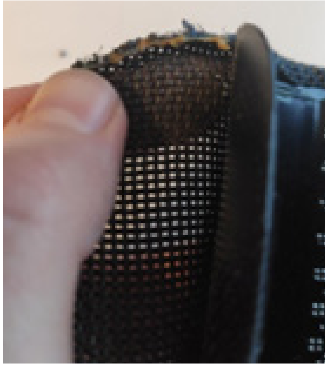


On top of the housing there is an interface with four controls. In the plastic part underneath these "buttons" are tabs that bend inwards when the buttons are pressed: these consequently touch buttons on a PCB underneath the textile housing.



You can remove these figures and they consisted of a small plastic shape with pins on the bottom, which stick through the fabric into holes in the bendable tabs.

When popping of a small aluminium logo plate, it reveals a square shape that's sunken a few millimetres into the black plastic. A hole is cut into the fabric to allow the logo plate to be attached.

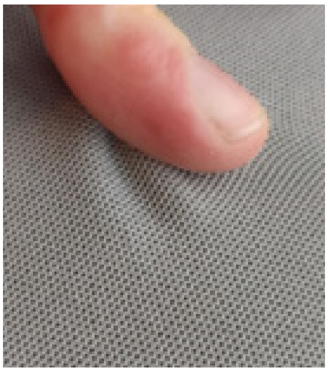


The edges of the textile are glued with tough yellow-greenish glue. Using a screwdriver, the textile was relatively easy to remove. The textile was thoroughly glued at the edges and loosely glued onto the whole surface of the housing: also on the parts with the holes. The fabric is not stretchable.

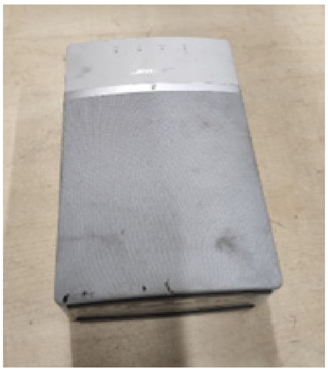

It was surprising to discover that this is a woven fabric with two sizes of yarns visible. The thick yarns are clearly visible, but the smaller ones could only be seen when the fabric was held against the light.

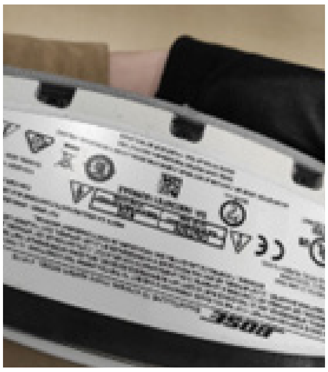
When holding the textile housing underneath a running water tap the liquid did not immediately seep through. Only after holding the tap at the same spot for more than 5 seconds, the textile allowed water to pass through. My theory is that the thinner strands make the holes in the weave smaller, which causes the water to bounce off because of the surface tension. This is a very clever design solution to remain a defined textile look and feel on the outside, whilst enhancing waterproofness.

Bose Soundtouch 10



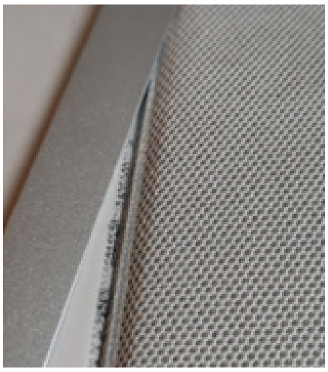
When rubbing the textile you can see that it stretches a bit and it feels as if it is not glued to the plastic part of the housing.





At the bottom of the speaker there are three screws that need to be loosened in order to detach the textile housing part at the front.

On the inside there is again a honeycomb-like structure to allow music to pass through the plastic part of the housing. The fabric on this product is much thinner than in the previously discussed JBL Flip 4. Therefor it seems to be less sturdy and more prone to damaging. Unlike the JBL Flip 4, this product is not meant to be held so the fabric is not required to be as sturdy.


To take of the fabric you have to remove a metal strip first. Under the strip, the fabric is glued very neatly onto the plastic housing so it hides under the strip.



The fabric is only glued at the backside of the housing part, at the edges. It was easy to take off the fabric with my fingers, without any tools, because the glue was not very strong.

The fabric consists of two bidirectionally stretching knit fabrics: a more defined grey fabric on top and a highly transparent black knit at the bottom. This this two-layer composition might enhance the sound quality or acoustics. The fabrics are not glued to the plastic housing so they are stretched around the plastic and they can move freely when stretched slightly.

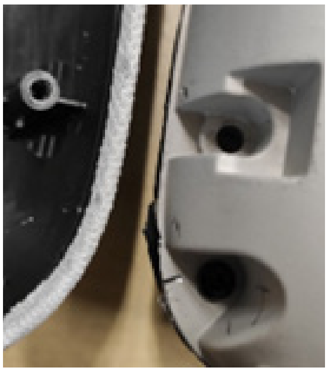
Google Nest Audio (2x)



There were two of these speakers available for disassembly: a white and a dark grey one. They were both used this disassembly analysis, therefor you will see pictures of different coloured textile housing parts.

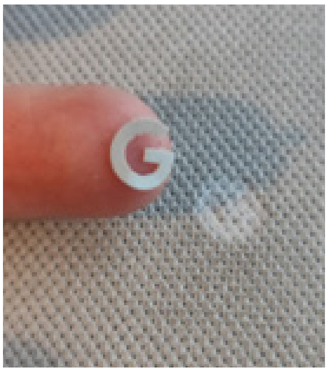
One side of the housing is easy to pop off with a flathead screwdriver because the housing is clamped with pins around the housing.






In the holes of these pins, there are rubber or flexible plastic caps that you need to take out to unscrew the screws underneath. This way you are able to detach the other textile housing part. This is a clever system to be able to easily disassemble the housing.

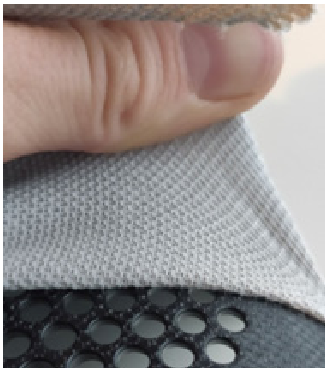


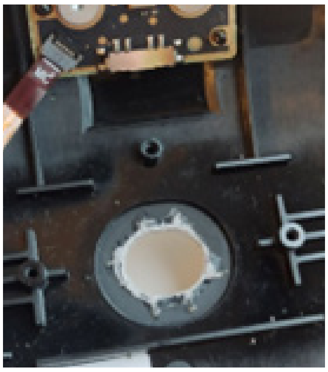


The housing part where the speaker is located behind contains a honeycomb-like structure, the other part consists of a solid plastic layer.


Some edged were easy to remove by hand, but the glue that Google used to attach the textile to the housing is very strong. Therefor tools were used (screwdriver and Stanley knife) to detach the fabric.


It was interesting to see that at curved surfaces there were snips in the fabric to allow it to make a shape. This technique is similar to one that is being used for sewing clothes when the fabric does not stretch enough to allow a round shape.



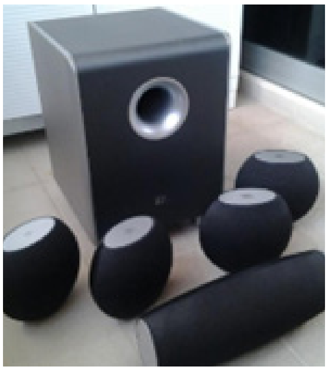
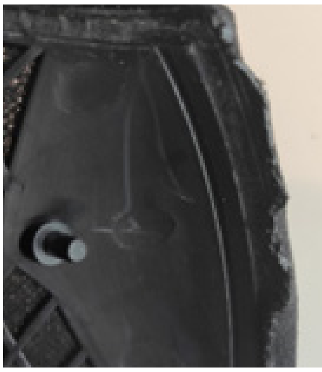
The fabric is glued onto the plastic housing in the same fashion as the JBL Flip 4 speaker: over the whole surface including the honeycomb structure.

At the holes in the housing where the on-off-switch for the microphone is, there is some extra glue on the outside as well as the inside.

JBL CS460 sat




The textile housing part was easy to pop off with a screwdriver: it attached with pins. This product contains the same system as the Google Audio: underneath these pins there are flexible knobs that need to be removed to reach the screws which you need to loosen in order to take off the other part of the housing.

The fabric of this product is thinner than the textile in the JBL Flip 4 and Google Nest Audio. This speaker was part of a surround sound home speaker set.

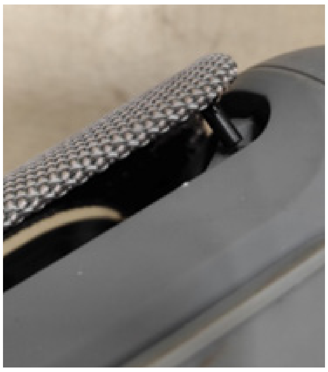
The fabric was only glued to the edges of the housing. The glue was not difficult to remove at all and The fabric could be peeled off with your fingers. The single-layer fabric is bidirectionally stretchable.

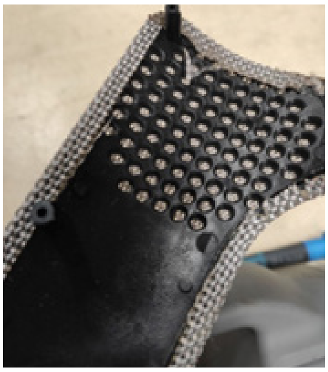
There is no glue on the outside surface so the fabric can move freely over the surface of the plastic. Since this speaker was part of surround sound speakers, it was not meant to be picked up regularly, so the fabric did not need to be fixated onto the housing.

Brandless grey bluetooth speaker


This speaker without brand has two textile housing panels. They were easy to detach with a screwdriver. They were clicked into the housing below with pins.

On the inner housing there seems to be a ridge: this creates some room for the fabric at the backside of the textile housing part, where the fabric is wrapped around the plastic.

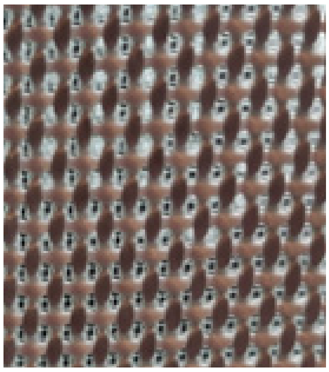





The fabric is glued to the plastic housing part with thick yet not so tough glue: it could picked off by hand without the use of tools.

The difference between the JBL Flip 4 and this housing part, is that this one contains a raised edge at the inside. Probably to give some space to the thick glue and fabric that are stacked onto eachother at the edges of this part.

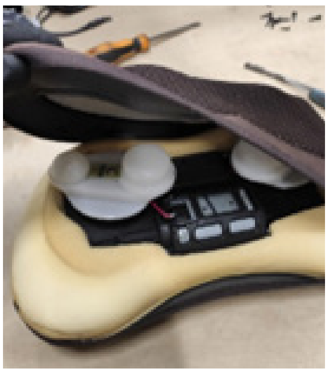


The fabric was glued onto the whole outer surface of the plastic housing component.

This woven fabric is very similar to the textile of the JBL Flip 4. It has almost invisible thin yarns woven into the structure of the thick, visible yarns. Probably to enhance the waterproofness of the component. It is also not stretchable.

Neck massage pillow


This neck massage pillow was chosen from the product containers because it contains a fabric that was observed during the field research. This is spacer fabric which is slightly compressibl
The cover could be removed with a zipper. Probably so it can be washed.

Brandless headphones

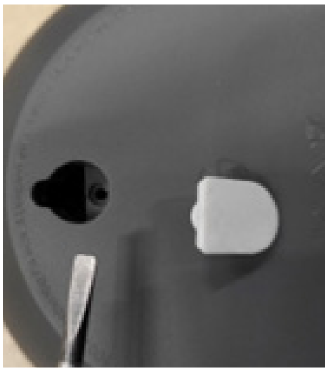



This product is a little different than the previously discussed ones because the textile is not stretched over the surface of a housing part. Nevertheless, it could be interesting to learn how the fabric is attached to the plastic parts for inspirational purposes of this project.

The earpads of this brandless headphones are easy to detach. They have an extra flap of fabric that you can shove between a slot in the plastic part. From earlier experience with disassembling headphones it was known that the top layer of the fabric will abrade and release small pieces of coating. Therefor these earpads are easily replaceable.

At the top of the product where the headband is, two layers of leather-like fabric are sewn together with a feston stitch. Underneath there is a foam layer to give the part some softness. You could feel that there is a rigid layer of plastic inside to give the headband its strength and shape.

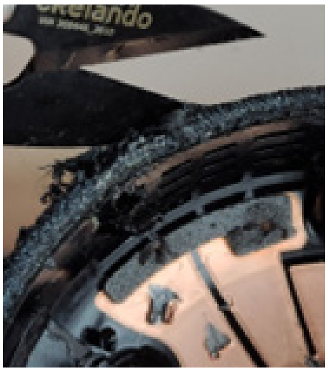
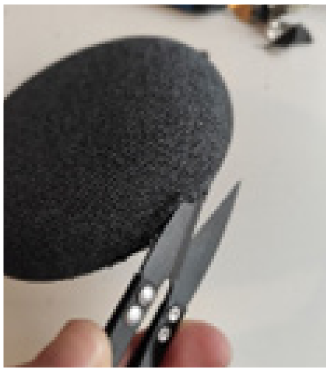
Google Nest mini (2x)


The Google Nest Mini has an interesting pebble shape. There were two identical black-grey speakers which were both disassembled. In one the fabric was stripped, the other was remained intact to be able to analyse how it was stretched around the shape.

A white flexible part had to be levered out, revealing a tiny torx screw. When this was loosened, the top and bottom part could be turned counter clockwise and this released the textile housing from the bottom part.



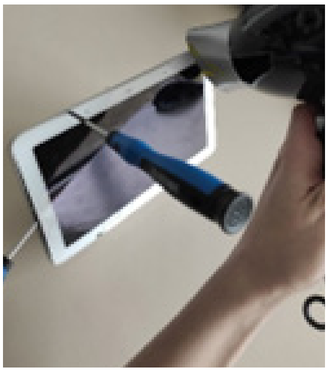
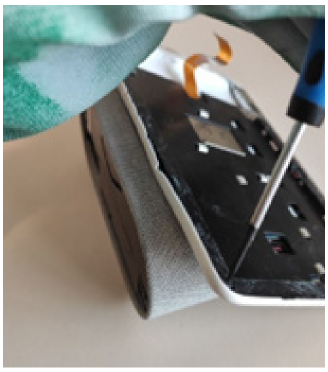
Two layers of components had to be detached to isolate the textile housing part from the other parts. This was done by unscrewing these two layers.

