Sustainable furniture design

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MASTER THESIS

Soeco

Sustainable furniture design

Giving new life to abundant table tops

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Abstract

To face the rising challenges of climate change, average consumers, institutions and governments need to work towards more sustainable production and consumption. *Soeco Kontorsmöbler AB* is an established company focused on refurbishing and bringing older furniture back into circulation. On behalf of *Soeco,* the project team was challenged to create a sustainable lounge furniture constructed entirely from old leftover tabletops, and working to adhere to requirements set by prominent eco labels on the Swedish market. The resulting furniture is meant to be a competitive product that will prove the usefulness of discarded materials.

Furniture design is a storied subject that spans centuries of discoveries and innovation. To design a furniture in a vacuum without the proper understanding of what has come before is an impossibility. To both pay respect and push the envelope, by creating a familiar yet unique design, the team thoroughly researched the relevant history of furniture design.

From scratch, the project team generated a complete design and construction concept that utilises old tabletops made from medium density fibreboard as material for the frame, textile created from 100% recycled ocean plastics and with minimisation of other used materials. To meet the requirements set by eco labels the team also tested samples of different old medium density fibreboard tabletops for formaldehyde emissions at RISE. The product developed in this project is a visually striking design developed for sustainable production and ready to become a market competitor certified by eco labels.

Keywords: MDF, Formaldehyde, Sustainability, Design, Furniture

Sammanfattning

För att överkomma de ökande klimatförändringarnas utmaningar måste konsumenter, institutioner och myndigheter arbeta för en mer hållbar produktion och konsumtion. *Soeco Kontorsmöbler AB* är ett etablerat företag inriktat på att rusta upp och återbruka äldre möbler. På uppdrag av *Soeco* utmanades projektgruppen att skapa en hållbar loungemöbel helt konstruerad av gamla överblivna bordsskivor, och arbeta för att följa krav som ställs av framstående miljömärkningar på den svenska marknaden. Den resulterande möbeln är tänkt att vara en konkurrenskraftig produkt som kommer att bevisa användbarheten av kasserade material.

Möbeldesign är ett historiskt ämne som sträcker sig över århundraden av upptäckter och innovation. Att designa en möbel i ett vakuum utan ordentlig förståelse för vad som har kommit innan är en omöjlighet. För att både visa respekt och tänja på gränser, genom att skapa en välbekant men ändå unik design, undersökte teamet grundligt den relevanta historien om möbeldesign.

Projektgruppen genererade från grunden ett fullständigt design- och konstruktionskoncept som använder gamla bordsskivor gjorda av MDF som material för ramen, med textil skapad av 100 % återvunnen plast från haven och med minimering av andra använda material. För att uppfylla kraven som ställs av miljömärkningar testade teamet även olika gamla bordsskivor av MDF för formaldehydemissioner vid RISE. Produkten som utvecklats i detta projekt är en visuellt tilltalande design utvecklad för hållbar produktion och redo att bli en marknadskonkurrent certifierad av miljömärkningar.

Nyckelord: MDF, Formaldehyd, Hållbarhet, Design, Möbler

Foreword

The team would like to thank the amazing personnel at *Soeco Kontorsmöbler AB* for their immense patience and assistance with seeing this project through. No matter the problem they would assist the team to their fullest extent. The team would also like to thank Ola and Tor Sjödin for their expert knowledge of the furniture sphere and for giving the team this opportunity in the first place. Lastly the team would like to thank Thomas Vaessen at RISE and Per Kristav for being an understanding supervisor.

Lund, June 2023

Henrik Wikström Lilliehöök and Marcus Johansson

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1 Introduction

During the summer of 2022 Henrik was working as a CAD-designer for Soeco Kontorsmöbler AB and as an experiment he was tasked with recreating the wooden frame of a prototype armchair entirely from leftover medium density fibreboard (MDF) previously used as office tabletops. The result was an armchair frame almost entirely constructed without the use of screws or other bolted connections in only MDF. This frame became the groundwork and principal idea behind the company's decision to expand the concept into an entire product line, and as such the authors of this report were tasked to design this product line concept with a focus on sustainability, reusable materials and recycling.

1.1 About Soeco Kontorsmöbler AB

Soeco Kontorsmöbler AB is a company based in Dalby, Skåne, specialised in revitalising and recycling office furniture. It was founded in 2012 with a vision to help contribute to a sustainable world and a human society. Their main business model is to obtain worn and undesirable tables, chairs, sofas, etc. in order to recondition and sell them at about half the new price. They also offer services such as tailored adaptations of existing products and furniture that do not meet quality standards are taken apart to be recycled. As a reference, they own the exclusive right to refurbish all furniture at Grand Hotel in Lund.

1.2 The Problem and Brief

Soeco has a large and constant flow of office furniture and accessories to said furniture, this flow generates a surplus of some unused materials that after enough stockpiling most often only ends up leaving the company as trash. These unused materials serve as the origin of the problem presented by *Soeco* to the authors of this report, and the brief they formulated goes as follows:

1.2.1 The Brief

Create and design a modular lounge furniture, constructed from the surplus material present at *Soeco Kontorsmöbler AB* in Dalby, Skåne. The furniture created shall put sustainability first and adhere to the requirements set by eco labels such as *Nordic Swan Ecolabel* and *Möbelfakta*.

2 Methodology

This chapter accounts for the methodology of this project, what framework used and how the different phases of the project were planned and performed, this chapter also serves as a rough overview of the pre-sprint part of the project. An initial broad strokes Gantt chart was created early to outline a general timeframe of the project. The Gantt chart can be seen in appendix A.1.

2.1 Double diamond and Scrum

This project is going to adhere to the principles of the double diamond design process as described in an article by The British Design Council (2007, p.6) and the Scrum methodology presented by Ken Schwaber and Jeff Sutherland in their publication *The 2020 Scrum Guide™* (2020). This will work by merging the two methodologies together, the double diamond design process entails four steps; Discover, Define, Develop and Deliver. The first two, discover and define are done initially through research and collecting inspiration, and then the last two, develop and deliver will be done repeatedly through four sprints. From one sprint to the next, data gathered and lessons learned as well as feedback from the company will refine the concept to a completion point. The modified hybrid design process can be seen in figure 2.1.

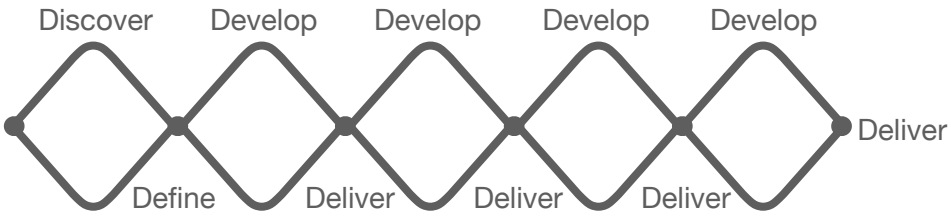

Figure 2.1 The modified hybrid design process used in this project.

To complement the design process, occasional uses of elements from the book *Product Design and Development,* Ulrich and Eppinger (2012) will be used. Their practices can be considered the golden standard of product development and elements can be weaved into any design process.

2.2 Discover and Define

To correctly design and develop a product, proper respect and time must be given to research and data gathering. The team spent most of the beginning of the project researching any relevant topic to furniture design and the results of that data gathering can be read in following chapters, these chapters serve as a databank of relevant and important information for this project. The topics discussed are;

- Chapter 3 Relevant History of the Subject
- Chapter 4 Needs analysis
- Chapter 5 Market analysis
- Chapter 6 Function analysis
- Chapter 7 Anthropometrics and Standards
- Chapter 8 Materials and Constraints.

2.2.1 Needs Analysis

Every product ever created serves a purpose, because products invented serve to solve the needs of the world through functions and solutions. In their book *Product Design and Development,* Ulrich and Eppinger (2012), the titular writers describe the early stages of product development and their concept for needs analysis will be utilised in this project. The need analysis concept was deemed an industry standard methodology that is easy to apply to any project.

2.2.2 Market Analysis

One of many goals with this project is to deliver a product and a production concept that is competitive with existing or future products on the market. To achieve this goal proper market research needs to be performed and time spent understanding what lounge furniture needs to be unique on the market. Many points of interest relevant to the market today was identified through varied means and can be read in chapter 5.

2.2.3 Function Analysis

To extract any relevant information from a needs analysis, information that in turn provides usefulness to the project, the needs analysis must be followed by a function analysis, as described by Ulrich and Eppinger. The function analysis defines how to provide solutions for the needs in the form of functions of the product.

2.2.4 Anthropometrics and standards

Anthropometrics is the study of standard measurements in conjunction with products that interact with the human body, and is an important part in designing any furniture. Another important aspect of designing furniture are the standards that need to be met. Sweden is a European country and as such the relevant standards to adhere to are ISO.

2.2.5 Materials and Constraints

The material chapter will discuss what materials the project has access to and to analyse initial information or relevant starting points for the material situation and constraints the project is bound by. The limits and possibilities of the materials will come to light through the course and sprints of the project, but expectations and hypothesis' regarding the materials will be discussed here.

Since the team seek to meet the requirements set by eco labels, the demands they enforce will be a reoccurring component present throughout the entire project. How the eco labels work and how the team will adhere to them will be discussed here.

2.2.6 Expert guidance

Throughout this project the team will consult with experts from the executive board at *Soeco*. This expert guidance will serve as a substitute for user research, as their knowledge of the market and consumer base will serve to elevate this project.

2.3 Develop and Deliver

This is the part of the design process that this project will repeat in an attempt to assist in achieving goals quicker and keeping the project on track and on time.

2.3.1 The sprints

The four sprints were planned to span around three weeks a piece and to each encompass three phases; Concept Generation/Selection/Refinement, Testing and Evaluation (see appendix A.1 for Gantt chart). When evaluating each sprint a sprint review will be held with company executives, where they get to voice input and feedback. These sprint reviews are important to keep the project going forward in a steady productive pace and to make sure the company whose project this is get the results they desire.

The fourth and final sprint will be five weeks instead of three, this was done with the expectation that the final prototype will need more time, since the final prototype will be full scale and full function.

2.3.2 Concept Selection

To select the most promising concept to develop further the team constructed a concept selection process inspired by Ulrich and Eppinger, that ties the generated concepts back to the needs and function analysis and ranks each concept on how well they solve the stated needs.

3 Relevant History of the subject

Furniture manufacturing and design has a long and widespread history that is to complex to recount shortly. However parts of that history is relevant and gives insight into choices made by the team during the project. The relevant history and inspiration brought through said history will be discussed in this chapter.