It was almost impossible to get the fabric cover off because the glue was extremely strong. It was tried to peel off, using screwdrivers and a Stanley knife but finally fabric scissors did the trick.


The fabric was not glued over the whole surface of the plastic part, but only at three circular patches on top (and very strongly to the inside border of the housing). Yet the fabric was stretched around the shape so tightly that you could not slide the fabric over the surface when it was still attached.

This fabric is a knit with some bidirectional stretch.

Google Nest Hub


In order to reach the fabric foot of the hub, the screen had to be detached. This was difficult and dangerous because the right tools were not available: the screen had to be broken in order to unscrew the chassis to reach the textile foot.

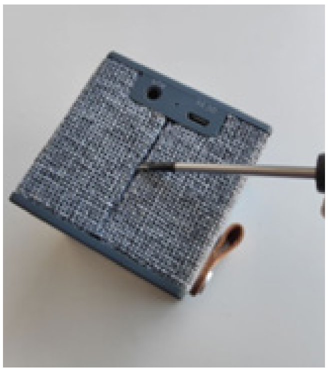

After unscrewing eight screws from the inside, the fabric foot was isolated. It is a shame that it was so difficult to disassemble.

If the textile around this foot would be made from a flat sheet of fabric, you would expect to see a dividing seem somewhere along the cylindrical shape. There were no visible seam lines. This textile was either knitted in a round shape or glued together at the meeting ends very neatly. The fabric was decided to be kept on the housing, so the search for a seam could be continued.

The fabric is not moveable over the plastic housing part, so it is probably glued to the surface just like the Google Nest Audio. Similar to the Google Nest Mini, the inside edges are glued very strongly to the plastic.

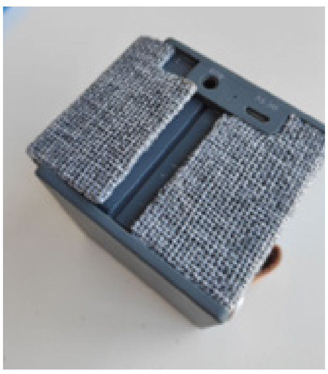
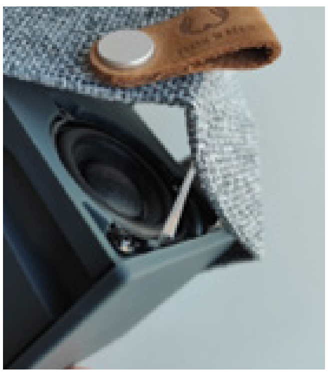
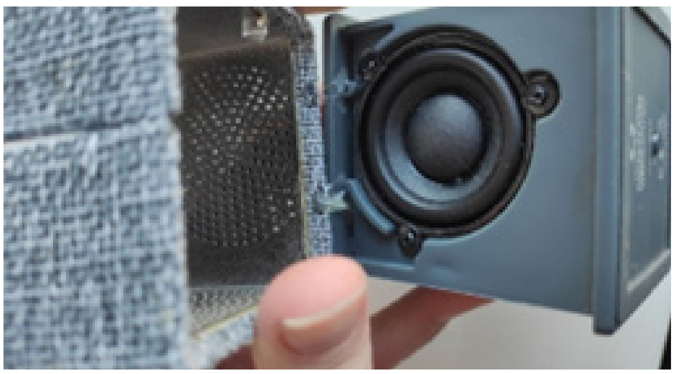
Fresh 'n Rebel Rockbox cube mini

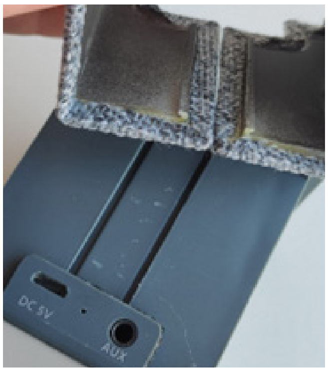




This little box has sharp edges where the fabric is wrapped around. The textile housing part required some force to be opened.

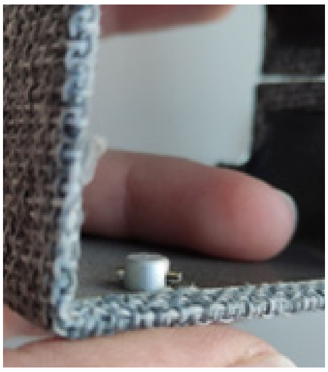
At the front, the housing part was glued to the inner housing with two small dots.

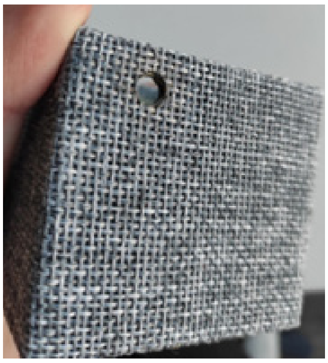
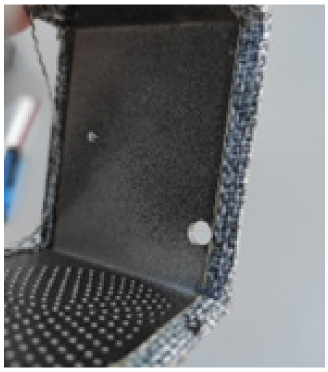






The fabric cover is clicked into the inner housing with two long slots.

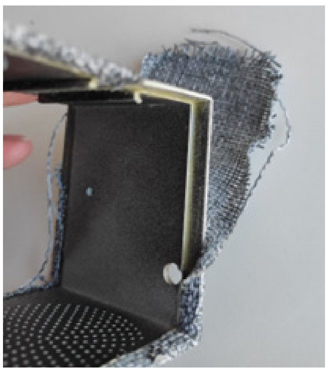
The fabric is glued around the inner edged of the square shape. At the rounded parts, there is not much fabric overlap: the yarns look like they can easily fray and slip off.



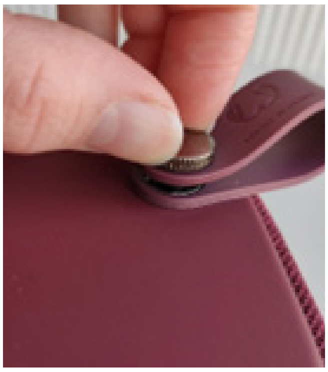
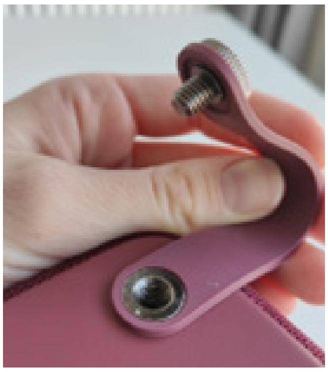
The leather “handle” is attached to the inside of the housing with a pal. It is secured with glue and when this is removed, the pal fell right out and the leather strip came loose.

The fabric in the hole that this pin leaves, looks like it is burned to stop the fraying. The fabric does not go inside to be glued onto the backside (which is the case for the Google products).

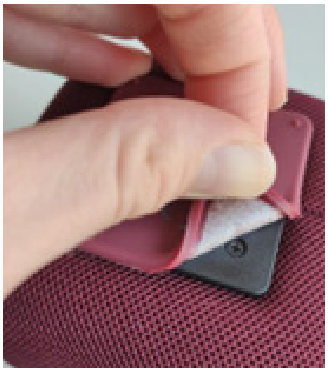


The fabric in the hole that this pin leaves, looks like it is burned to stop the fraying. The fabric does not go inside to be glued onto the backside (which is the case for the Google products).

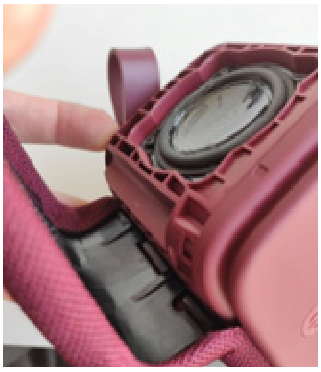
Fresh 'n Rebel Rockbox Bold S

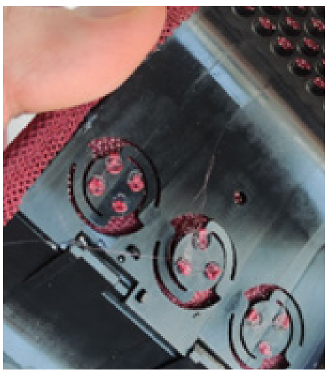
This Fresh 'n Rebel speaker has intrigued me since I have touched one, because of its squishy feel. The "handle" can be screwed loose, so you can wrap it around something.



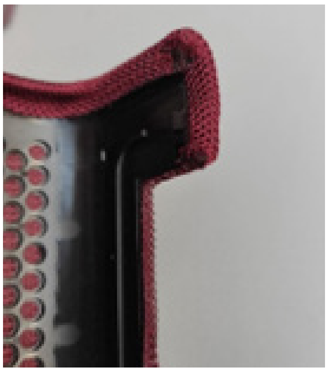
You have to remove a silicone bottom cover and screws from a bottom part, in order to remove the textile housing. This part is easy to pry open. It pivots at the other end.

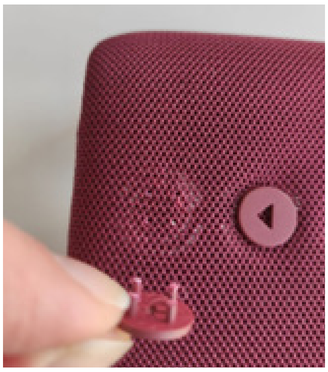
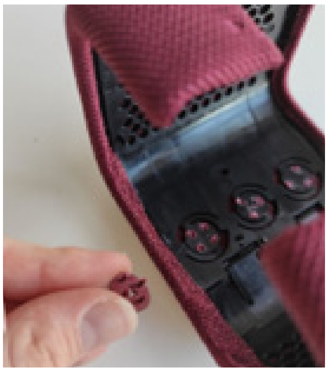


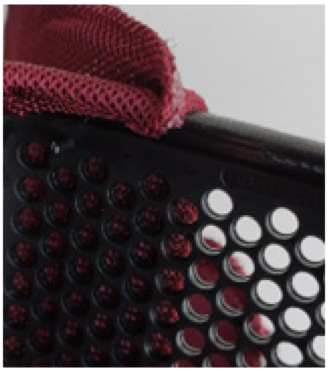
The buttons press onto buttons in the inner housing in the same fashion as the JBL Flip. However, the shape of the latches is different.


At the part with a square hole in the housing, the fabric is not wrapped all the way into the back of this housing. Therefor you can observe the structure of the spacer fabric very well at these edges.

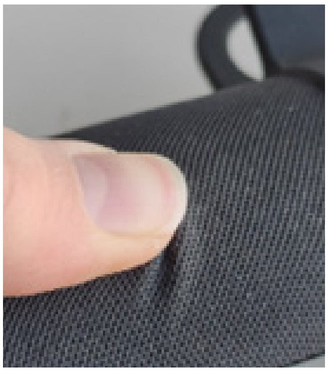




The buttons on top can be preyed off, since there are pinned into the fabric. They pin into holes at the bottom of the housing, similar to the system of the JBL Flip 4. Only here, the pins seem to be molten a little bit to fasten them to the bottom of the housing.



The fabric that is glued around the edges is difficult to remove, especially at the corners. The fabric is glued over the surface of the housing with a glue that remains sticky after the removal of the textile.

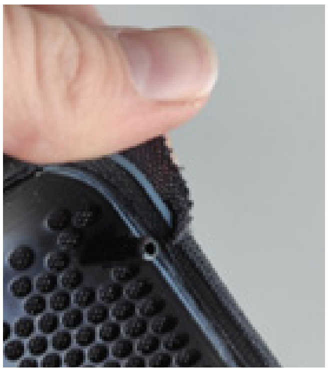
Miniso speaker


The fabric on this speaker is clearly not glued onto the whole surface of the housing, because it is movable. Two housing parts can be easily preyed off.



The two fabric caps are clicked onto the inner housing of the speaker. They have a nice double rounded surface.


The fabric is only glued onto the inside edges and is easy to peal off without any tools. Interestingly, the textile is not glued to the surface, which you would expect in a product that is meant to be picked up. The fabric is bidirectionally stretchable.

Pulsar leopard print speaker

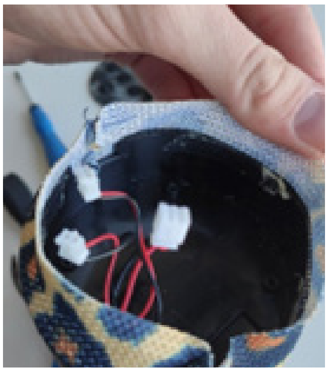
The fabric of this bluetooth speaker feels smooth. The textile is printed with a leopard motive.

Once again, a silicone bottom which is glued to the bottom of the product needs to be removed before screws are revealed, which hold the bottom cap. This silicone part tore apart very easily.

Interestingly, the fabric cover is sewn together at the backside. In the inner housing, there is a slot to hide this seam.

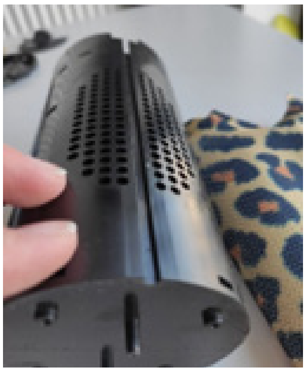


In order to remove the leopard sleeve, the top cap needs to be removed. First I took of the silicone layer with buttons, then I unscrewed the housing and then I popped it off.


The sleeve was folded inwards and at two small spots it was glued to the inside of the plastic. When removed, the sleeve came loose and it could be slid off very easily.





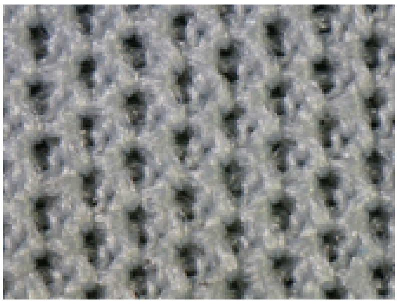
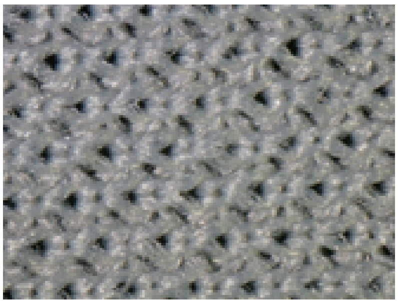
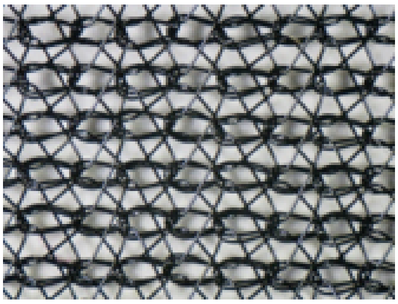
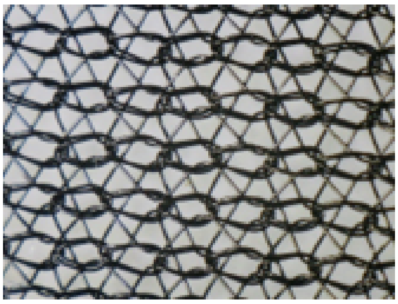
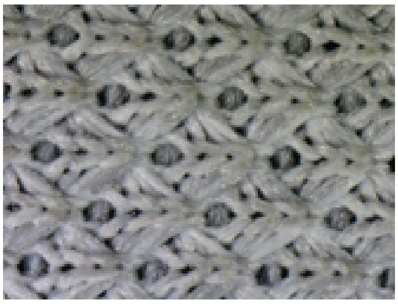
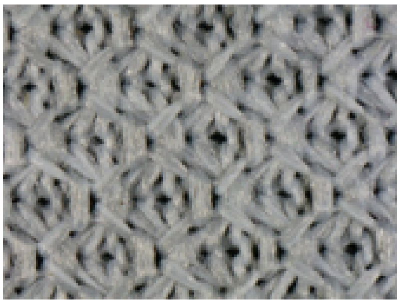
The sleeve is a cylinder with a round cut-out at the top to follow the shape of the inner housing. the fabric on the inside is white, making it clearly visible that the fabric is printed and not dyed. On the inner housing you can see the slot that makes room for the seam of the fabric sleeve.

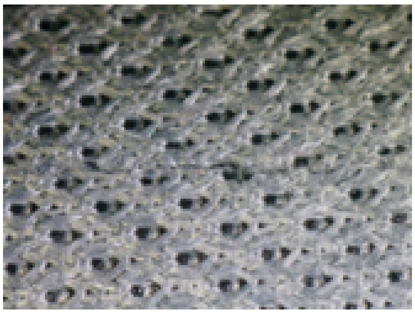
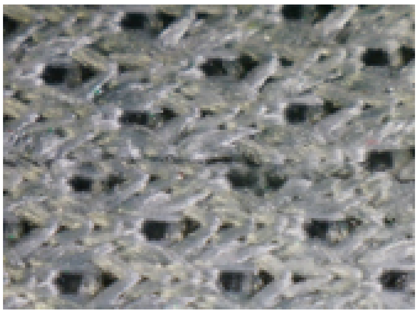
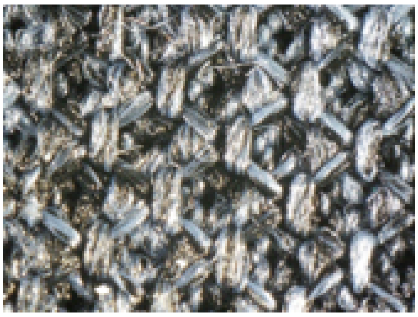
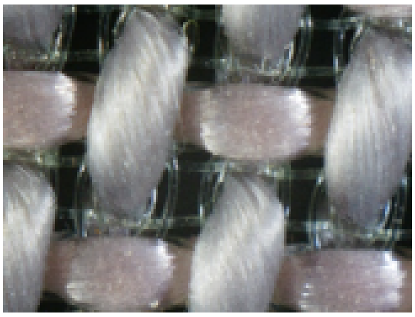
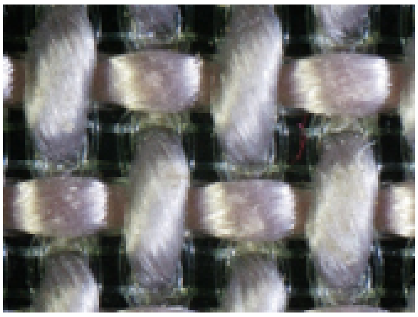
E.2 Fabrics under the microscope

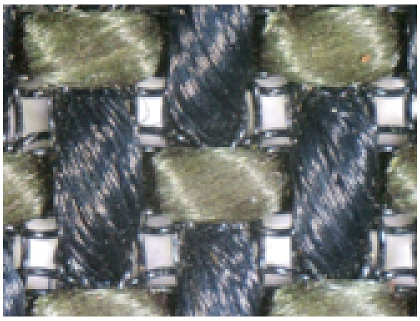
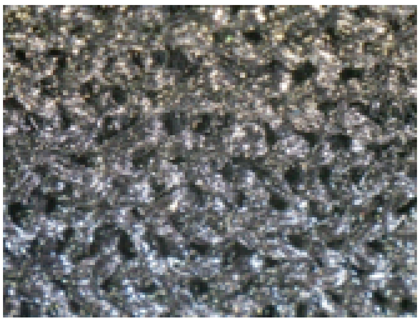
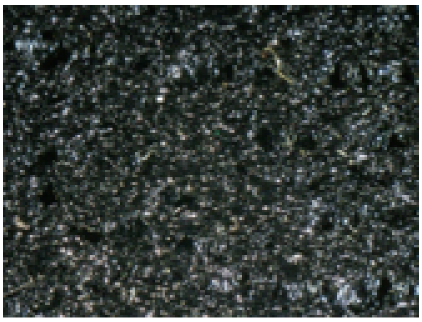
To discover the weave and knit patterns of the products, they were observed under a microscope at the faculty. This way you can determine whether it is a woven or knitted fabric (with weft- and warp-yarns or formed by looped yarns) and it allows you to see what colour yarns are being used.

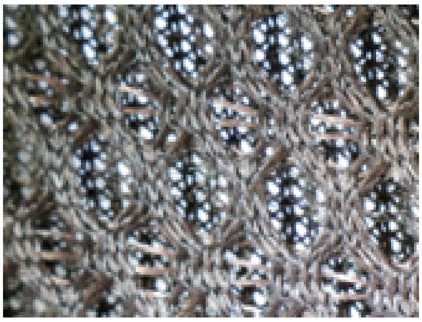
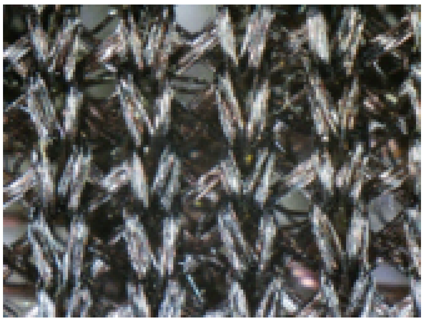
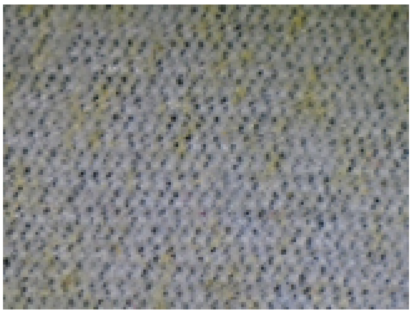
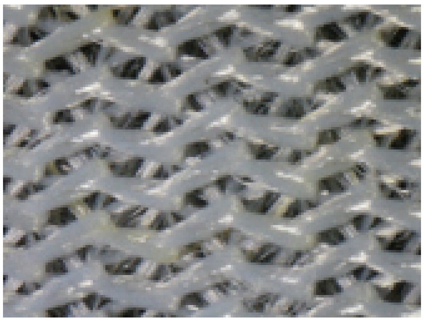
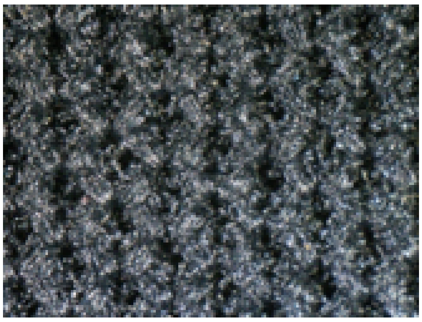
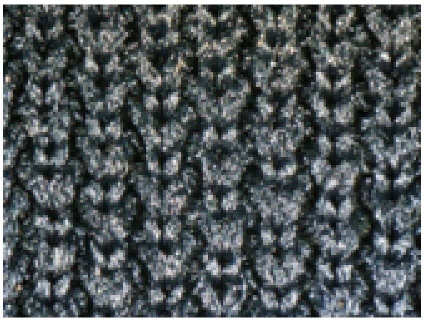
A few products had the same fabric, like the JBL Flip 4 and the Google products. Only one of these fabrics per colour were observed under the microscope.

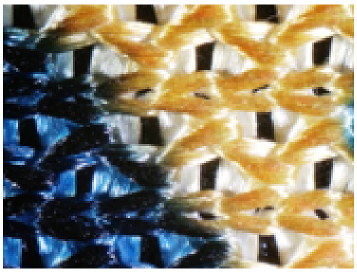
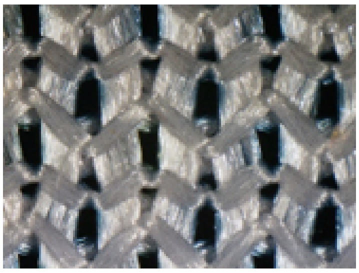
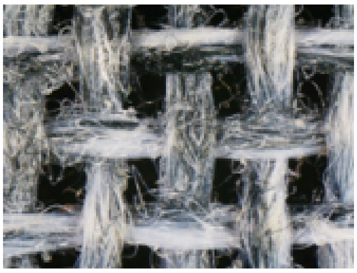
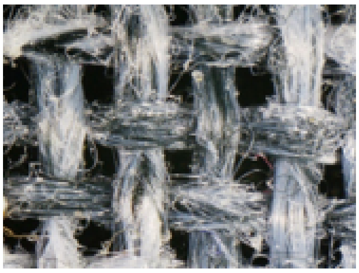
These are the observed fabrics:

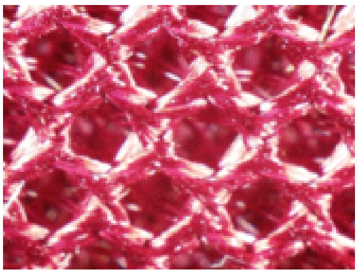
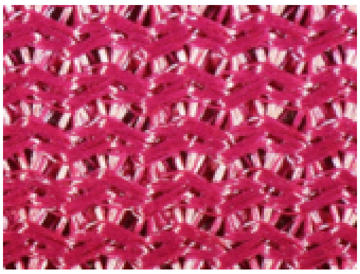
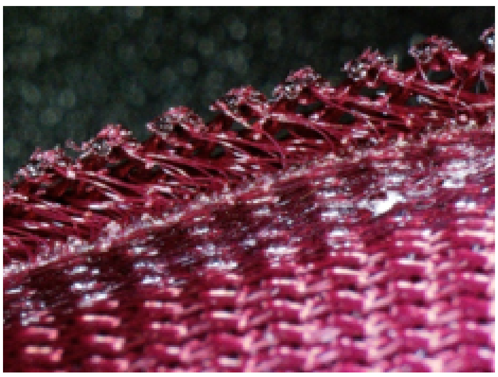
Bose Soundtouch 10		
		Jersey knit, densely woven. Mono white yarn colour. Stretchable in both directions.
Top layer, front side	Top layer, backside	
		Warp knit. Plastic like yarn. Less dense knit than top layer. Mono black yarn colour. Stretchable in both directions.
Bottom layer, front side	Bottom layer, backside	
Google Nest Audio, white		
		Special type of knit pattern. Mono white yarn colour. Little stretch in both directions..
Front side	Backside	

Google Nest Hub, white - dividing seam		
		This picture shows the connection seam. Probably ultra-sonic welded: the seam is almost invisible to the naked eye. Mono white yarn colour.
Front side seam, zoomed out	Front side seam, zoomed in	
Google Nest Mini, dark grey		
		Mixed yarn colour: black and white yarns. Little stretch in both directions..
Front side	Backside	
Grey brandless speaker		
		Woven into grid of transparent yarns: these might be water repellent. Two different mono yarn colours: varying shades of grey. No stretch.
Front side	Backside	

JBL Flip 4		
		Woven into a grid of black plastic-looking yarns: might be water repellent. Two different mono yarn colours: blue and yellow yarn colour → make black textile. No stretch.
Front side	Backside	
		Side view of this weave and the grid.
JBL Sat cs460		
		Difficult to see knit structure due to the colour and light reflections. It's a knit. Mono black yarn colour. Stretchable in both directions.
Front side	Backside	

Neckmassage pillow		
		Double layer knit. (Spacer fabric.) Mono yarn colour. Slight stretch in one direction.
Top layer, front side	Top layer, backside	
		Side view of the double knit. These "spacer yarns" give the textile some compressibility.
		Warp knit with one side which is brushed to become soft. Mono yarn colour. Slightly stretchable in one direction.
Bottom layer, front side	Bottom layer, backside	
Miniso speaker		
		Jersey knit. Mono yarn colour. Bidirectional stretch.
Front side	Backside	

Pulsar leopard print speaker		
		Warp knit. Mono yarn colour. Printed on one side. Slight stretch in one direction
Front side	Backside	
Fresh 'n Rebel Rockbox Cube mini		
		Plain weave with large gaps. Mixed yarn colour, fuzzy yarn. No stretch.
Front side	Backside	

Fresh 'n Rebel Rockbox Bold S		
		Spacer fabric, double layer knit. Mono colour yarn. Slight bidirectional stretch.
Front side	Backside	
		Spacer yarns for compressibility.
Cross-section view		

Appendix F: Fabric ideation

To discover out-of-the-box textiles for this product application, a fabric brainstorm was conducted. The website www.destoffenkraam.nl was consulted to search for suitable fabrics. They have an extensive collection (7057 different fabrics).

For equal comparison, plain white fabrics were chosen (234 products). Fabrics which are too thin, like voile or satin, were not included.

To summarise, the following requirements were kept in mind during the ideation:

1. Fabric must be white so the colour does not influence your perception and you can equally compare all fabrics.
2. It must be plain, without coloured motives to fit the simplistic Hue style.
3. It should have a visible texture to create an interesting feeling product.
4. It should be a durable fabric that can withstand being picked up many times.

A sample board was created with 15 fabrics that were considered most suitable. This board functioned for inspiration during the team brainstorming and the product ideation.


Bamboo
Recycled linen
Lace
Coolmax mesh
Spacer fabric
Punta di Roma
Bag felt
Cotton
Stretch cotton
Stretch jeans
Garbardine
Corduroy
Cooked wool
Baby waffle
PU leather

Appendix G: Surface shape experiment

This appendix explains the goal, fabrics and insights from the surface shape experiment. The shape matrix of this experiment can be seen in chapter 5.2 of this report.