3.1 How this information was gathered

Early during the projects timeframe the team spent some time in the library of the Architectural building at the LTH campus, researching relevant furniture design history. The books read and cited here are; *100 år Med Svenska Möbler,* Bertil Arwidson (2006), *Modern Furniture Classics Since 1945,* Charlotte Fiell and Peter Fiell (1991) and *Chairs: 20th-Century Classics,* Scala Quin (2013).

3.2 Modern Furniture Design; A Short Summary

In their book *Modern Furniture Classics Since 1945,* Charlotte Fiell and Peter Fiell, the authors describe and exemplifies the history of 20th-century furniture. The book is divided into five main chapters corresponding to five eras spanning from 1945 to 1980, with an introductory chapter glossing over 1900-1945 discussing trends from 20s and 30s that are relevant to understanding the later history.

The authors identify a clear change in furniture design around the birth of modernism. During the 1800s, pretty much all furniture was made from wood, but with the rise of more sophisticated metalworking factories and tools, furniture designers adopted metal into their modern designs. A few examples can be seen in the following figure 3.1.

Figure 3.1 Mart Stam, Chair S33 (1926) and Le Corbusier, Grand Comfort (1928)

Within the woodworking industry, the tools and ability to create bent wood also evolved during this period, giving rise to sleeker wood built designs like the Swedish Eva chair from 1934 (See figure 3.2), made from laminated beechwood and hemp webbing.

Figure 3.2 Bruno Mathsson, Eva (1934)

Before the second world war Bauhaus was an industry leading pioneer, but in slew of growing Nazi power in Germany the factory closed. The second world war put a halt on European furniture design. However in the USA the industry could sustain during the war, in particular Charles Eames and associates developed advanced techniques for pressing laminated wood, which paved the way for a new type of design during the 50s. The second world war increased the need for more cost effective manufacturing methods, as well as the generation of new materials such as nylon, acrylics, polyesters and moulding of plastics.

1945-1950 paved the way for rationalism, where function came before form and the manufacturing methods guided the design. The popular styles worldwide were Italian, American and Scandinavian (See figure 3.3). Consumers became more aware of design and retailers started using designer labels as a sales driving tool. This essentially gave birth to designer furniture as we know it today.

Figure 3.3 (American) Eames Birch LCW chair (1946), (Scandinavian) NV-45 by Finn Juhl (1945), (Italian) Side Chair by Carlo Mollino (1948)

The next era the authors describe is the ascendancy of organic design. Once the wounds of the war had started to heal, design started to push boundaries again becoming idealistic and parting from the geometric and organised to embrace organic and unbound forms. Here follows examples of organic design (Figure 3.4).

Figure 3.4 3107 by Fritz Hansen (1955), Tulip by Eero Saarinen (1955), Eames Lounge by Charles Eames (1955)

The social and political issues of the 60s can be seen in the furniture from that time. Baby boomers were coming of age which put youth into designer labels, pop culture became important for furniture as well, creating the mass market of furniture. The rise of socialism and the aspiration of a classless society took furniture from permanence, class and as a status object, to something unpretentious, cost effective and liberal minded. Norms were blurred or erased which gave rise to anti design. Cheap petroleum increased the usage of plastics, contributing to strong, lightweight and visually striking furniture becoming popular (See figure 3.5).

Figure 3.5 CL9 Ribbon Chair (1961) and Castle Chair by Wendell Castle (1969)

As the years went on the fight between the young and the old continue, traditionalism versus radical design, expressions that continued to evolve in more absurdist ways. However the energy crisis of the 70s revitalised the post war manufacturing methods as plastics became less economically feasible for mass production. This era was also the start of the climate movement, in Scandinavia this ecological reverence could be seen in furniture that required as few different materials as possible. Design overall became more reasonable and responsible, returning to the use of more traditional materials like wood and steel (See figure 3.6).

Figure 3.6 Omkstak Chair by Rodney Kinsman (1971) and Hombre Chair by Burkhard Vogtherr (1971)

The 80s were a time of great economic growth in conjunction with the apparent political global success of capitalism. Many companies grew and with that growth the furniture contract market grew as well, since companies realised that the public and office spaces they need furbished depend greatly on proper furniture and the furniture they buy help in creating a corporate identity. The late 80s and early 90s were a great period for lounge furniture. (Charlotte Fiell; Peter Fiell)

The decades since have had their comings and goings, but they can be encapsulated in trends of sustainability, functionalism and simplicity.

3.3 Inspiration

Early in the project the team spent some time looking through product catalogues of several large players on the Swedish furniture market. Seeking inspiration and understanding of the shapes, expressions and forms of the modern furniture market.

The company *Blå Station* has since 1986 created innovative furniture that has taken the Swedish market by storm, some of their most renowned products include *BOB, DENT* and *Innovation C,* seen in figure 3.7.

Figure 3.7 BOB, DENT and Innovation C by Blå Station

Offecct is a large Scandinavian design company with a broad repertoire of furniture for every purpose imaginable. Some of their furniture that partly inspired this project are *Smallroom Plus, Solitaire* and *Lucy,* seen in figure 3.8.

Figure 3.8 Smallroom Plus, Solitaire and Lucy by Offecct.

Other companies with relevant products that was used as inspiration are *EFG* and *Kinnarps*.

4 Needs analysis

The brief states that this project shall create a lounge furniture, but what defines a lounge furniture and what needs do it fulfill? Where, how and why are lounge furniture used? The following needs were generated through team analysis and help from Soeco executives.

Table 4.1 The needs of a lounge furniture.

Need Number	Need Description
1	Be able to sit down
2	Be able to offload items
3	Comfortable sitting
4	Easy to clean
5	Easy to reupholster
6	Easy to reconfigure (modular)
7	Sustainable
8	Easy to transport and assemble
9	Appealing design
10	Easy to manufacture

5 Market analysis

The modern furniture market is ever changing and to be competitive on said market one need a proper understanding over what is popular but also a reflective understanding to gleam possible future trends and opportunities. This chapter will discuss relevant market trends and why they are important to this project. Focus was to explore colours, shapes, textiles, materials and other expressions within the furniture market.

5.1 Lounge Furniture in Malmö and Lund, Skåne

As a startup to the project and an opportunity to gather inspiration the team visited many locations across Malmö and Lund. The aim was to view and analyse lounge furniture, but lounge settings as a whole were examined. The locations visited include, but not limited to; *Malmö University Niagara*, *Clarion Hotel Malmö Live, Scandic Hotel Triangeln, Lund University Library, Grand Hotel Lund and Stadshallen Lund.*

5.2 Stockholm Furniture Fair

From February 7th to 12th 2023 the annual *Stockholm Furniture Fair* was held in Älvsjö, a part of Stockholm city. The team was present at this fair to gather inspiration and information for this project (See figure 5.1). The *Stockholm Furniture Fair* is a tradition that started in 1951 and recently had their 70th jubilee. The fair partners with many giants within the Swedish and European furniture industry and this year around 500 companies and institutions had exhibitions present. The fair proved a valuable source of information and inspiration as well as an opportunity to meet and speak with peers within the field.

Figure 5.1 Stockholm Furniture Fair

5.3 Identified Trends

The following trends have been observed during research and at the Stockholm furniture fair:

5.3.1 Scandinavian

Scandinavian furniture design has for a very long time been regarded as one of the best in the world, and the impact and presence of Scandinavian design is still very much felt to this day. It was especially felt by the team, both generally in the Scandinavian country the team inhabit, but also during the *Stockholm Furniture Fair.*

Scandinavian design, as can be read in *Scandinavian Design Beyond the Myth*, Widar Halén and Kerstin Wickman (2003, p.) usually embodies minimalism, practicality and in the case of furniture, puts emphasis on materials used, such as exposed frames of wood or steel. Scandinavian furniture design also usually have few, gentle colours, wholly clad in just one textile and often bright and

unassuming. An example of Scandinavian furniture design can be seen in the following figure 5.2.

Figure 5.2 Example of Scandinavian Design, collected from The Spruce Magazine.

5.3.2 Coarse Textiles

Course textiles are currently popular in the furniture market, especially course rough textiles from specific manufacturers like *Kvadrat, Nevotex* and *Jörgensen*. *Kvadrat* in particular is a popular brand that furniture manufacturers like using for showpieces, since it is a luxury and expensive brand with a very unique look and feel.

5.3.3 Retro Colours

Retro colours are making a return in recent unveiled designs at the Stockholm Furniture Fair. There are many possible reasons for this. Colour trends are cyclical and popular designs fall out of fashion and just as suddenly can become the staple again. Some of the retro colours in question are mustard yellow, brown and orange, colours reminiscent of the 70s.

5.3.4 Modular

A popular feature, especially in lounge furniture is modular design. Where elements of the entire furniture can be arranged in different ways to create new constellations of assembly. The degree of modularity varies from design to design, but some form of changeability is present in most if not all lounge furniture sold today. The exception would be something like just a basic chair or armchair.

5.3.5 Isolation

In recent years there has been a great rise in a specific type of "furniture" dedicated to isolation and silence. The "furniture" in question are isolation boxes or booths, where people can be detached from the noisy environment and take calls, have meetings in peace or just sit and work in complete silence. One of the first brands that made these were *Evavaara Design*, a Finnish company that has according to their website, created furniture that isolates the user since 2002, pioneers of the isolation trend.

5.3.6 Activity Based Furniture

Much of the furniture presented at the *Stockholm Furniture Fair* could be considered activity based, or in other terms, designed for a particular purpose. Not in the way that chairs are designed to be sat on, but that there today exist furniture with more specific purposes. You have one furniture for meetings (Isolation box), one furniture specifically for working at a laptop (chair and table in one), one furniture for relaxation (lounge furniture or beds) etc. See the following figure 5.3 for an example of an activity based workplace, with activity based furniture.

Figure 5.3 Example of an Activity Based Workplace, collected from Martela.com.

5.3.7 Upholstered Surfaces

How much of a furniture is clad in textiles vary greatly and upholstered surfaces as a fad comes and goes. Many furnitures today do not have any upholstered surfaces because in the end it is just a design choice. However what was perceived at the *Stockholm Furniture Fair* was a modern resurgence of furniture with great use of upholstered surfaces. This trend aligns well with this project, since exposed used MDF might not be a pleasing visual element and the team suspects upholstered surfaces will be an integral part of the design created in this project. (More on the exposed MDF issue can be read in chapter nine, sprint two.)

5.3.8 The Absence of Lounge Sofas

An observation made during the inspiration gathering across Malmö and Lund was a general absence of lounge sofas in public areas. Chairs and other seating arrangements were still common, but they were sporadically placed and overall open areas indoors were more empty of furniture than the team expected. More specifically university grounds were very void of larger seating arrangements and really only supplied tables and chairs placed far apart.

After discussions on this matter, the team speculated that the reason for the lack of lounge sofas could be a result of the recent Covid-19 pandemic. Lounge sofas invite people to sit down and relax, to spend time in one area indoors close to other people. Having many people in close proximity indoors for extended periods of time is a liability during pandemics, and as such seating that groups people up closely together comfortably were removed, to encourage being outside more.

As the Covid-19 pandemic is coming to an end the team hopes for a resurgence in the lounge sofa market, and maybe even an opportunity to capitalise on the future upswing of said market. As the team speculate the demand for lounge sofas will rise in the nearest future.

5.3.9 Quality

Quality is always a factor for any product, especially for furniture. Consumers want products that last a long time and this is a big aspect of furniture. Long lasting is usually tied to quality in some way, but quality is more than that. Quality is an abstract concept because it depends on feelings and experiences, and it does not mean the same thing for everyone. An example is IKEA furniture. IKEA creates affordable (cheaper) furniture with heavy focus on practicality and manage to lower their costs through consumer assembly, cheaper materials and other means. Some would say IKEA is quality furniture, due to how good the product you get is compared to the price. However a clear trend in the wider furniture market are more expensive and design focused products that "feel" better than cheaper alternatives. The important word here is 'feel', what does quality 'feel' like? The team decided to keep this in mind throughout the project, since the ambition is to create a quality product.

5.3.10 Environmental Impact

It is important for both consumers and producers today that the furniture market is working for a more sustainable future. This importance and intent of companies and customers is conveyed clearly in the choices they make and the products and services they buy.

5.3.11 EPD - Environmental Product Declaration

An EPD is a way of communicating a product’s environmental attributes and can be used on a variety of goods and services. It is based on a life cycle analysis which signals a manufacturer’s commitment to measuring and reducing their environmental impact in a transparent way. Many public procurers require EPDs

or something similar today, as a part of the sustainable awareness companies need to show.

5.4 Green Procurement

Many governments across the modern world realise that they have a responsibility of where the future is headed and that choosing alternative methods of procuring consumer goods can drive down emissions and set good precedent for consumers to chose sustainable options. One of these acts to choose sustainable options is GPP, Green Procurement Procedures. As can be read in the report *GPP in practice*, the European Commission (2019), Malmö city has since 2018 successfully used GPP to lower emissions by purchasing used furniture. GPP states that 50% of all procured goods need to come from sustainable sources, Malmö city does this by procuring from local suppliers which as a side effect also stirs competition and promotes growth in said local businesses.

Many positive points relevant for this project can be gleamed from the report in question. The first is that refurbished, recycled or reused furniture is a growing market, with strong reliable consumers like governments. The second is that there is monetary value present, as Malmö city alone spent €370,000 on refurbished furniture during the period 2019-2023. Third point is that Malmö city, one of the teams and *Soeco's* closest consumer is only expanding said procurement, giving opportunities for products made from reused material like this project to find stable markets.

5.4.1 Second hand market

Second hand furniture is a big market in Sweden. Websites/apps like *Blocket* and *Tradera* are large platforms where anyone can sell and buy anything. Furniture in particular has become a large market on these platforms, making it easy to buy and sell second hand furniture. These websites show a flourishing market that will only grow bigger as more people want to do their part for a more sustainable future, this trajectory of the second hand furniture market and the widespread want for sustainable furniture is a relevant market factor for this project.

6 Function analysis

A function analysis of the intended product must be made in regard to all involved parties in the user chain, including manufacturer, transporter, buyer and end user. To solve the needs placed by a lounge furniture, the following functions can be implemented:

Table 6.1 Function analysis.

Need Number	Need Description	Function
1	Be able to sit down	Appropriate levitated seating area
2	Be able to offload items	Horizontal non-seating area
3	Comfortable sitting	Appropriate sitting position and sufficient padding (Anthropometrics)
4	Easy to clean	Removable textiles, hydrophobic textiles
5	Easy to reupholster	Simple elements
6	Easy to reconfigure (modular)	Elements of the furniture can be rearranged into new constellations
7	Sustainable	Re-used materials
8	Easy to transport and assemble	Optimises pallet space during transport
9	Appealing design	Subjective
10	Sustainable	Möbelfakta certified

7 Anthropometrics and standards

This chapter will explain the variables regarding standards to live up to and appropriate basic measurements of furniture.

7.1 Anthropometrics

Anthropometry is a branch of ergonomics that deals with human body measurements. The word anthropometry originates from the two Greek words anthropos (man) and metros (measure). Hence, anthropometry is the science that deals with human measurements regarding size, shape, strength and working capacity. The purpose of using anthropometry in a development process is to be able to design the product in a controlled and systematic way so the product physically fits the intended user.

Anthropometric measurements are obtained in different ways, depending on what they are intended to be used for. In the past, manual callipers called anthropometers were used. Today, different types of body scanners are used to generate three-dimensional images of the human body. People are different in several ways, from an anthropometric perspective humans can be short or tall, wide or slim, weak or strong, etc. Furthermore, people have different proportions. An example of this is that a person who is of average height rarely has average values for other body measurements. In a development process, it is important to take into account the variation that exists within the target group so that the product is optimised for the user. See figure 7.1 for standard anthropometric measurements.

In analysis of anthropometric data, the concept of percentiles is often used. For example, a workplace is designed to fit both a man who has a body height of the 95th percentile and a woman with a 5th percentile body height. Thus, a man of 95th percentile height means a man who is taller than 95% of the selected male population and a woman of 5th percentile means a woman who is shorter than 95% of the selected female population.

A person of the 50th percentile is of average height with respect to the selected population. However, there are no people with the same constant percentile value for all body measurements (Antropometri's website, 2023).

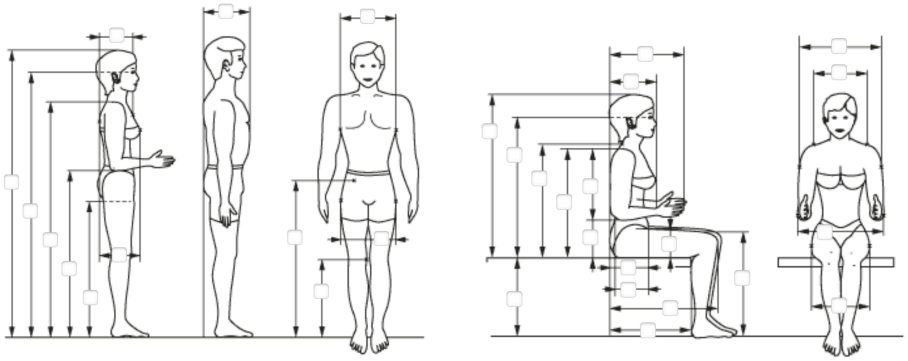

Figure 7.1 Anthropometric measurements (antropometri's website, 2023)

7.2 ISO Standards

ISO standards are important to follow when designing and producing products for the European market. There are three standards that are relevant to the furniture construction present within this project, ISO 7173:1989; *Furniture — Chairs and stools — Determination of strength and durability,* ISO 8191-1:1987; *Furniture — Assessment of the ignitability of upholstered furniture — Part 1: Ignition source: smouldering cigarette* and ISO 8191-2:1988; *Furniture — Assessment of ignitability of upholstered furniture — Part 2: Ignition source: match-flame equivalent*.

These ISO standards can be used by themselves but the requirements set by them overlap or are directly used by eco labels to ensure proper products bearing those labels. The requirements set by the eco labels are discussed in chapter 8.2.

8 Materials and Constrains

Working with Soeco Kotorsmöbler AB allows the team access to specific materials, tools and services. These materials, tools and services, as well as the constraints the team will adhere to (be they from the team itself or from Soeco executives) will be discussed in this chapter.

8.1 Medium Density Fibreboard

Medium density fibreboard (MDF) is a wood based sheet material composed of various wood fibres bonded together with a resin adhesive. Compared to other materials such as plywood and particle boards (see figure 8.1), MDF is much harder, denser and smoother. Due to its sufficient moisture resistance it is mainly used for internal purposes.

8.1.1 Properties and Uses

MDF is a commonly used building and DIY sheet material in furniture and cabinetry. The boards have a consistent light-brown color without grains and textures and are rarely used as a finish alone but is instead made with a veneer or laminate, giving expression of real wood. A strong aspect for choosing MDF is the economic benefits in relation to its mechanical properties. Compared to real wood and plywood it less expensive, however it is very hard and dense, perfectly flat, and extremely resistant to warping. Due to its very smooth surfaces it is also very susceptible to paint coatings (Popular Mechanics website, 2023). Although many benefits, MDF is a porous material and does not respond well to driving screws into the edges and surfaces. To avoid splitting, it is important to drill pilot holes and counter bore holes first, so the screw heads sits below the surface. MDF can be machined with normal woodworking tools, however the hardness tends to dull saw blades and routing tools more quickly.

8.1.2 Manufacturing

The process of manufacturing MDF has changed over time and with more advanced technologies it has become more economically feasible. The first step is to collect various wood chips and shavings from sawmills. Selected fibres are then sorted out and sent to refinement where water also is removed. Further, a resin adhesive is added, acting as a binding agent. The most common binder for boards intended for dry environments is urea-formaldehyde. The mixture is then rolled out in large sheets of uniform thickness to be pressed, cut and dried in several steps. Depending on purpose of use, the boards are either sanded smooth, laminated with wood veneers or paint coated (Civil today's website, 2023).

8.1.3 Formaldehyde

Formaldehyde is a commonly occurring organic chemical in nature, including most forms of life, foods we eat and trees. Hence, all products made of wood will contain and emit a small amount of natural formaldehyde. Air, both indoors and outdoors, will always contain low concentrations of formaldehyde, usually less than 0,03 ppm. Environments such as offices and homes with many wood products may have formaldehyde levels greater than 0,03 ppm. Formaldehyde in higher concentrations is a health hazard, due to its carcinogenic effects.

MDF boards made in Europe must achieve European standards BS EN 622-1:2003 and BS EN 622-5:2009. These point to two different classes, E1 and E2, depending on measured levels of formaldehyde. The release of formaldehyde from E1 boards is less than 0.1 ppm and for E2 boards it is between 0.1 ppm and 0.3 ppm. By using formaldehyde free binders such as PMDI (Polymeric Methylene Diphenyl Diisocyanate) some manufacturers can produce boards that will only emit the natural occurring levels (Health and Safety Executive UK, 2023).

Figure 8.1 From left to right: particle board, MDF and plywood.