G.1 Goals of surface shape experiment

After analysing the existing product portfolio of Philips Hue, it was discovered that all products consist mainly of one basic shape: cylindrical, spherical, conical or rectangular. To make the new product fit within the current portfolio it could consist of one of these shapes, however it is not mandatory. An open mind was kept about which shapes could be possible, but the insights of the product portfolio analysis functioned as a starting point and to gain inspiration.

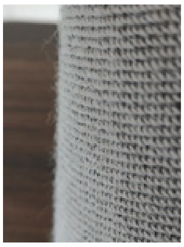
Six of each shape were 3D-printed in hand size and wrapped with fabrics. The goals of this experiment are as follows:

1. Learn how different fabrics behave around varying shapes, by wrapping and gluing them around the shapes.
2. Use these 24 shapes for inspiration for the product brainstorm with the textile application team at Signify.
3. Discover how users perceive different textile-covered shapes, by asking people about their experience when picking up the shapes.

G.2 Chosen fabrics

Six textiles were chosen which were considered most interesting and suitable for the new luminaire design:

- Rough woven cotton



This material is sturdy and can be seen in many interior products like couches or curtains. It is very similar to the fabric observed during the trend analysis in the products of Harman & Kardon Citation. It is durable and homely.

- Soft knitted bamboo

Bamboo could be a great sustainable alternative to polymer-based fabrics (polyester) because it is made from a renewable source. It has an amazing smooth touch. It is novel, as is has not been seen it in any of the products that were analysed previously. This fabric has a very warm, homely feeling, which is highly suitable for the new product.

- Spacer fabric

Spacer fabric is found in the Rockbox Bold products from the brand Fresh 'n Rebel: the fabric feels foam-like. It is inviting to touch and it creates a unique product experience. Spacer fabric is broadly used in upholstery and backpacks as cushioning. It can also be found Apple's Home Pod products: this is a relatively new application which could be interesting for a Philips Hue product as well.

- Flocking:

Flocking is a technique of attaching small soft fibers to the surface of a component to give it a velvet feel. At the disassembly company (Road2Work) there was a toy with this surface treatment. This material is usually associated with tacky interior objects, but it could create interesting effects when used on simplistic shapes. That's why it was included in this experiment.

- Felt

Before this thesis project started, Signify had already experimented with integrating felt into the housing of a luminaire. Felt is a common textile that can be seen in accessories like hats and bags. For the context of luminaires it could look warm and inviting to touch. In addition, there are sustainable variations available made from recycled material like used denim.

- Corduroy

Corduroy is a sturdy fabric that can be seen in upholstery like this beanbag. It is sturdy and soft to the touch. It has not been observed being used in portable consumer electronics, so this could be novel for the new product design.

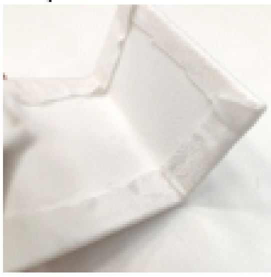
G.3 Insights of surface shape experiment

- Rough woven cotton
  - This fabric was easy to glue around the shapes, because it did not stretch.

    
    Easy to wrap with woven cloth: developable cylindrical shape
  - For the sphere, the fabric had to be forcefully shaped around a spherical bowl before being able to wrap it around the shape.

    
    Woven fabric around sphere: neat finish

- Soft knitted bamboo
  - The bamboo knit was easy to wrap around the shapes because of its stretch.
  - This thin fabric does not accumulate in the inner corners of the rectangular shape. It's suitable for this application.

    
    Thin fabric: does not accumulate in inner edges
  - It was easier to shape it around the sphere than the woven cotton, but it was not stretchable enough to cover the shape without any folds. Maybe with better tools that can stretch the fabric out further, a smoother finish could have been achieved at the edges.

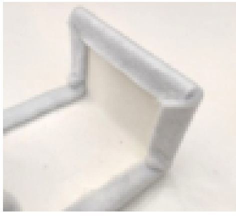
    
    Pleats in the bamboo fabric around the spherical shape.

- Spacer fabric
  - It's important to not stretch the spacer fabric when wrapping it around the shapes because that flattens the fabric, losing its compressibility.
  - With the sphere, it had to be stretched slightly to cover the shape but not too much to preserve its compressibility.

- Flocking
  - Flocking is industrially done with the use of static electricity so only one end of the fibres touches the surface of the housing. For this experiment it was done by hand with a sieve and glue spray. The glue was spread all over the fibres, making them lose their soft touch. The spherical shape succeeded the best in staying soft to the touch.
  - This surface is a magnet to dust.


Dirt is trapped on the surface of the flocked shapes.

- Felt
  - This thick felt was difficult to wrap around the sphere. A thinner variant will be easier to wrap around a shape.
  - At the inner corners of the rectangular shape, the felt needed to be folded which creates thick layers of fabric inside.


Folding at the inner edges of the felt.

  - This felt is prone to catching dust and dirt particles, but less severe than the felt.

- Corduroy
  - Was easy to wrap around all of the shapes because of its stretch.
  - You have to strategically choose the directions of the ribs over the shape.


Curvature in the ribs of the corduroy, in the spherical shape.

  - Stacking the shapes regularly for transportation caused the corduroy to permanently dent in certain spots.

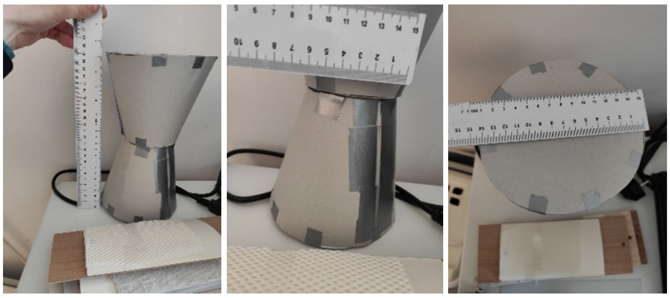

Dents in the ribs of the corduroy.

Appendix H: Ergonomics test with cardboard prototype

This appendix explains the ergonomics test that was done with a cardboard dummy of the Rotation Lamp.

This luminaire will evoke a different user interaction than the textile housing Bluetooth speaker products that were analysed in the product disassembly. Some of these products are hand-gripping size so they can be comfortably picked up with one hand. This product is expected to be handled differently.

The textile in the housing of this rotation lamp does not invite to pick up the whole product, rather to touch it and rotate the top part. To explore the user interaction that would occur with this product, a quick experiment was set up with a cardboard model. The diameter of the top and bottom is 14 cm and the product is 25 cm in height



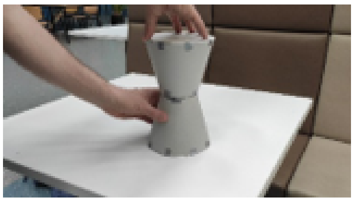
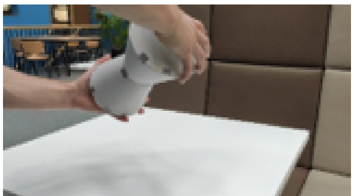
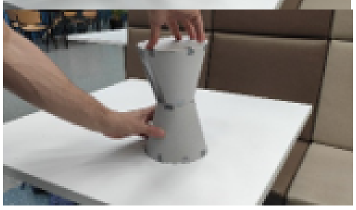
Top & bottom diameter: 14 cm; Middle part diameter: 7 cm; Height: 25 cm.

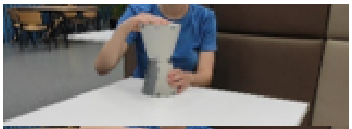
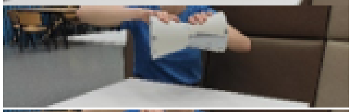
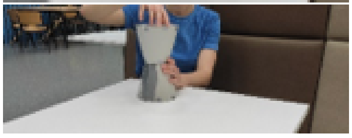
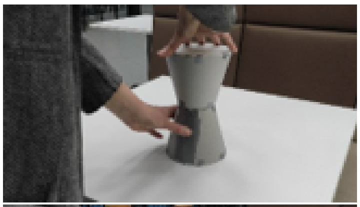
The chosen cardboard model was used and placed on a table. 9 participants (4 women, 5 men) were asked to intuitively rotate the product. The participants were all right handed. Since the product is symmetrical, it was not necessary to find more left handed participants: the user interaction would be the same but mirrored.

Filming these actions captured the intuitive movement and allowed to evaluate the minor changes in hand posture that happened during the interaction.

The observational notes are listed on the next page.

Expected user rotation handling.

No.	Gender	Pictures	Remarks
1	woman		
2	woman	 	With fingertips is most natural. Flat hand could also happen but is less comfortable.
3	man		Fingertips go slightly over the edge.
4	man		Uses his fingertips to apply pressure to the top to rotate it.
5	man	 	The participant said that he wanted to intuitively pick up the product to rotate it. In a stationary position, he would use his fingertips to rotate.

6	woman		Her hands were too small to grab over the top of the product, so she grabbed it to the top and the side. She also said that it would be logical to hold the lamp horizontal. Another alternative was to use her fingertips to the top.
7	man		This man had very large hands, so gripping with his fingertips over the edge gave him a lot of grip on the product.
8	woman		The top was too large to comfortably grab. She suggested making the top smaller for easier grabbing.
9	man		

Conclusion:

All participants intuitively grabbed the product at the top. For the people with smaller hands (mostly women) the top was too large in diameter (14cm) to grab it comfortably.

Interestingly, all the participants agreed on rotating from the top of the cone. It was expected that some would grab it on the side, but this was not the case.

Appendix I: Sock samples from Esther Jubbega

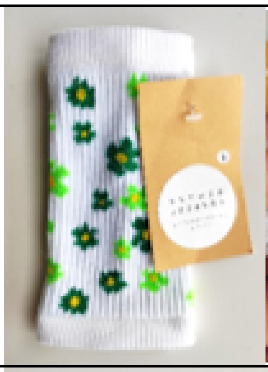
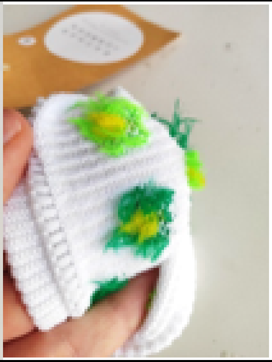
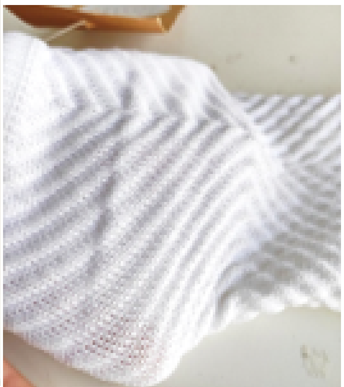
Circular knitted samples were provided by Esther Jubbega, a supplier connection from Signify. She is specialised in the production techniques and knitting patterns suitable for circular knitting, usually for the purpose of socks and underwear. For Signify she created 10 distinct different "socks" (tubes with two open ends) on a 16-cm diameter circular knitting machine.

These socks show the possibilities of making interesting patterns and shapes on circular knitting machines. They were used in the Socks & Cylinders experiment.

All sock samples have a tighter brim at the top and bottom so they will stay in place when stretched over a shape. This brim can be left out of the knitting process if desired.

This appendix provides information on each sock.

Sample no.	Pictures of sock	Properties
1		- White - Pure white and off-white yarns. - Horizontal square pattern.
2		- White - Pure white and off-white yarns - Open knit structure
3		- White - Pure white and off-white yarns - Diagonal diamond pattern
4		- White - Pure white and off-white yarns - Open knit structure
5		- White - Pure white yarns - Pattern bulges, flattens when stretched

6	 	- Pure white yarns - Two shades of green yarns - Yellow yarns - Flowers were embroidered after knitting process
7	 	- Pure white yarns - 4 pastel colour yarns - Dots were embroidered after knitting process
8	 	- Pure white yarns - Rib structure, vertical lines
9	 	- Pure white yarns - Three knit patterns - One pattern bulges, becomes flat when stretched
10	 	- Pure white yarns - Beige yarns - White-grey mixed yarns - Three knit patterns - Grey squares were embroidered after knitting process

Appendix J: Socks & cylinders experiment

In this appendix we will discuss the Socks & Cylinders experiment that was conducted to discover the design guidelines for continuous shapes with circular knitted fabrics.

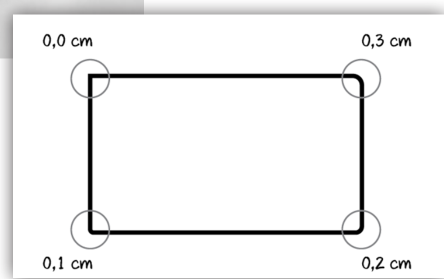
For this experiment we used 7 of the 10 sock samples of Esther Jubbega. The samples with colours and separately embroidered figures were left out because they do not fit with the sleek style of Philips Hue products (sock 6, 7 and 10).

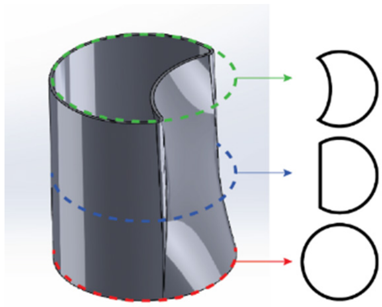
6 Shapes were collected and 3D-printed to be covered with these socks. They were covered with the 7 chosen socks to observe how they look. Four of these shapes were inspired by the shapes of Philips Hue products: cylindrical, conical, rectangular and spherical. The extra two were meant to explore more shaping possibilities.

The rectangular shape was used to assess the wrapping around edges with varying sharpness (fillets of 0,0-0,3cm). This was done to inspect the difference a sharp or rounded edge would make in the knitted fabric.

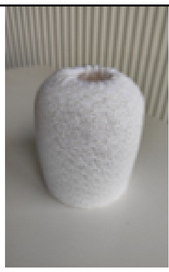
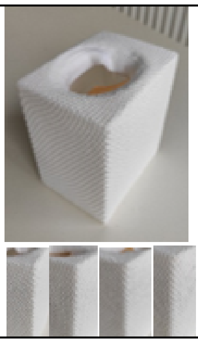
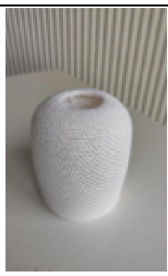
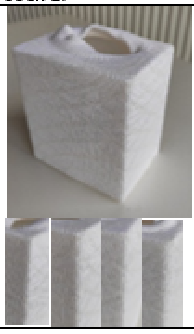
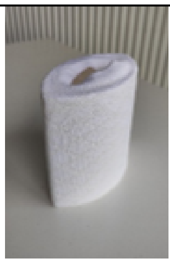
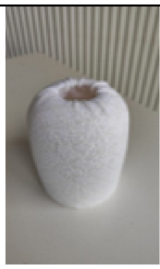
Instead of making a perfect cylinder, it was chosen to use this one as a demonstration for convex and concave shapes. The bottom cross-section makes a perfect circle and as we go upwards this shape transitions into a moon with one concave side.