8.2 Eco Label Requirements

One goal set by the outline of this project is to design a furniture that adheres to the requirements set by one or several eco labels. The eco labels in question, as recommended by the executives at *Soeco* are *Möbelfakta* and *Nordic Swan Ecolabel.*

8.2.1 Möbelfakta

Möbelfakta is not only an eco label but also a quality label with a heavy focus on certifying safe, sustainable and long lasting furniture. The company likes to identify itself as a sustainability label and a certification from *Möbelfakta* is also a sales tool for specific furniture producers, since public procurers tend to buy mostly *Möbelfakta* certified products, knowing that the products being labeled *Möbelfakta* guarantees long lasting, safe and sustainable furniture.

Their requirements can be specific or references to both national or European standards. The most common standards *Möbelfakta* reference are SS-EN, but parts of ISO standards referenced can be relevant for this project as well. A specific requirement from *Möbelfakta* relevant for this project is that formaldehyde emissions from MDF may not exceed 65% of the value needed to achieve E1 according to BS EN 622-1:2003 and BS EN 622-5:2009 (≈0,195 ppm or ≈0,065 mg/m^3). A big part of *Möbelfakta* requirements is to also take social, environmental and ethical responsibility for the materials, product and production.

8.2.2 Nordic Swan Ecolabel

While *Möbelfakta* is an eco label specialised in furniture, *Nordic Swan Ecolabel* is a more broad label that encompass a wide range of other products as well. *Nordic Swan Ecolabel* also have their own worded requirements or reference SS-EN or ISO standards, but being a larger label their requirements are more thorough and detailed than *Möbelfakta*. *Nordic Swan Ecolabel* is a more commonly known eco label, since its certification can be found on many products consumed by the average household.

8.3 Available Materials from Soeco

The materials available to the team through *Soeco* are leftover materials stockpiled through the restoration that the company regularly do as a means of business. The most common materials left over are plastic and metal parts from old office furniture and old tabletops made of MDF. *Soeco* also have a workshop at their

headquarters where smaller consumer materials like screws, nuts, bolts and leftover construction wood (mostly pine) is available to the team.

A large part of *Soecos* business is the reupholster of worn furniture, meaning the team has access to textile materials from various producers. Their textile workshop also has a stockpile of foam and wadding.

8.4 Available Tools

The workshop at *Soeco* gives the team access to most commonly used tools needed for woodworking. Tools like industrial saws, sanders, drills and much more. Through contacts available from *Soeco* the team also have access to a CNC mill located in Jönköping, Sweden.

The textile workshop has sewing machines and pressure powered staple guns, as well as smaller sewing utensils available for the team to use.

9 The Sprints

The sprints where initiated after the trip to the Stockholm Furniture Fair. This chapter encompass the whole timeline for the four sprints.

9.1 Sprint 1

The first sprint became an opportunity to "test the waters" and gauge what the team can generate as possible solutions. The focus was to be as broad as possible and let any and all ideas take shape, no matter how outlandish or farfetched.

9.1.1 Concept Generation

The team generated many ideas, the more promising ones can be seen in the following figure 9.1.

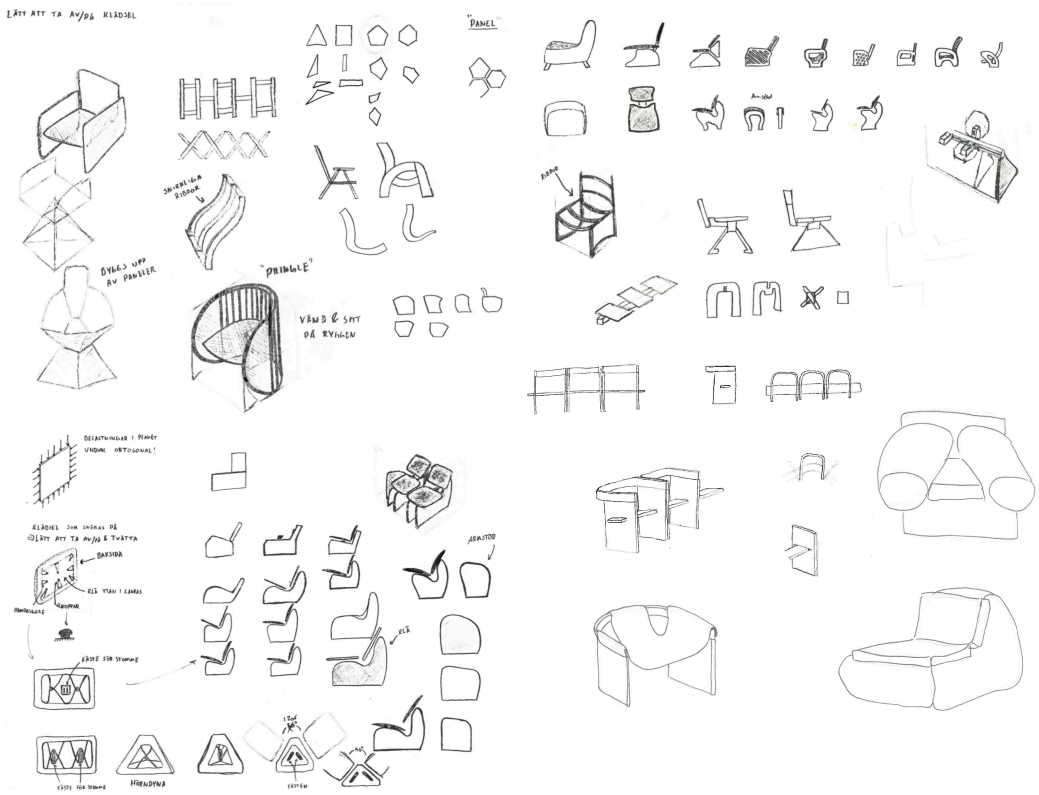

Figure 9.1 Promising Generated Concepts Sprint 1.

9.1.2 Prototyping

Some of the more promising concepts where further expanded upon by creating them to a basic extent in *Fusion 360™*. This was done to get a better grasp of the concepts, but also to properly convey them to the company executives. Images of the concepts in *Fusion 360™* can be seen in the following figure 9.2.

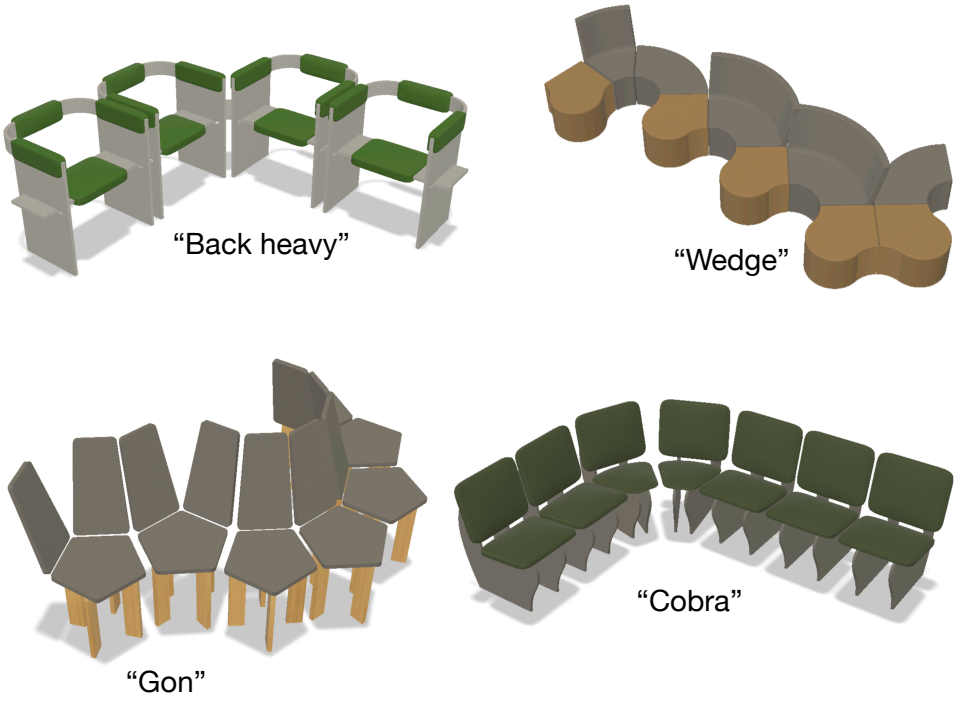

Figure 9.2 3D Renders of the More Promising Concepts From Sprint 1.

Two of the concepts, the ones dubbed; '***Cobra***' and '***Backheavy***' were deemed extra interesting and possible to in a simple way create as small scale prototypes.

The project is still early in the development of a solution, and therefore making full scale prototypes was deemed an unnecessary time sink at this stage. Since the primary material we are working with are old tabletops made from MDF with a thickness of around 20 millimeters, making prototypes from 4 millimeter thick MDF creates an accurate representation in a 1 to ≈5 scale. Since the team has access to a laser cutter through the Institution of Design Sciences at LTH, laser cutting was deemed the most appropriate method of creating elements for the prototypes from 4 millimeter MDF (See figure 9.3).

Figure 9.3 Models cut from MDF by a laser cutter, from Sprint 1.

9.1.3 Evaluation and feedback

The results of the sprint was presented before executives at *Soeco* and many relevant and interesting topics were brought to light and discussed. The prototypes presented from sprint one, both CAD and physical had a "waiting room" aesthetic according to *Soeco* and although this does not detract from the quality of the concepts, it was deemed an aesthetic best left behind for future sprints.

During sprint one the team primarily created concepts were plate like elements were a clear structural and visual component. This was done due to several reasons, one reason was to keep it simple during the early concept generation. Another reason was the constraint of the tabletop material becoming a focus, since it afforded itself to think in the realm of 'plates'. You could say the teams main thought was to create the furniture from the provided material in easy ways, instead of designing the visual and comfortable furniture first and then solving the construction of such a design afterwards. The team decided that going into sprint two, these 'plate' designs had been explored enough and that the concepts of sprint two should have more volume and more focus on the visual design.

Another topic discussed was the limitations of modularity. The modular aspect is a big part of lounge furniture and it is a need the team deemed very important. However, the modular aspect limits what shapes and visual components the furniture can have, since complex shapes and forms will either require a large amount of small unique elements to create or larger elements that are difficult to

place and use in multiple different ways (which is not very modular). The most useful and modular LEGO® pieces are the simple ones.

The concept by the name of '***Wedge***' led the team and *Soeco* to discuss how lounge furniture need to optimise the space it occupies. Very round and elliptical shapes are hard to put in corners and as such designs similar to '***Wedge***' are not easy to use in any way the consumer might see fit. Smaller constellations of modular elements and or just smaller elements in general tend to optimise the space they occupy and also leaves more floorspace available for other or more furniture.

9.2 Sprint 2

The second sprint was utilised for more concept generation, as the feedback from sprint one was used as a stepping stone for the creation of concepts more congruent with the vision from the brief.

9.2.1 Concept Generation

The concepts created during sprint two can be seen in the following figure 9.4:

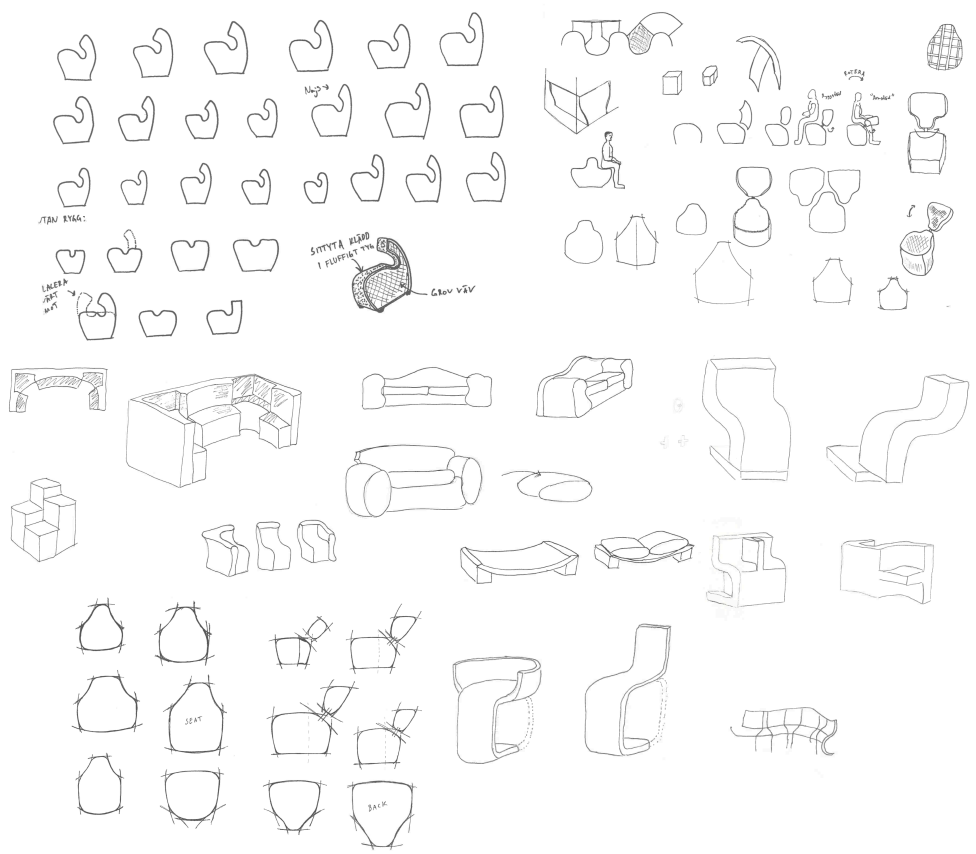

Figure 9.4 Promising Generated Concepts Sprint 2.

9.2.2 Prototyping

Just like in sprint one, some of the more interesting and promising concepts were modeled in *Fusion 360™* and images of these digital prototypes can be seen in the following figure 9.5:

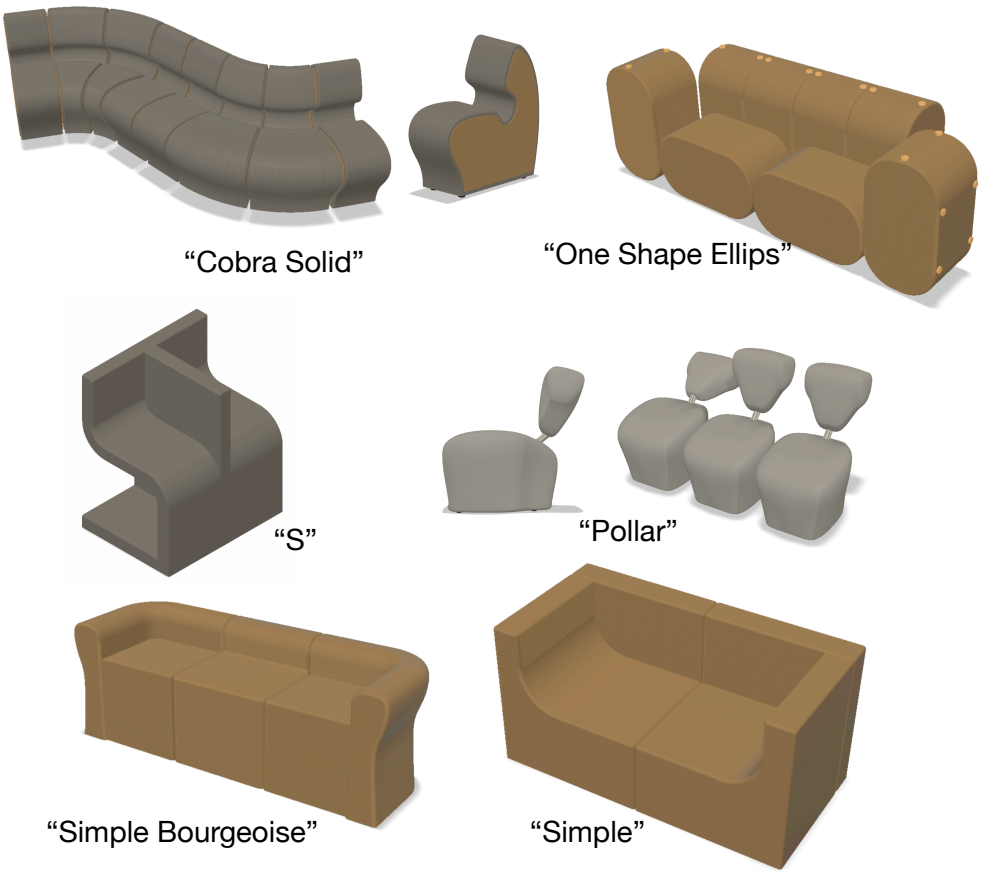

Figure 9.5 3D Renders of the More Promising Concepts From Sprint 2.

Two of the digital prototypes were also created as small scale models from 4 mm MDF with the help of a laser cutter. These prototypes were named '***Cobra Solid***' and '***S***', images of these prototypes can be seen in the following figure 9.6.

Figure 9.6 Models cut from MDF by a laser cutter, from sprint 2.

9.2.3 Evaluation and feedback

The results of sprint two were again presented before executives at *Soeco*. '***Cobra Solid***' shares more than a name with the design generated during sprint one, it also shares an overall shape and design but differentiate itself in construction and "bulkiness", among other things. '***Cobra Solid***' was on purpose a redesign of the successful sprint one concept focusing on the feedback given during the sprint review from sprint one. Most of the sprint review for sprint two was spent discussing '***Cobra Solid***', but also general ideas and prospects that could apply to any concept.

One interesting idea discussed was how to upholster concepts and whether concepts could be designed to be both clad in textiles and/or clad in form fitted harder materials slid over a frame. Could a concept the team designed like '***Cobra Solid***' have just a frame as a base and then be clad in anything, be it textiles, wood, metal or plastic.

Another prospect discussed was the ability to move furniture and elements around, and how it should be done. An issue with using MDF as a construction material is that to achieve adequate structural integrity a lot of material is needed, since MDF is structurally weaker than wood or steel, but weigh about the same. This means that frames made of MDF tend to be heavier. To solve the issue of moving heavier furniture and/or elements, the team discussed to possibility of having wheels integrated in the designs somewhere.

One design aspect of '***S***' was the concepts ability to be used as a seat regardless of its orientation. Did not matter if it was placed standing up or lying down, there was always a place to sit. Such modularity is intriguing due to its rarity within the

furniture sphere, but in practice it places strain on every surface of the furniture. Since every surface now has to be accounted for as a surface with contact to the floor. Which brings to light another important question. "Can the MDF of the frame be exposed and be shown as a part of the design?"

The MDF available to *Soeco* are old tabletops with existing surface treatments that vary greatly from board to board, and when the old tabletops are processed with a CNC mill there is great risk for chips and ugly cross sections. The exposed cross sections are also possible sources of formaldehyde emission. Therefore it is more favourable to upholster every surface to hide such things, unless the exposed MDF is chosen as a deliberate design choice. In the specific case of concept '***S***' either option of upholstered textile, wood, MDF or anything else will be heavily damaged over time from being scraped across the floor. '***S***' gave the team and the executives at Soeco the insight of the importance of furniture feet.

Going into sprint three the team and the executives at *Soeco* agreed that a sufficient amount of concepts had been generated, and that it now was time to select a concept for further refinement.

9.3 Sprint 3

Choosing the best concept to refine can be done in many ways, but the most efficient and objective way was deemed a concept selection methodology inspired by the book '*Product Design and Development*' by Karl T. Ulrich and Steven D. Eppinger, as previously mentioned in chapter two.

9.3.1 Concept Selection

A matrix was constructed and the importance (weight) of the needs were defined according to percentage, with a score between 0 and 100 percent instead of a total 100 percent between all needs. This was done as to inflate the total scores to emphasise the disparity between good and bad concepts. The score then given to an individual concept solution or relation to that need would be multiplied by the weight of said need to give that specific score its affect on the overall score of the individual concept. The scoring of each need for each concept was done by the team according to the teams individual opinions compared against the opinion of the executives at *Soeco*. In an attempt to objectively define the best concept. Some scores were altered and changed along the process, but the final concept selection matrix can be seen in the following table 9.1.

Table 9.1 The Concept Selection Matrix.

Need / Concept	Weight	1. Backheavy	2. Wedge	3. Gon	4. Cobra plt	5. Cobra sld	6. Pollar	7. OS Elipse	8. "S"	9. Simple	10. Simple B
1. Stability	85 %	4	4	2	4	4	5	4	3	3	4
2. Offload items	55 %	2	3	2	3	3	1	3	2	2	2
3. Comfortable	70 %	2	3	3	4	4	2	3	2	3	3
4. Easy to clean	55 %	5	3	3	3	4	3	3	2	3	3
5. Easy to reupholster	70 %	4	3	3	4	4	2	2	1	3	3
6. Easy to reconfigure	85 %	2	4	4	3	4	3	5	2	3	3
7. Sustainable	100 %	3	3	3	4	3	2	4	3	4	3
8. Easy to transport and assemble	55 %	3	3	4	4	4	2	4	1	4	2
9. Appealing design	85 %	4	2	3	3	5	4	3	4	2	3
10. Easy to manufacture	85 %	3	2	3	4	3	2	4	3	4	3
Total:		**23,75**	**22,35**	**22,35**	**27**	**28,25**	**20**	**26,6**	**18,05**	**23,35**	**22,1**

As such the concept named '***Cobra Solid***' was selected as the most promising and the concept of which the next two sprints would refine.