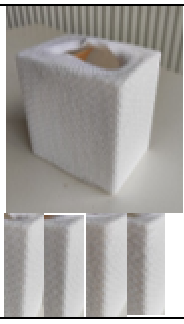
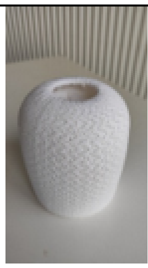
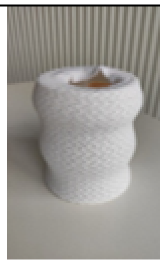
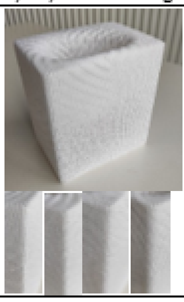
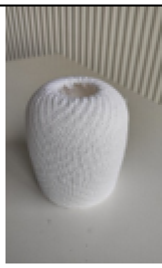
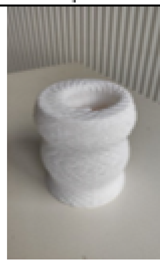
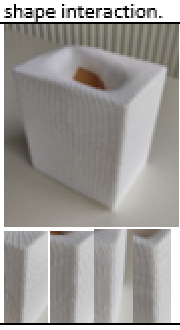
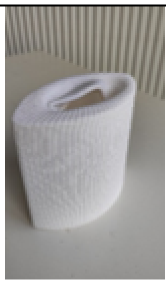
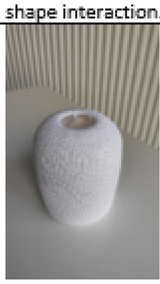
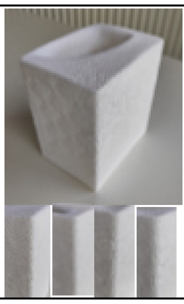
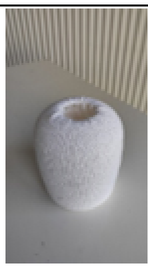
Each shape and the remarks when wrapping it with the socks are listed in the tables on the following pages.





a. Rectangular b. Flattened cylinder c. Spherical d. Cylindrical e. Wobbly f. Conical

Sock no.	**a. Rectangular shape**	**b. Flattened cylinder shape**	**c. Spherical shape**	**d. Convex-concave demo (cylindrical shape)**	**e. Wobbly shape**	**f. Conical shape**
1						
	The knit structure is opened slightly at the 0,0-0,2cm fillet edges.	Pattern suits the shape well.	Thickness does not allow tucking in at the top.	Vertical lines are clearly visible. Slight inwards pull.	Sock is too tight: inner diameter is not covered.	Square pattern gets smaller towards the top.
2						
	The knit structure does not allow to be opened as much as sock 1.	The knit structure has no distinctly visible lines.	Open knit structure allows tucking in.	Pattern is not apparent. Inwards pull.	Sock is evenly distributed.	Pattern is easy on the eye.
3						
	The knit structure is opened slightly at the 0,0 and 0,1cm fillet edges.	Knit pattern is mainly visible because of colour difference.	Thickness obstructs tucking in.	Strong inwards pull.	Interesting pattern-shape play.	Diamond shapes are consistently sizes throughout the surface.

4						
	The knit structure is opened slightly at the 0,0-0,2cm fillet edges.	Diagonal pattern is easy on the eyes.	Open knit allows tucking in.	Strong inwards pull.	Pattern is distributed over the shape.	Knit pattern is easy on the eyes.
5						
	The knit structure is opened slightly at the 0,0-0,2cm fillet edges. Interesting pattern-shape interaction.	Interesting shape-pattern interaction.	Fabric bulges at the top: not tight enough around shape. Interesting pattern-shape interaction.	Sock is tight, so inwards pull is little.	Pattern-shape interaction is interesting.	Pattern does not work well with this shape.
8						
	The knit structure is opened slightly at the 0,0-0,2cm fillet edges.	Vertical knit pattern is difficult to align with shape.	Rib knit structure allows tucking in.	Tight sock, so little inwards pull.	Lines do not have to be aligned straight	Orientation of the vertical lines is important.
9						
	The knit structure is opened slightly at the 0,0-0,2cm fillet edges.	Pattern change directs attention towards middle of the shape.	Dense knit does not allow tucking in. Pattern directs attention towards the middle.	Tight sock, little inwards pull.	Knit pattern difference does not suit this shape well.	Sock is not tight enough around the top part, the sock bulges.

Appendix K: Meeting with Roma Strickstoffe

The Textile Application Team of Signify had a digital meeting with Jürgen from the German company Roma Strickstoffe. They are specialised in the surface covering of components with textile. Acoustic translucent fabrics and the automotive industry are their main field of work. This appendix lists the meeting notes.

Textile covered parts, by Roma.

About the company:

- They have 20 employers.
- They are located in Balingen in the south of Germany. There is a lot of textile production in this area.
- They have over 10 years of experience in the field of textile covering.
- 75% of their business revenue consists of the production of knitted fabrics. The other 25% for covering housing parts with textile.
- They have about 150 different clients, in the field of womens fashion, toys (Schleiff), technical textiles, medicine industry and more.
- They have 40 round knitting machines. The smallest has a diameter of 65cm, the largest 100cm. These round fabrics can be cut to make a flat sheet with a maximum width of 200cm.
- They can make plain fabrics or patterned textiles with for example logos.

About the production of textile-covered parts:

- Can be done with gluing or ultrasound welding.
- For complex shapes glue is used, not ultrasound welding.
- The same method is used for the front and back (surface and inner edges).
- Parts that can be covered:
  - It is possible to cover wooden, metal or textile parts. Wood is usually used in high-end products.
  - For plastic you could use PS, ABS or PC for 3D-prints for example.
  - It is not possible to cover silicon or fat or greasy materials, or PP.
- To cover shapes properly it is necessary that sharp edges have a little radius.

Gluing:

Process:
For the surface they make use of two-component glue. One is spread onto the surface of the housing, the other to the textile.
These glues are sprayed onto the surfaces and the fabric is then formed over the shape by hand.
The glue is then thermally cured with light.
Finally the fabric is cut with a hot knife.

Glue:
There are different glues available for different usages, like solvent or water based. Water based glues are easier to remove.
For the automotive industry, special adhesives are used that can withstand temperatures of -40 to 60 degrees, and 90% humidity.

Ultrasound (thermal) welding:

- Is done only for large quantities because the start-up costs are relatively high. This is because of the complex tools that are being used.
- Is quicker for large quantities. 0.8 seconds per piece.
- Max 100.000 pieces per year.

About the textiles:

- They mainly use their own knitted fabrics for surface application, but it is also possible to used wovens.
- Because there are many other textile production companies in the area, they have connections that can provide textile they cannot produce themselves.

Custom fabric:
If you order fabric at Roma that needs to be dyed or printed, there is a minimum order of 200m2.
If different coloured yarns are used, the minimum order is 1000m2.
For fabric they have in stock, there is no minimum.

Spacer fabrics:
They are able to make spacer fabrics in-house of up to 3mm thick through circular knitting.
They have a supplier in their network with spacer fabrics up to 55mm.
Spacer fabric is often used to cover professional sound systems, for protection purposes.
It can also be used in climatic seats in upholstery.

- They offer fabrics from recycled polyester. Those are €10-20 per m2. Non-recycled polyesters are €5-10m2, about half the price.
- For acoustic panels they use 100% polyester. The acoustic qualities of cotton are not so good as those of polyester.
- It is possible to use coatings for the textiles with flame retardant or water repellent properties. This is done by a supplier. It can also be done by using flame retardant yarns in the knitting process.

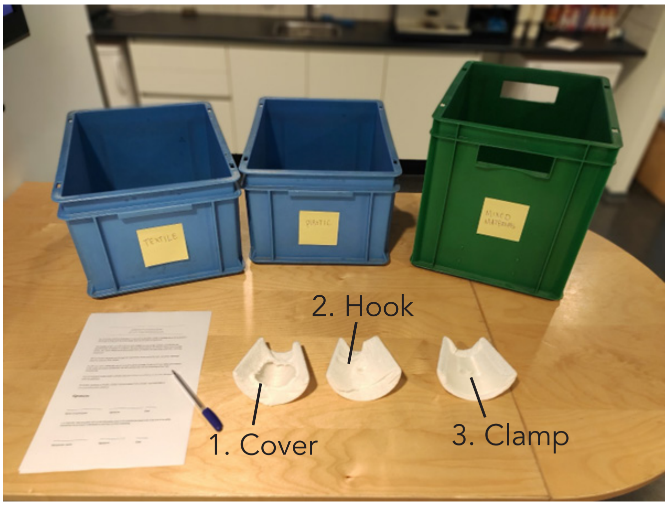
Appendix L: Disassembly methods validation test

To test the easy disassembly methods that were developed during this project a few prototypes were made. An experiment was set up to validate the users understanding of these prototypes. This appendix will describe the setup of the validation with a user test.

L.1 Goal

The goal of this research is to validate the intuitive understanding of three easy disassembly methods. These methods do not require any glue to fasten the textile onto product housings. We want to know the following:

- Do people intuitively understand that the fabric can be taken off?
- Are people willing to put in the effort to disassemble the textile housing?



Setup of the user test.

L.2 Method

A table was set up with the experiment materials. There were three bins labelled "Textile", "Plastic" and "Mixed materials".

Three prototypes of easy disassembly methods; one with a textile cover that is stretched over the surface (1. Cover); one with a hook in the middle over which fabric flaps are attached (2. Hook); one with a clamping mechanism (3. Clamp).

On the table there was also an informed consent form that the participants had to sign, which told them that their input would be used anonymously. (Shown on the next page.)

The participants were told that they were employees of a recycling facility and that they had to recycle these three product housings. The correct materials should go in each bin. If they could not take apart the textile from the plastic housing, they could drop the part in the "Mixed materials" bin.

After they had attempted to take apart each housing, they were debriefed about the context of this project and asked about their opinion on each of the three prototypes. The insights were collected and can be found in the results.

Informed consent form

User test - textile housing disassembly

You are being invited to participate in a research study titled "Textile as building blocks for luminaires". This study is being done by Tessa Arnold from the TU Delft and Signify B.V.

The purpose of this research study is to gain insights in a new design solution, and will take you approximately *10* minutes to complete. The data will be used for the Masters Thesis report of Tessa Arnold. We will be asking you to disassemble three prototypes, by separating textile from a housing component.

The researcher will guide you through the experiment. At the end of the test, you will be debriefed about the context of the project.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by processing all user data anonymously.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

For further questions or doubts, contact research student Tessa Arnold: +316 4209 0969 or t.w.n.arnold@student.tudelft.nl.

Signatures

____________________________ ___________________________ _________

Name of participant Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

__________________________ ____________________ _________

Researcher name Signature Date

L.3 Participants

In this experiment, 5 participants were asked to disassemble the product housing prototypes. In reality, this action would be executed by employees of a recycling facility. It was important to choose participants who are not familiar with this thesis project and who are not biased with knowledge of the easy disassembly methods. 5 random people from the faculty participated in the test and they resembled the unknowing recycling facility employees.

L.4 Results

Did the participants manage to take off the fabric from the housing, without any instructions?

	1. Cover	**2. Hook**	**3. Clamp**
Participant 1	Yes	Yes	Yes
Participant 2	Yes	Yes	Yes
Participant 3	Yes	Yes	No
Participant 4	Yes	Yes	Yes
Participant 5	Yes	Yes	Yes

All participants managed to take off the textile from the prototypes, except participant 3 with the clamping system. They thought that it took too much effort to do so, or that they would break the prototype.

The cover of prototype 1 was easily understood by all participants that the textile could be taken off. The same as for prototype 2. However all participants indicated that prototype 2 was easier to disassemble than prototype 1. It took them some effort to stretch the elastic of prototype 1 over all of the edges of the housing, whereas the flaps of prototype 2 cost no effort to take off.

The clamp was not intuitively understood by the participants. All participants who disassembled prototype 3 started by plucking at the edges of the textile to pull it from inbetween the housing and the clamp, before they noticed that the clamp could be slid out. After they discovered this they all said they preferred this method, because it only requires a single action to take off the textile contrary to the other prototypes. Participant 1 and 3 suggested to add a use cue like an arrow to indicate that the clamp can be slid down for removal.

L.5 Conclusion

- Do people intuitively understand that the fabric can be taken off?
For prototype 1 and 2 they do, but not for prototype 3. Thus, the cover and hook model are intuitively understood. The clamp did not communicate clearly enough that it could be clicked out.

- Are people willing to put in the effort to disassemble the textile housing?
For prototype 1 all participants were willing to disassemble the textile cover with ease. For prototype 2 the participants were careful when taking of the textile from the hook because they were afraid to break the housing. Prototype 3 was taken apart by four participants: one of them did not disassemble it because they did not understand how it should be done and they were afraid to break the prototype.

	Advantages	**Disadvantages**
1. Cover	- Clear usecues for disassembly	- Fabric will deform plastically over time - It requires some fiddling to take the textile off
2. Hook	- Clear usecues for disassembly - Easiest to disassemble	- Fabric will deform plastically over time - Disassembly process requires a few steps
3. Clamp	- Fabric does not deform plastically - On-step disassembly process	- Disassembly not intuitive without any instructions/usecues

L.6 Discussion

The participants were hesitant to disassemble the textile from the housings, because they were afraid to break the prototype. In reality, the employees of the recycling facilities are not afraid to use tools like a hammer to break a housing. It would be a problem for repairing or refurbishing, if the textile could not be taken off without breaking the housing: but for the recycling it would not be a problem.

Holes in the fabric of prototype 2 are stretched out.

The stretchability of the knitted fabric causes the holes for the hook system of prototype 2 to stretch and enlarge. The same goes for the overall fabric, causing the textile cover to fit loosely over the prototype over time. This is an undesired effect because the textile cover could become too loose to fit the housing element correctly.

This test focussed on the disassembly of the textile from the housing. In reality, these textile housings should firstly be taken off the rest of the product before arriving to this step. Since the recycling of the housings does not only rely on the textile housing part, the context of the whole product could influence the recycling employees' understanding of the disassembly potential.

Elastic band in prototype 1. Cover.

Making a textile cover similar to prototype 1, requires the fabric to be sewn. It might be required that an elastic band is added as well, to make sure the cover will stay on the housing. The question is however if these extra added yarns and elastic obstruct efficient textile recycling, since it requires more effort to separate the materials. Therefor this prototype is considered the least sustainable of the three.