9.3.2 Initial Refinement

The concept for refinement had been identified, but every aspect that would be needed to refine had not. To gather all ideas the team had thought of surrounding the refinement of the final concept, the team decided to create a mind map surrounding '***Cobra Solid***'. Any relevant idea or subject that the team could see play a part was included in this mind map, it can be seen in the following figure 9.7.

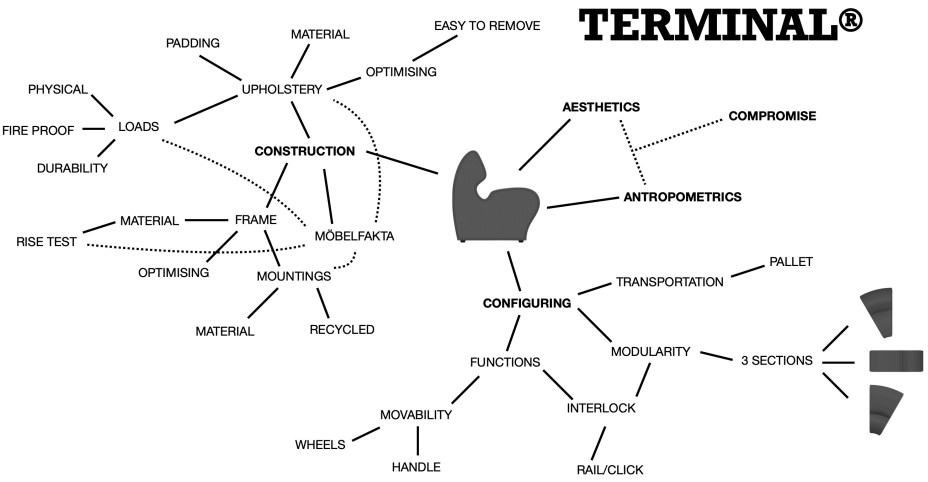

Figure 9.7 The Refinement Mind Map.

The official product name was created at this stage, '***Terminal***'. The main subjects of refinement for '***Terminal***' are:

- Anthropometrics
- Aesthetics
- Construction
- Configuration/Configuring

The dotted lines show what factors play a part in meeting the requirements of *Möbelfakta*.

9.3.2.1 Anthropometrics of Terminal

The dimensions of the selected concept was directly compared against the average anthropometric standard measurements, and the dimensions were adjusted accordingly. The anthropometric measurements in comparison to the selected concept can be seen in the following figure 9.8.

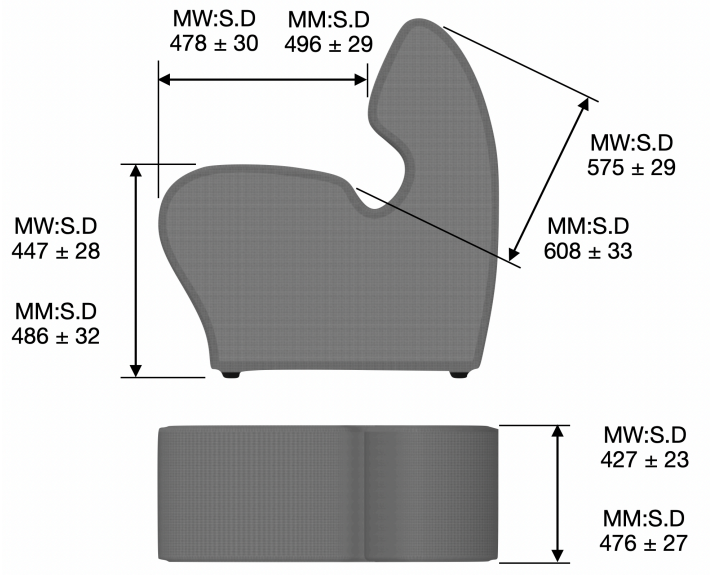

Figure 9.8 Anthropometrics of Terminal (mm).

A cardboard cutout was created to full size dimensions for the purpose of evaluating the side profile of the concept, and what further adjustments could or should be made. The following figure 9.9 shows a team member sitting on a chair of the same height, to illustrate the side profile in comparison to a human body.

Figure 9.9 Cardboard Cutout Size Test.

9.3.2.2 Aesthetics of Terminal

The visual attractiveness of the final concept is important to the team, and as such the team were willing to make sacrifices to retain desired aesthetics. An example of an early sacrifice was the identification of '***Cobra Solid***' as a structure with a center of mass located a bit forward of the structures measured center. This identified fact was deemed a slight issue, but ignored since the center of mass was low enough vertically that its forward position was deemed irrelevant.

A big factor in why '***Cobra Solid***' was chosen as the final concept was due to its aesthetics, and deviating to much from that aesthetic would undermine why it was chosen in the first place.

9.3.2.3 Constructing and Configuring Terminal

There are a lot of factors involved with the construction and configuring of '*Terminal',* as can be seen in figure 9.7, that part of the mind map is the most expansive one. Material factors had been a well discussed topic amongst the team throughout the whole project. MDF being a central pillar in the brief, but ideas regarding other material uses had been discussed as early as the *Stockholm Furniture Fair,* where the team had an extended conversation with a representative from *Nevotex* regarding textiles. It was during this conversation the team first learned about textiles made from plastic fished out of the sea. The team also had an ambition to lower the amount of other materials used, trying to construct a concept with as little screws and other small fittings as possible.

The 3D model created in *Fusion 360™* for '***Cobra Solid***' had corner pieces created theoretically with 30° degrees angle between the side profiles, creating a 90° degree turn when three of them where placed together. These corner pieces were created to showcase potential modularity of the concept, but due to time constraints and to simplify the refinement process, these corner pieces were decided to stay theoretical and focus on creating working prototypes for the straight element only. The straight elements consist of a "chair" element and thin "end" pieces made to cover the sides of the seated elements. These end pieces theoretically will be thinner ≈5 mm MDF clad in textile and fitted with the same connectors that will hold every element together.

The focus early on in this stage of creating a fitting construction concept for '*Terminal*' was to test full scale viability of a frame from reused tabletops, and as such the team moved forward with building a full scale starting prototype viable for physical testing.

9.3.3 Prototyping

With the anthropometrically revised design now created, the team went ahead and made a template in full scale dimensions and contacted the employees in the workshop at *Soeco.* They were able to swiftly cut the two side profiles out of an old tabletop (MDF) with the help of and industrial saw. Out of leftover pine planks the team then cut several ribs that were screwed together with the side profiles, creating a first rough prototype. Parts of the process can be seen in the following figure 9.10.

Figure 9.10 Full Scale Prototype Assembly.

9.3.4 Testing

A furniture that you sit on need to not only stay together safely under heavy loads, it also needs to be comfortable to sit on. The team felt compelled to make '*Terminal*' the most comfortable it could possibly be and as such spent ample time testing different ways of designing the construction of the seat.

The first test was to place the ribs along the top of the seat edge on the side profile, and then dressing the seat and back in 30 mm thick foam (See figure 9.11). This effectively makes the seat only MDF ribs and foam. Both team members and the executives at *Soeco* who sat on this arrangement deemed it to be comfortable. It was possible to feel the ribs through the foam, but since there was many ribs placed tightly together it was not uncomfortable or egregiously noticeable.

Figure 9.11 First Padding Test.

The second test was to replace the ribs of which the user sat on in the last test with elastic bands, a common seating construction material in other furniture manufacturing. The ribs were moved or removed from the top of the seat edge on the side profile and elastic bands were stretched thoroughly across the span between the side profiles (See figure 9.12). The 30 mm foam was then placed on top of these elastic bands. When sitting on this iteration the elastic bands were stretched quite a lot, making the seat incredibly soft. The team deemed such a soft seating unviable for the final product, since people with wider hips would clearly feel the side profiles, since they are noticeable through the 30 mm foam.

The third test was to replace the elastic bands with rough, inelastic canvas (See figure 9.12). This was done in an attempt to reduce the softness from the previous test, while still eliminating the ribs from the seat. Stretching the canvas was a complicated ordeal and required a lot of force and time, this was one detriment to the canvas construction viability. Another detriment was that for canvas, just as the elastic bands, the side profiles could very clearly be felt. The softness of the seat was however more firm and deemed much better than the elastic bands.

Figure 9.12 Elastic Band (left) and Inelastic Canvas Test (right).

9.3.5 Möbelfakta and RISE

A significant part of this project is the team attempting to adhere to the requirements of eco labels. The team thoroughly read and studied the specifications of both *Möbelfakta* and *Nordic Swan Ecolabel*, and attempted to reach representatives for both at the *Stockholm Furniture Fair*. In the end the team spoke in person with *Nordic Swan Ecolabel* representatives and over the phone with the CEO of *Möbelfakta*. After these conversations the team decided to focus on the requirements of *Möbelfakta*, since the dialogue with the CEO was more rewarding and the specifications clearer.

The CEO of *Möbelfakta* was very interested in the details of this project and the team had a long and fruitful conversation with him. The highlights discussed included materials and what the team should think when designing according to *Möbelfakta*. But also how the team could go about getting official data for important topics.

The use of MDF for *Möbelfakta* certified furniture is dependent quite heavily on formaldehyde emissions. The limit allowed is an absolute and using reused material does not matter, proper data on how much the formaldehyde the old tabletops emit is a must for achieving *Möbelfakta* certification. The CEO also gave the advice to avoid metal and plastics, as these materials have strict requirements that require data that is harder to collect than for other materials. To be able to get data on how much formaldehyde the old tabletops at Soeco emit, the CEO advised to contact RISE, *Research Institutes of Sweden*.

After a meeting with a representative from RISE, the team had an understanding of how they go about testing products for emissions and the team started the process of testing four to six samples of tabletops from different producers and of different ages. The RISE representative advised testing samples of about equal size to what will be produced for the final product.

9.3.6 Evaluation and Feedback

The executives at *Soeco* were involved with the tests exploring the construction of the seating, and the opinion they voiced at the sprint review for sprint three was that the first arrangement of ribs along the edge of the side profile was the best one. The issue that the executives emphasised was that the elastic band and inelastic canvas had too big difference in softness between the bands and the side profiles. Even though the ribs was slightly less soft it was deemed more important to have an homogenous feeling across the seat, the team also decided that thicker foam can be used for the seat if the profile seat edge is lowered a bit. This would hopefully make the seat softer and the ribs less noticeable while keeping the shape of the profile.

The executives at *Soeco* agreed with the choice of '***Cobra Solid***' as the final selected concept to refine. During the second sprint review they were very vocal with the strengths of '***Cobra Solid***' and had many interesting ideas around an eventual realisation of its design. The executives seeing the full scale rough prototype further solidified their belief in the design and they continued to be vocal about how pleased they were.

Sprint three was the start of the refinement and as such there was not many conclusions reached within the timeframe of this sprint. But the progress is clear and going into sprint four the refinement will continue, including load testing, upholstery and final design of construction concept.

9.4 Sprint 4

Sprint four is the final sprint and during it the team will continue to refine the concept and deliver a final prototype.

9.4.1 Continued Refinement

Sprint four began with a finalisation of the construction concept for the final prototype of '*Terminal*'. A 3D render of this construction concept can be seen in the following figure 9.13.

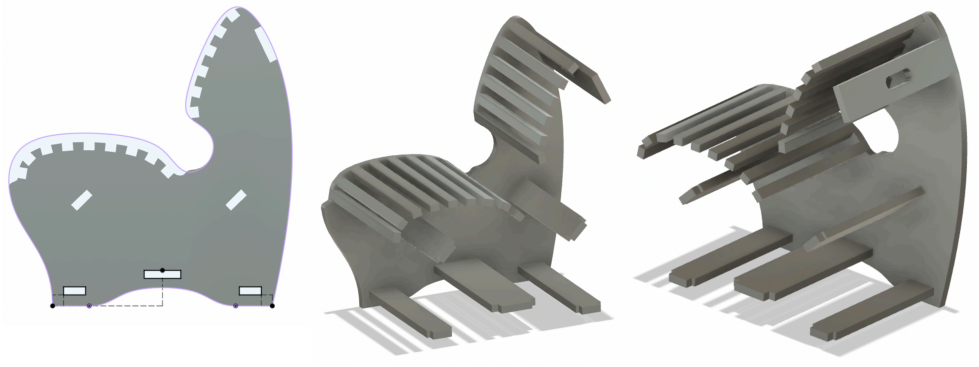

Figure 9.13 Revised profile (left), final profile with ribs (middle & right)

The ribs are smaller and there are more of them in comparison to the rough prototype built in sprint three. The components that span between the side profiles, but are not seating or backrest ribs, have been designed to only be able to move in one direction. This was done to easy the use of glue as a joining agent instead of screws. The edge of the side profile that run along the seat has been lowered ≈25 mm to keep the same profile when using thicker foam for the seat. A handle was also added on a thicker rib at the top backside of the backrest.

The files for the CAD model of the final construction concept was sent to Jönköping to be milled using a CNC mill from four old tabletops sent from *Soecos* headquarters in Dalby.

While the team waited for the pieces of the final full scale prototype to be delivered, a 1 to ≈5 scale model of the final construction concept was cut with the help of a laser cutter from 4 mm MDF, like in earlier sprints (See figure 9.14). This scale model was made to test upholstery propositions and other late stage construction aspects.

Figure 9.14 Final Small Scale Prototype.

Solving the issue of how '*Terminal*' should be upholstered was a long running problem that the team needed assistance from the upholsterer at *Soeco* to solve. They know better than the team on how one would go about creating the upholstered surfaces. One prospect the team had been mulling over for a while was wether the upholstery should be removable and replaceable easily by anyone or if it should be stapled stuck. Ultimately the team decided with the help of feedback from the executives at *Soeco* that removable upholstery was worth working towards. After consulting the upholsterer they suggested either sewing a canal in the fabric and threading a twine through it, twine that then can have several anchor points in the side profile, the twine when wound tight holds the upholstery in place without any permanent fixtures. Or the upholstery could be fastened with velcro.

The team also decided on using both foam and wadding. These would be joined to the fabric, making everything soft part of one piece that was removable. The upholsterer at *Soeco* also advised that the large open areas of the frame on the front and back be covered with paperboard (See figure 9.15), as to give bearing to the eventual textiles that would be strung across those open areas. The textile used for the upholstery was decided to be bought from *Nevotex*.

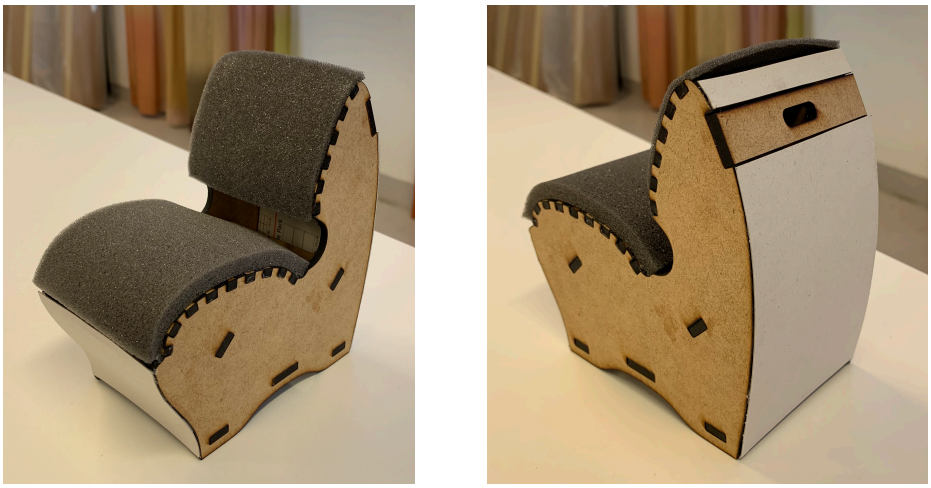

Figure 9.15 Final small scale prototype with cardboard cover

The small scale model of the final construction concept, clad in upholstery, can be seen in the following figure 9.16.

Figure 9.16 Final small scale prototype, upholstered and raw

The team started exploring connectors and other fittings that would be required to finalise the concept. *Soeco* regularly buy small materials from a industry producer called *Theofils* and after searching their catalogue of products, the team found appropriate wheels and door stoppers from rubber which will be used as feet. Most actual feet produced by *Theofils* are made from harder plastic or steel, yet the team wanted a softer material touching the floor.

9.4.1.1 Lifting and Moving of Terminal

An important part of need number six, easy to reconfigure, is movability and ease of handling. The concept features a hole in the upper back rib which in conjunction with wheels serves as a handle for transport along the floor. Discussions were brought up concerning how many wheels that should be used and where to place them. Four wheels would maximise movability, however some sort of lock mechanism would be needed. By using only two wheels in one end and feet in the other, a better ground support could be provided while stationary. Hence, this design requires either lifting or pushing down, depending on the wheel placement. To determine the best option, the team performed a user test by first placing the wheels and later in the back. The upper pictures in figure 9.17 displays handling of the chair with the wheels placed in the back. This configuration demands a small initial push with the foot to tilt the chair backwards, a gesture causing unnecessary stress on the back cover. Another drawback of this design is the awkward walking position while simultaneously pushing it downwards. The front heavy profile also contributes to this alternative being harder to maneuver. By placing the wheels in the front, a much easier lift was required which made the movability experience much more pleasurable, as seen in the bottom right picture in figure 9.17. Therefore, the team chose to continue with the latter alternative.

Figure 9.17 Lift Test Performed with Full Scale prototype.

9.4.2 Design validation - FEA

The chair must be able to withstand normal use such as a person sitting on it. When designing the seat the ribs were given a cross section which enabled both compliance with the organically shaped profile and enough spacing to make it comfortable to sit. This resulted in 15 ribs, nine in the seat and six in the back rest, with dimensions of 444x30x22 mm. The thickness is set to 22 mm due to constraints of the raw material and the length is determined by anthropometrics (width of the chair). To ensure robustness, the only variable parameter is the width of the cross section, which has been set at a semi-arbitrary value of 30 mm (See figure 9.18).

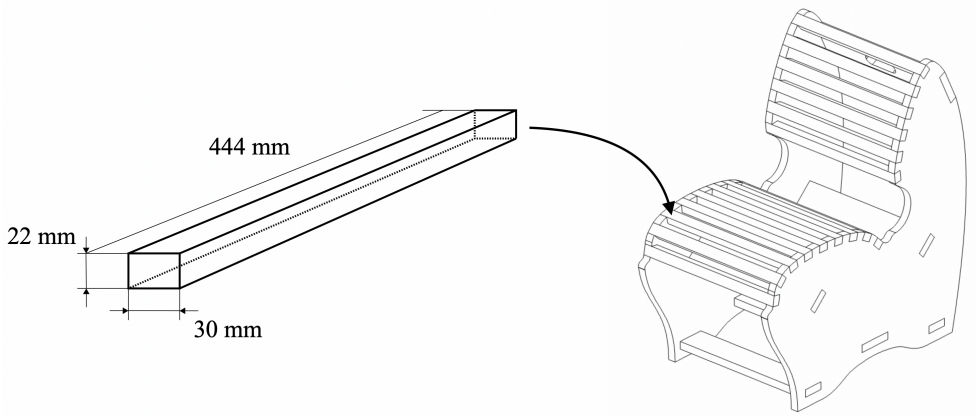

Figure 9.18 Initial dimensions of the ribs.

9.4.2.1 Workbench modelling

Before starting manufacturing a final prototype a fast and easy design validation is performed using an ANSYS Workbench Finite Element Analysis, FEA. A finalised CAD model is exported to a STEP-file which then is imported into a Static Structural analysis. The bodies of the assembly are all assigned a simulated material with the properties of MDF. Default structural steel is altered according to data (MakeItFrom's website) with the following modifications: Density = 0,75 g/ cm^3, Young's Modulus = 4 GPa, Poisson's Ratio = 0,25, Yield Strength = 10 MPa and Tensile Strength = 18 MPa (See figure 9.19).

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	0,75	g cm^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young's Modulus and Poisson...			
8	Young's Modulus	4000	MPa		
9	Poisson's Ratio	0,25			
10	Bulk Modulus	2,6667E+09	Pa		
11	Shear Modulus	1,6E+09	Pa		
12	Strain-Life Parameters				
20	S-N Curve	Tabular			
24	Tensile Yield Strength	10	MPa		
25	Compressive Yield Strength	10	MPa		
26	Tensile Ultimate Strength	18	MPa		
27	Compressive Ultimate Strength	0	Pa		
28	Isotropic Thermal Conductivity	60,5	W m^-1 C^-1		
29	Specific Heat, C_p	434	J kg^-1 C^-1		
30	Isotropic Relative Permeability	10000			
31	Isotropic Resistivity	1,7E-07	ohm m		

Figure 9.19 Material Properties, ANSYS Workbench.

The chair stands on the ground and is therefore modelled with fixed supports on the underside surfaces displayed below (Figure 9.20).