L.7 Recommendations

To make sure that people who repair, refurbish or recycle these textile housings correctly, they should be designed in a way that they do not feel fragile. This could be done by altering the shape of the hook in prototype 2.

In order to communicate the recycling potential of these easy disassembly methods, some instructions or use cues (arrows) could be added to the inside of the product. This applies mainly to the clamping mechanism of prototype 3. It was not clear to the participants that the clamp can be removed, so this needs to be communicated through the design.

Improved clamp with arrow.

For further research, it is important to look at the complete context of recycling a textile housing product to see if this makes any difference in understandability of taking apart the textile from the rest of the product.

For prototype 3, a 3d-knitted cover could be made in order to maintain the highest recycling potential. In the prototype sewing was used to add an elastic band. However this costs extra effort to disassemble and this will probably not be done at recycling facilities. 3D-knitting allows the cover to be made from one type of yarn solely, which is favourable for the recycling.

The fastening of textiles in prototype 1 and 2 relied on stretching the fabric over the surface or onto a hook. Plastic deformation of these fabrics will take place over time, causing the fabric to loosen. Therefor these methods are more unreliable than the clamping method (prototype 3). This method does not require the fabric to stretch substantially.

If the design of the clamping method is improved, this method is considered the best for the application on circular textile housings. This is because it has the easiest single-step disassembly process in comparison to the other methods.

Appendix M: Team brainstorm

On the 14th of March, a brainstorm with the Signify textile application team was held. This appendix describes the setup and outcomes of the brainstorm.

M.1 Setup

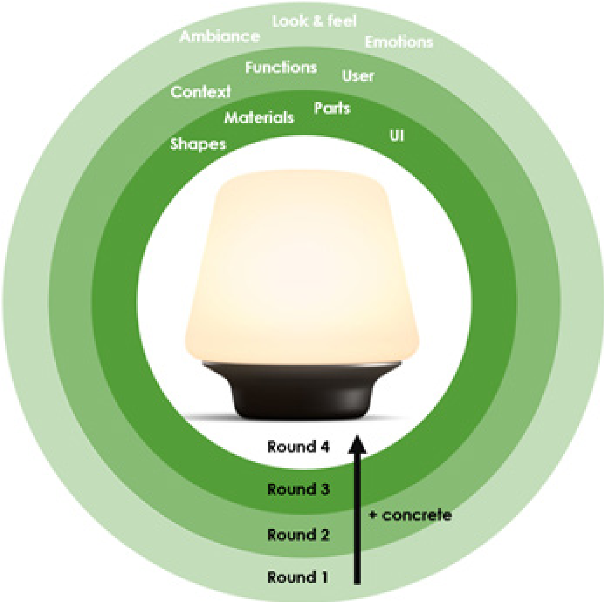
The team consisted of 6 people from Signify and one brainstorm leader.

The three main goals of the brainstorm were:

1. To discover the product vision of the new luminaire: what message should the product convey and how should the product be perceived?
2. To list all of the existing ideas that live in the minds of the people of this team: a few employees have been working on ideas for a textile luminaire design for multiple years now.
3. To kickstart the ideation phase, which will eventually lead to new product design concepts.

You can describe a luminaire very concretely: which materials, interfaces and shapes does it contain? However, we can also zoom out and ask ourselves what functions the luminaire has, or where and by whom the product will be used. If you zoom out even further, you can ask more fundamental questions about what message the product should convey.

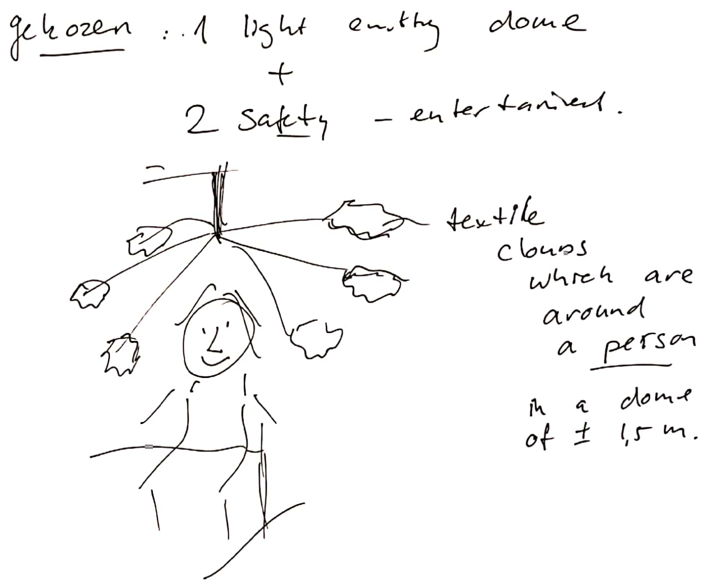
Four brainstorming rounds were prepared in which the team would work from the outer, more abstract circle, towards the concrete inner circle: which is basically the product design. This happened in 4 rounds.

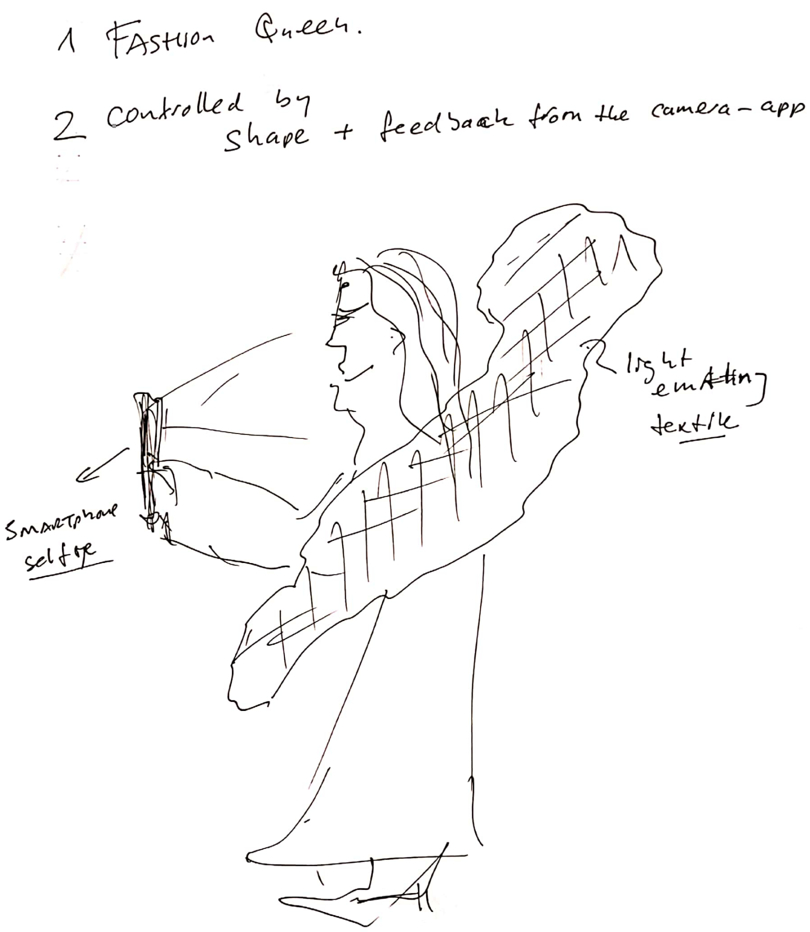


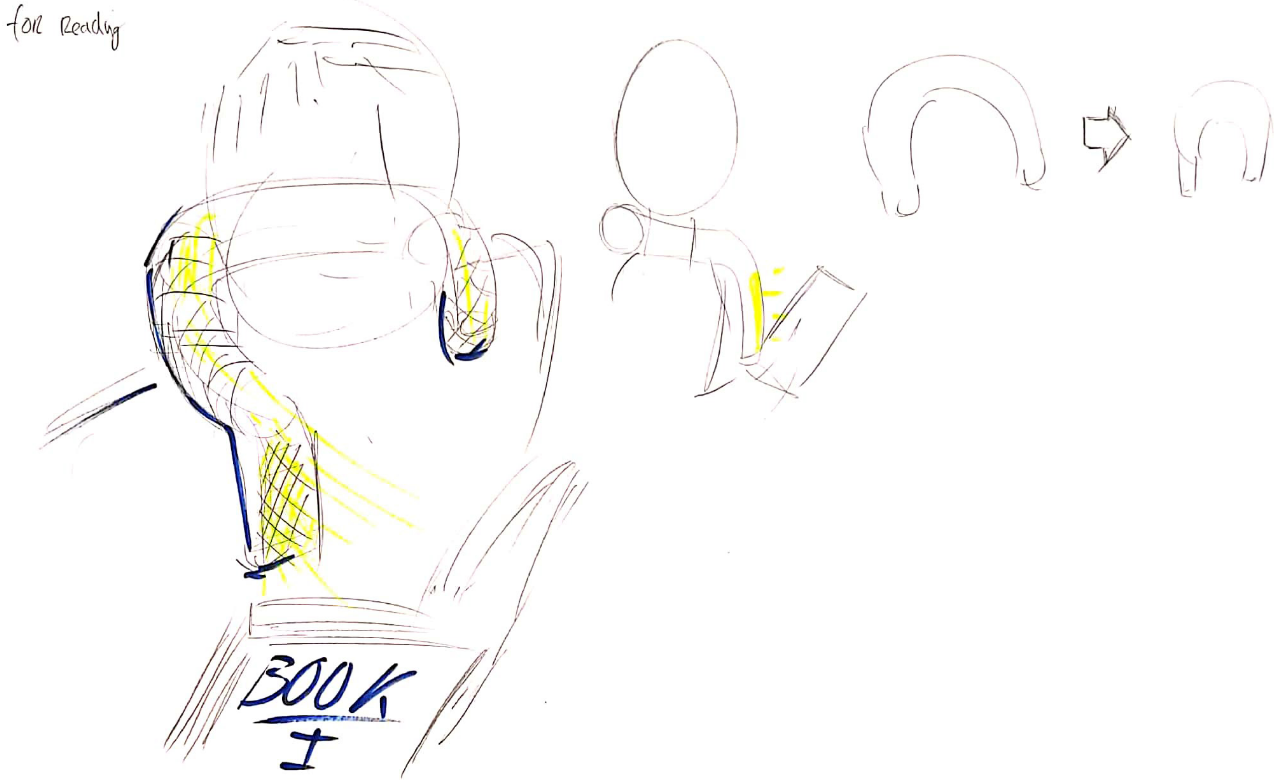
For inspiration in the last round, the surface shape experiment and fabric sample board were introduced to the team.

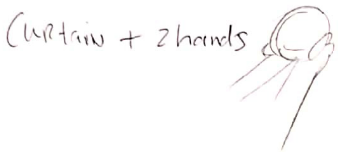
On the following pages you will find the outcomes of the last round.

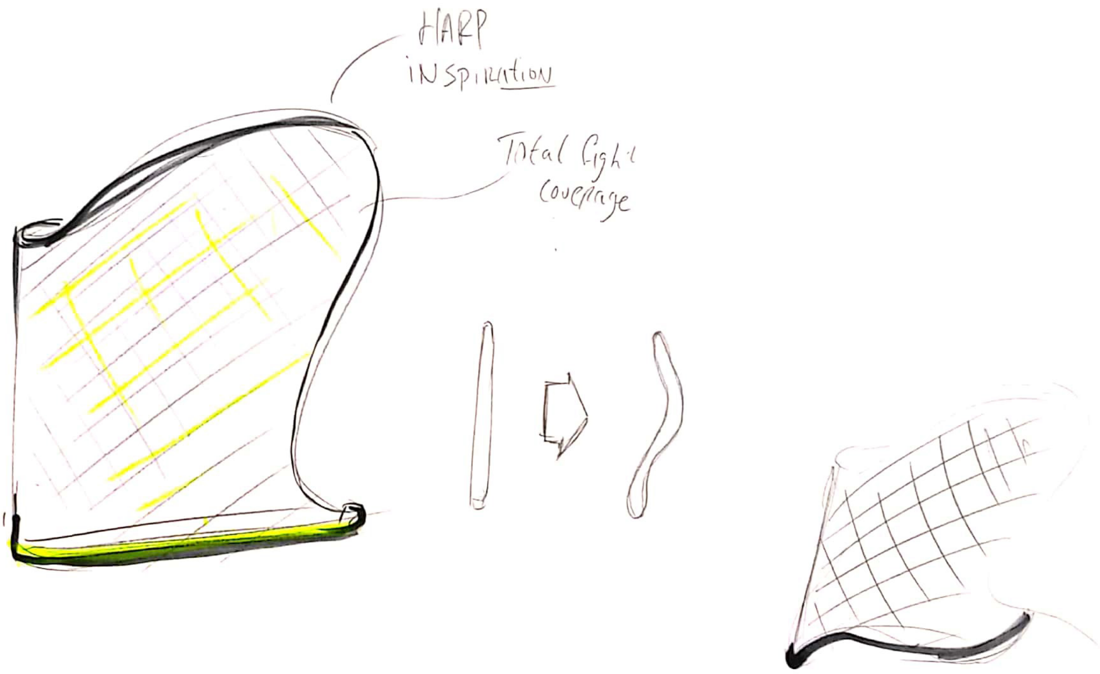
M.2 Results


gekozen: 1 light emitting dome
+
2 safety - entertained.
textile clouds which are around a person
in a dome of ± 1,5 m.


1 Fashion Queen.
2 controlled by shape + feedback from the camera-app
light emitting textile
smartphone selfie


for Reading
BOOK
I

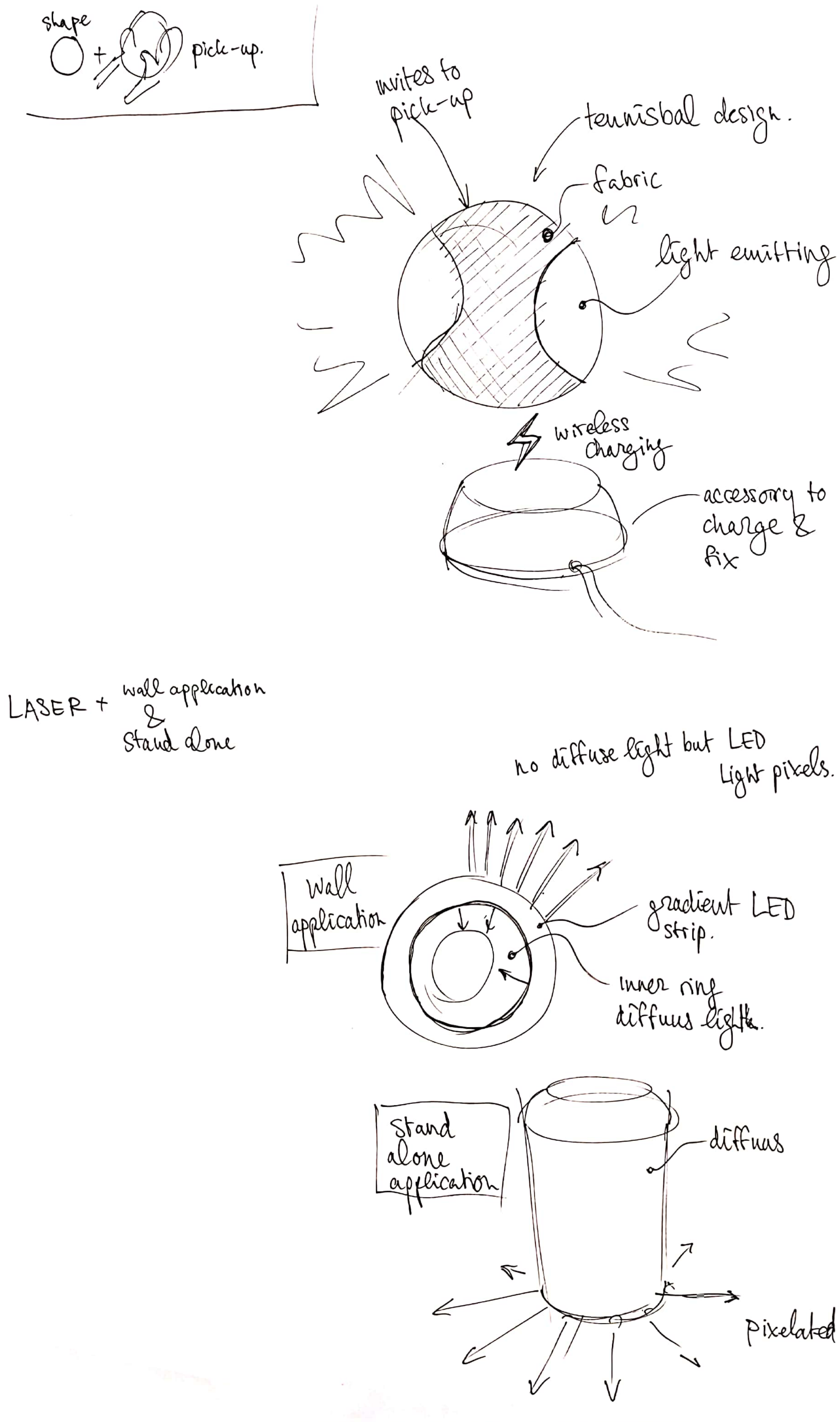

Curtain + 2hands


HARP
INSPIRATION
Total light
coverage

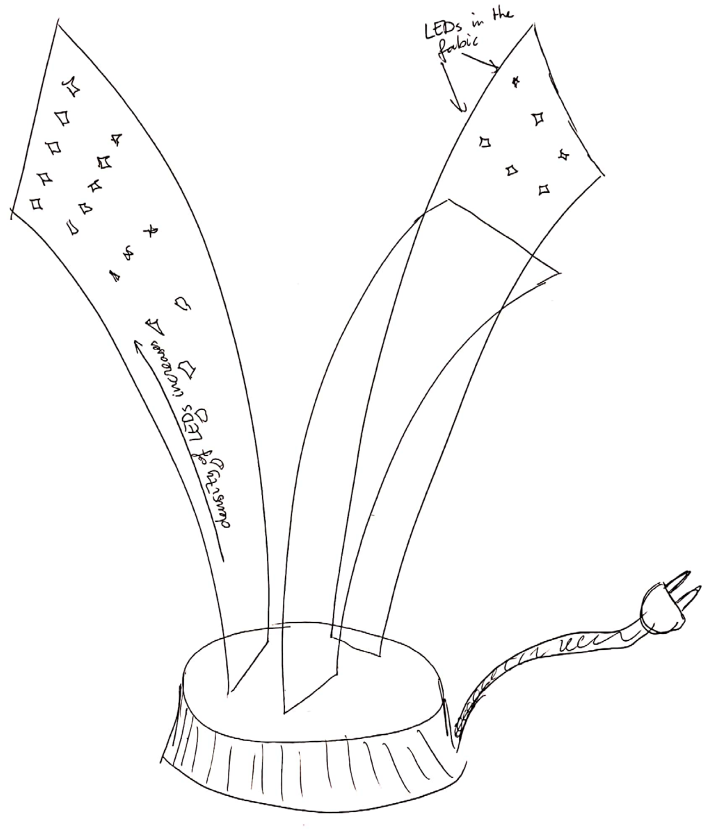

FOR
you!
GLOW
1. THE GIFT OF LIGHT.
2. JUST GLOWS.


FASHIONISTA
SNAKE.


you & me
tochtrol
Kussen.

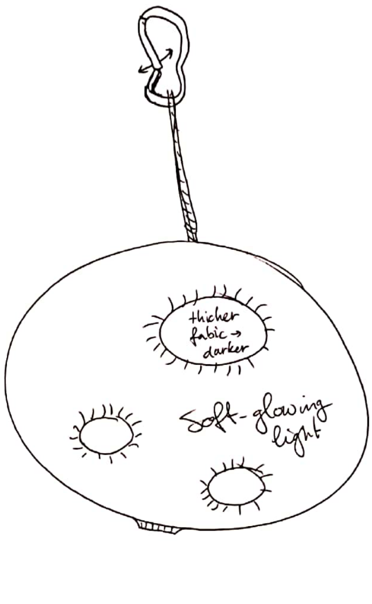

shape
+
pick-up.
invites to pick-up
tennisbal design.
fabric
light emitting
wireless charging
accessory to charge & fix
LASER + wall application & stand alone
no diffuse light but LED light pixels.
wall application
gradient LED strip.
inner ring diffuus light.
stand alone application
diffuus
pixelated

Reading
+
Diffuser



Moonlighting

Moon
+
off-the-grid
(in a forest)



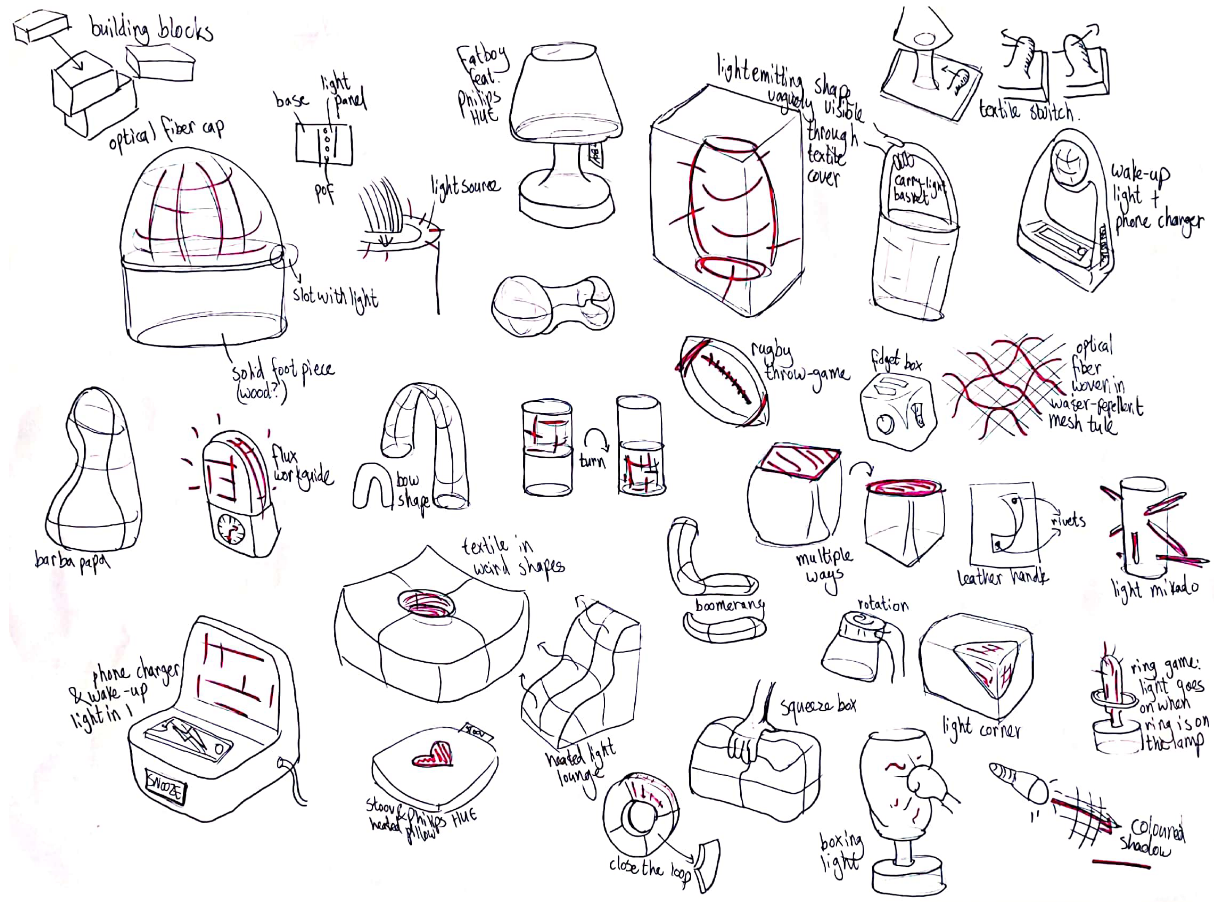
With the results from round 2 and 3 of this brainstorm, a morphological chart was created. This is an overview of the brainstorm ideas, placed in a grid. A selection of the most promising suggestions from the brainstorm were used and the empty spots were filled with some extra ideas. This morphological chart was the starting point of the product ideation.

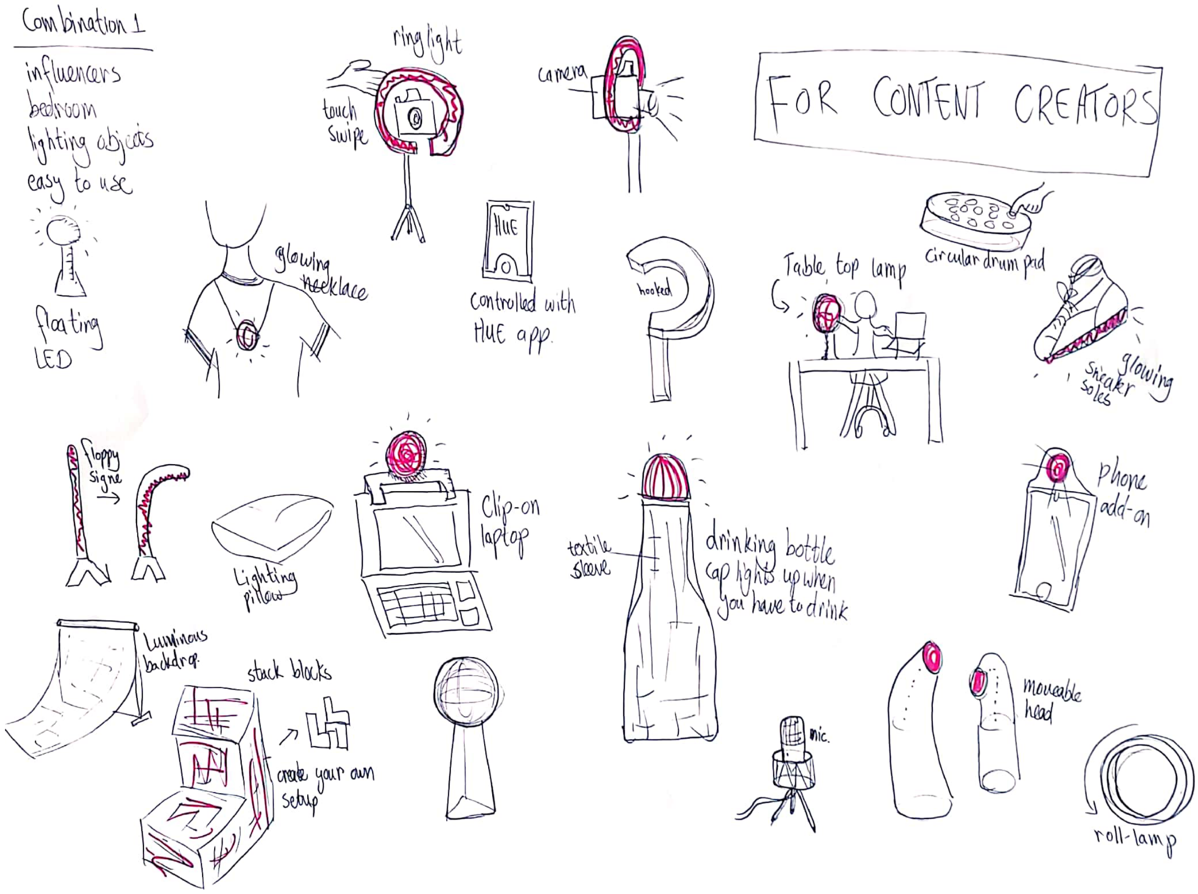
Morphological chart:

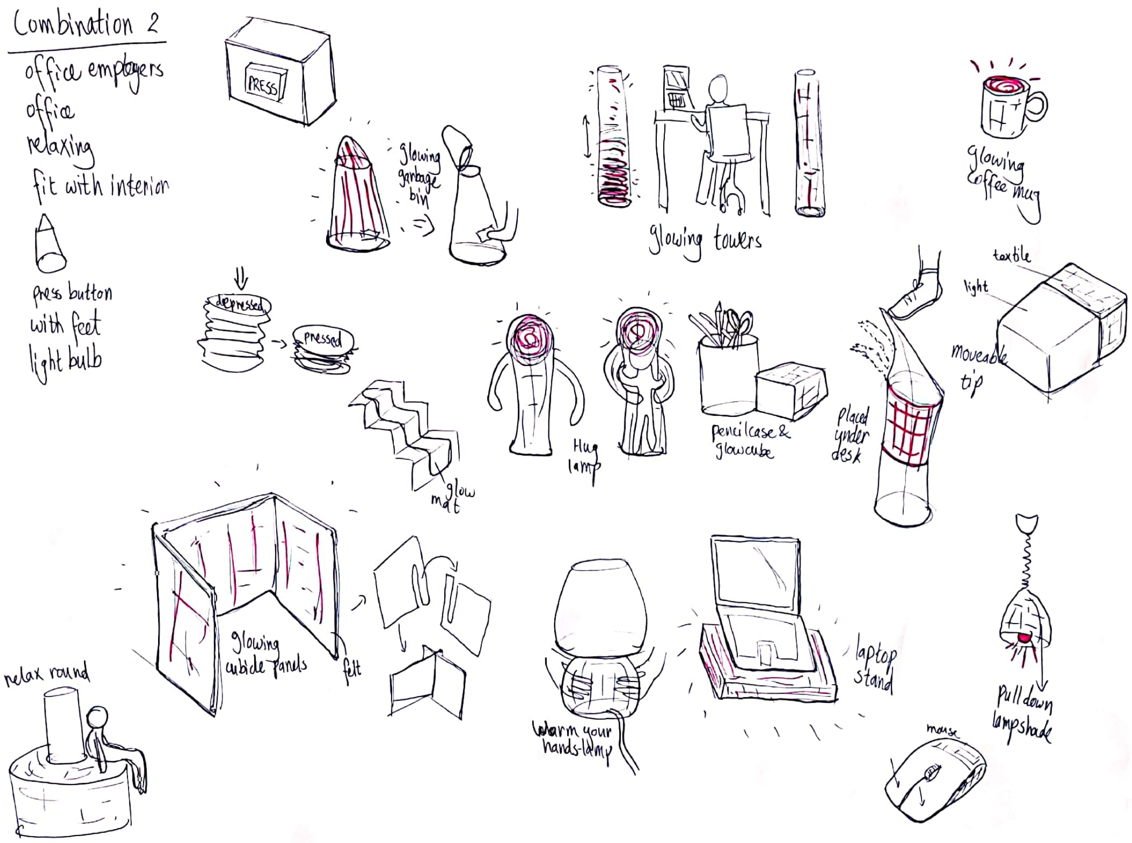
User	kids	influencers	families	moms	dads	women	men	office employers	elderly
Context	Living room	Bathroom	Kitchen	Bedroom	Outdoor	Rural areas	Office	When traveling	Party
Function	Providing safety	Create ambiance	Lighting objects	Party decoration	Home entertainment	Relaxing	Gift	Fashion accessory	Interact with other lights
Requirements	Inviting to touch	Fit with interior	Interesting user experience	easy to use	beautiful	useful	fit within HUE products	cozy feeling	portable
Shapes									
Interaction elements	press button	swipe interface	voice control	squeezable	switch or lever		sensor	link with HUE app	rotation knob
Pick up methods	With one finger	With two hands	As a bracelet	Like a bag	Handle	With feet	Floating	Magnetic connection	Grab with one hand
Light-emitting material	moon	sun	illuminated textile	optical fibers	LED	LASER	light bulb	bioluminescence	Fire

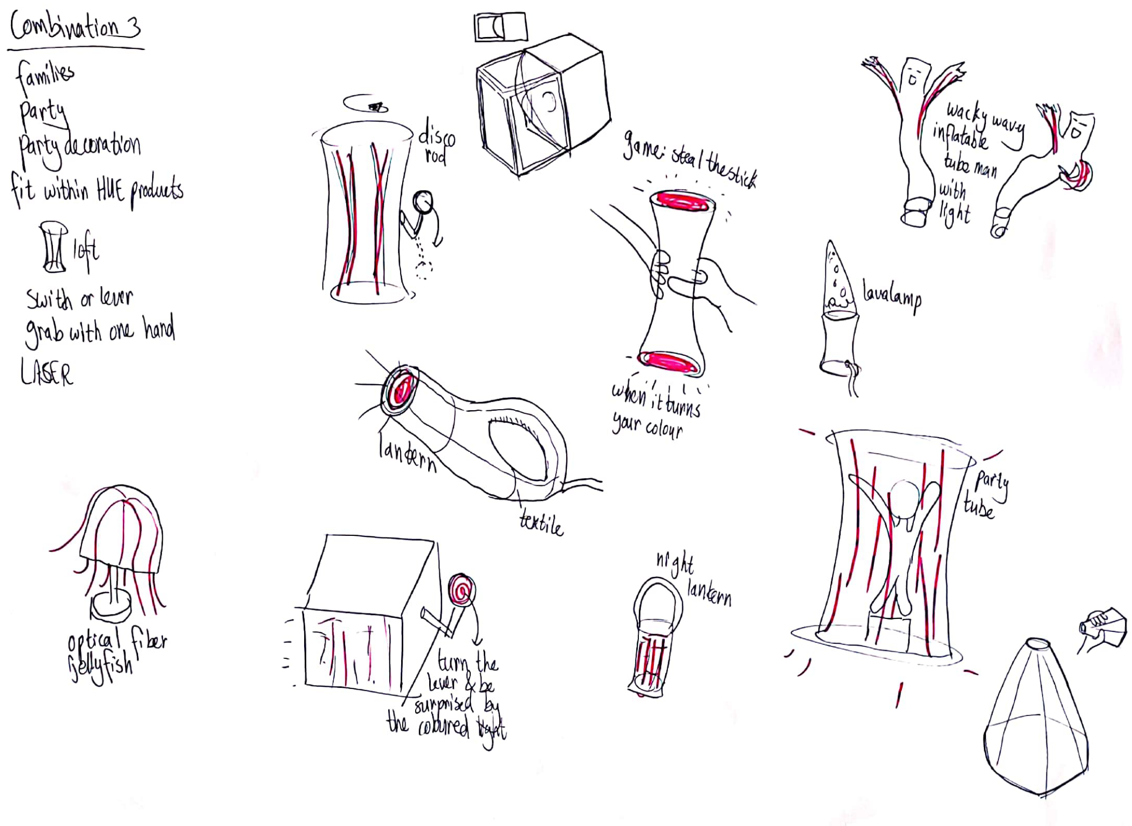
Appendix N: Product ideation

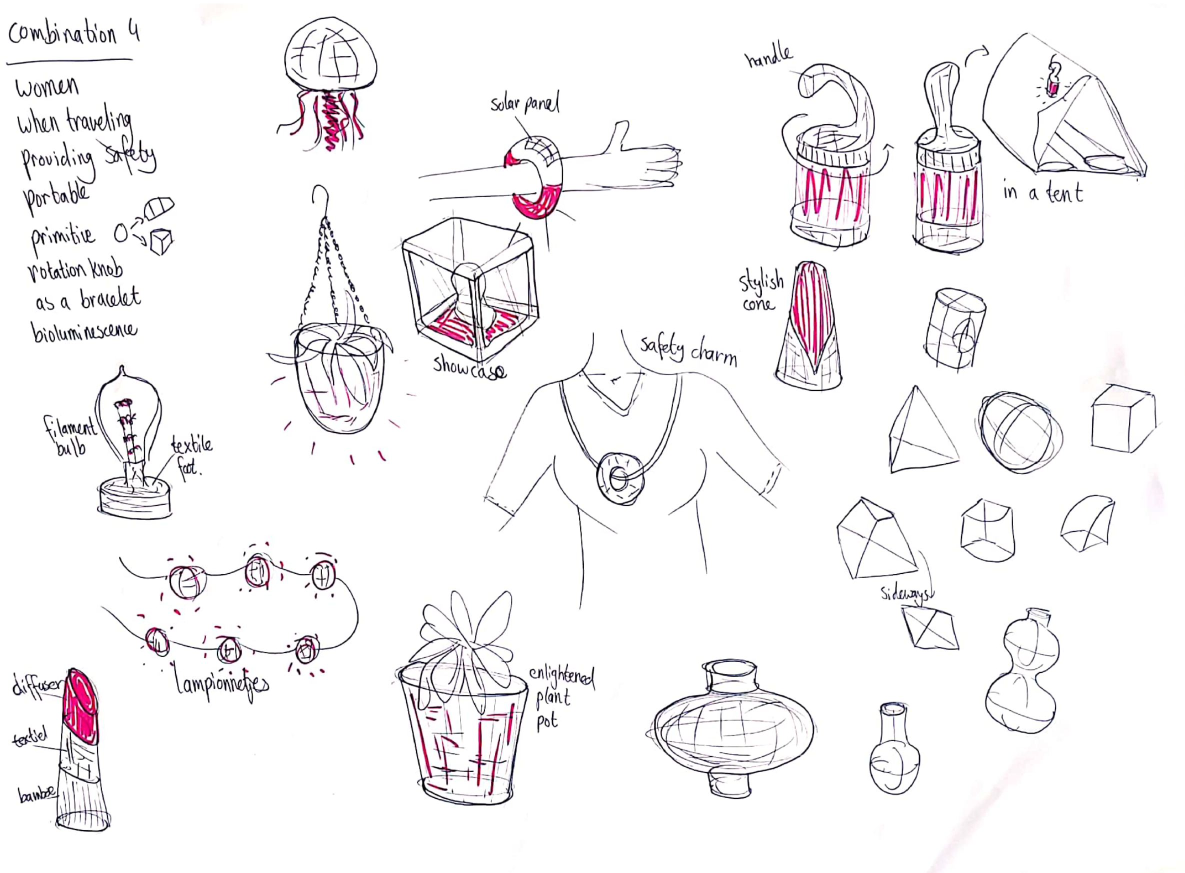
Many product ideas were generated during the ideation. The morphological chart was used to make innovative combinations, which inspired a part of the sketches. Other drawings were created during the project up until the point of the ideation. This appendix contains all sketches that were made during the ideation.

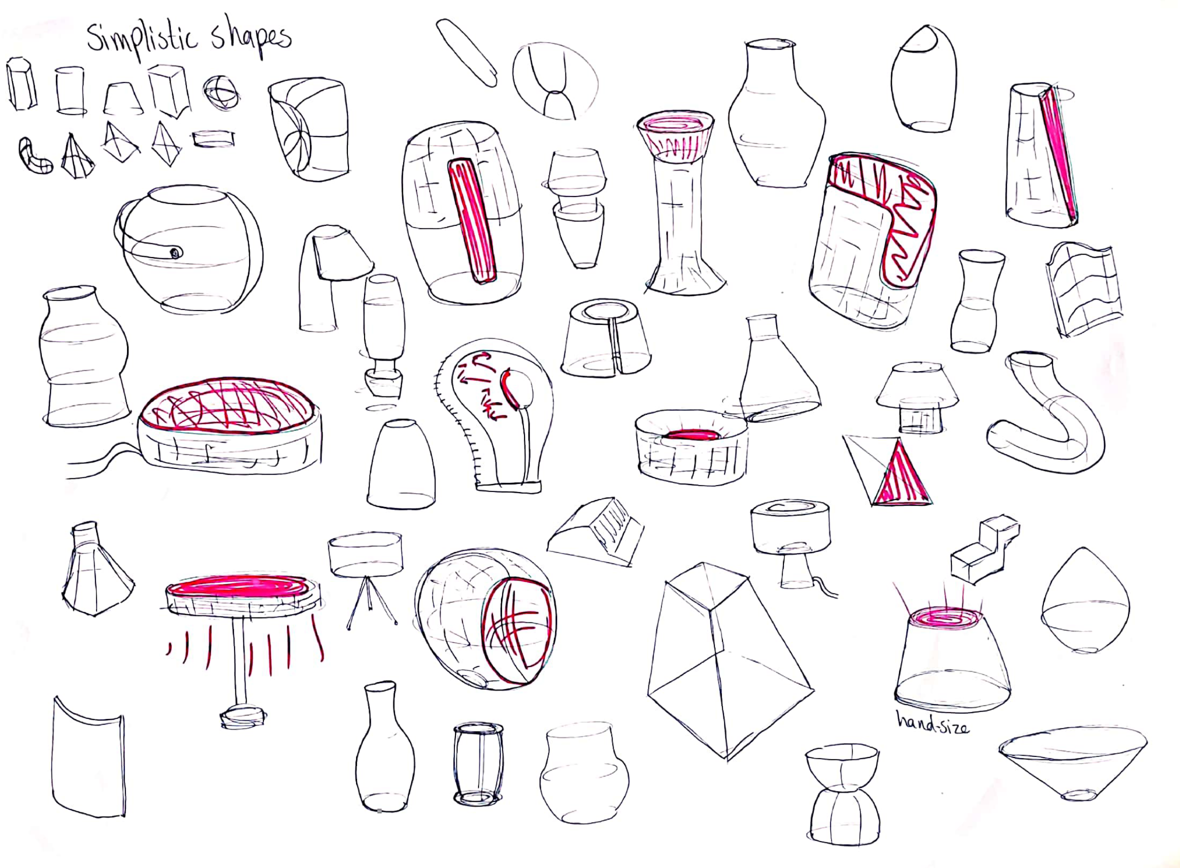

building blocks
optical fiber cap
base
light panel
pof
light source
slot with light
solid foot piece (wood?)
Fatboy feat. Philips HUE
lightemitting shape vaguely visible through textile cover
carry-light basket
textile switch.
wake-up light + phone charger
rugby throw-game
fidget box
optical fiber woven in water-repellent mesh tule
barbapapa
flux workguide
bow shape
turn
multiple ways
leather handle
rivets
light mikado
textile in weird shapes
boomerang
rotation
phone charger & wake-up light in 1
SNOOZE
Stoov & Philips HUE heated pillow
heated light lounge
close the loop
squeeze box
light corner
ring game: light goes on when ring is on the lamp
boxing light
coloured shadow


Combination 1
influencers
bedroom
lighting objects
easy to use
floating LED
ring light
touch swipe
camera
FOR CONTENT CREATORS
glowing necklace
HUE
controlled with HUE app.
hooked
Table top lamp
Circular drum pad
glowing sneaker soles
floppy signe
Lighting pillow
Clip-on laptop
textile sleeve
drinking bottle cap lights up when you have to drink
phone add-on
Luminous backdrop
stack blocks
create your own setup
mic.
moveable head
roll-lamp


Combination 2
office employers
office
relaxing
fit with interior
press button
with feet
light bulb
PRESS
glowing
garbage
bin
glowing towers
glowing
coffee mug
depressed
pressed
glow
mat
Hug
lamp
pencilcase &
glowcube
placed
under
desk
textile
light
moveable
tip
glowing
cubicle panels
felt
relax round
warm your
hands-lamp
laptop
stand
mouse
pull down
lampshade


Combination 3
families
party
party decoration
fit within HUE products
loft
switch or lever
grab with one hand
LASER
disco
rod
game: steal the stick
when it turns
your colour
wacky wavy
inflatable
tube man
with
light
lavalamp
lantern
textile
party
tube
optical fiber
jellyfish
turn the
lever & be
surprised by
the coloured light
night
lantern


combination 4
women
when traveling
providing safety
portable
rotation knob
as a bracelet
bioluminescence
filament bulb
textile foot.
solar panel
showcase
safety charm
handle
in a tent
stylish cone
enlightened plant pot
diffuser
textiel


Simplistic shapes
hand-size

Tessa Arnold
Graduation thesis, 2022
MSc. Integrated Product Design