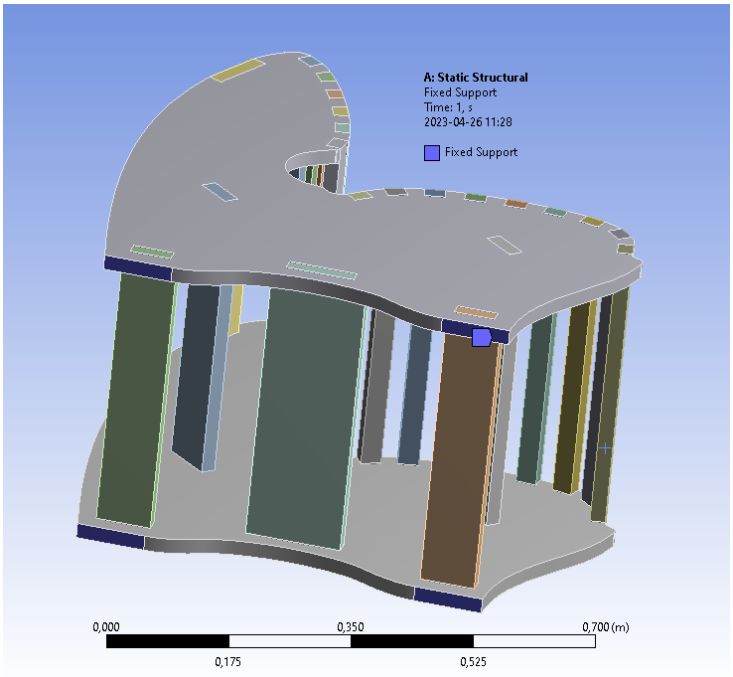

Figure 9.20 Fixed Support, ANSYS Workbench.

Möbelfakta uses the SS-EN 16139:2013 standard for load requirements, according to SS-EN 16139:2013 the normal usage weight in a public environment is 110 kg. If you want to design for higher loads than 110 kg, ISO 21015:2007 should be used instead. The load case used for this analysis was approximated to 1000 N (110 kg*9.82 ≈1080 N). The sitting position does not allow for larger amount of weight distribution on the back rest, therefore loads in this area are neglected. When a person sit, not all ribs in the seat will be subjected to loads. The first and last ribbon are consequently left out in this loading case. A load is specified as a 1000 N force vector in the negative y-direction evenly distributed over the seat ribs marked in red below (Figure 9.21).

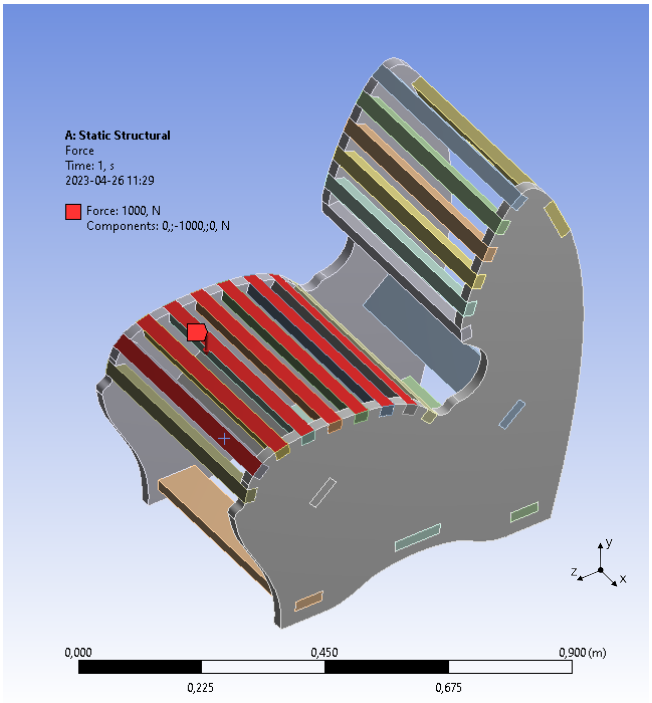

Figure 9.21 External Force, ANSYS Workbench.

The mesh was generated by using a sizing of 10 mm on all bodies, which resulted in 200 359 nodes and 36 645 elements, seen in figure 9.22.

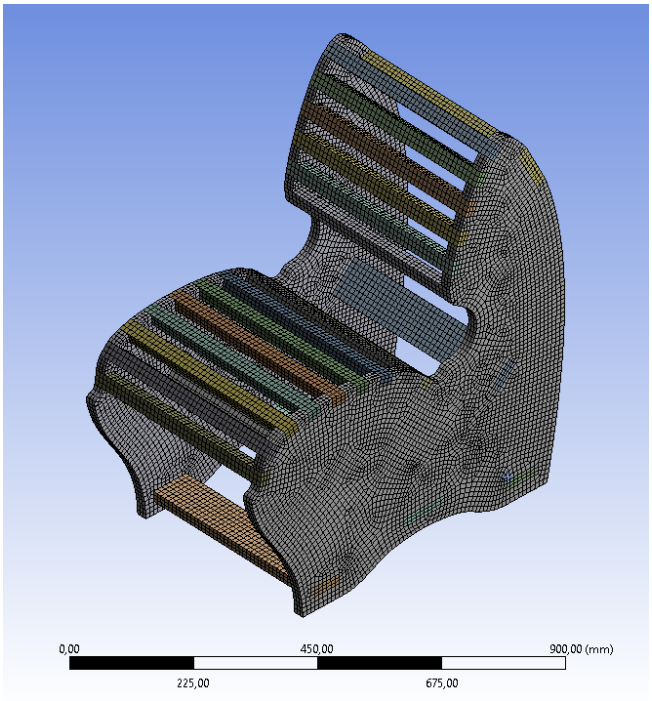

Figure 9.22 Mesh, ANSYS Workbench.

9.4.2.2 Results and discussion

The above mentioned boundary conditions resulted in a maximum equivalent stress of 2,29 MPa, a minimum safety factor of 4,37 and a maximum total deformation of 0,34 mm, seen in figures 9.23 - 9.26.

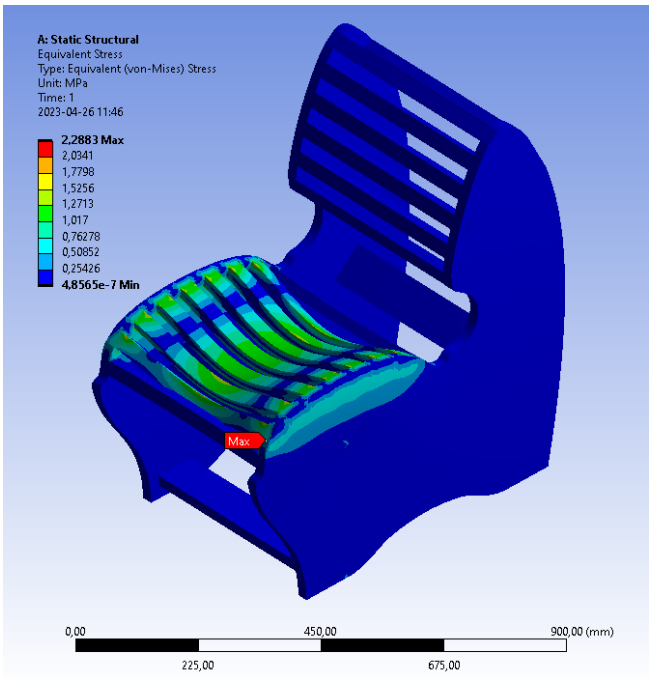

Figure 9.23 Equivalent stress, ANSYS Workbench.

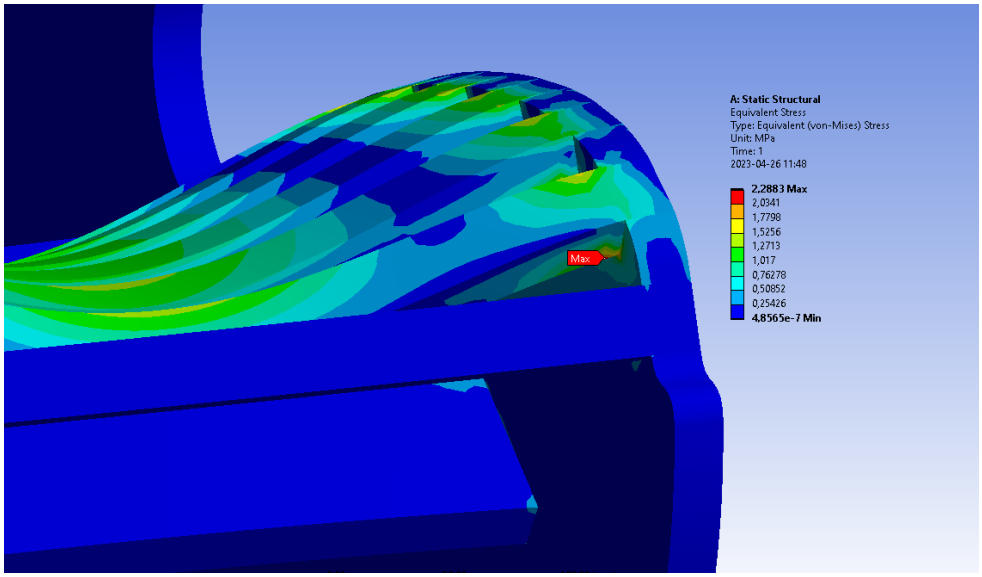

Figure 9.24 Equivalent stress magnification, ANSYS Workbench.

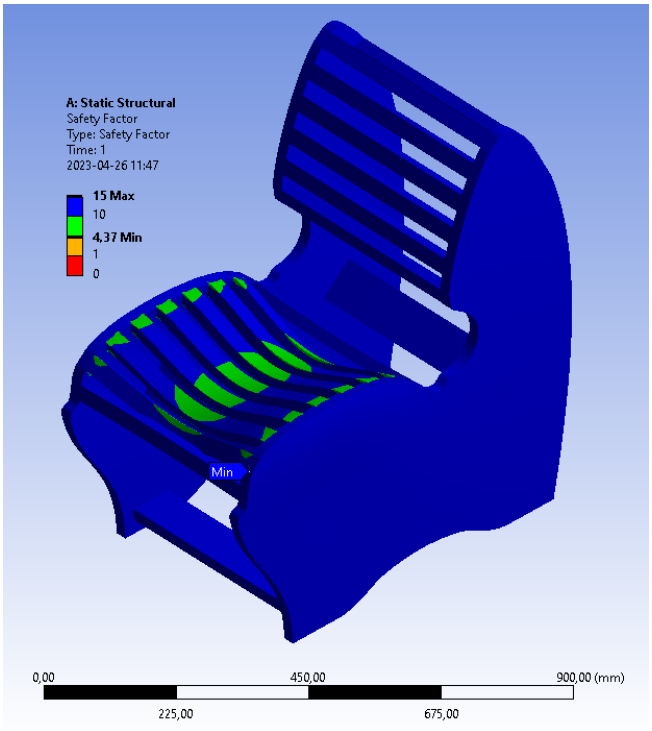

Figure 9.25 Safety factor, ANSYS Workbench.

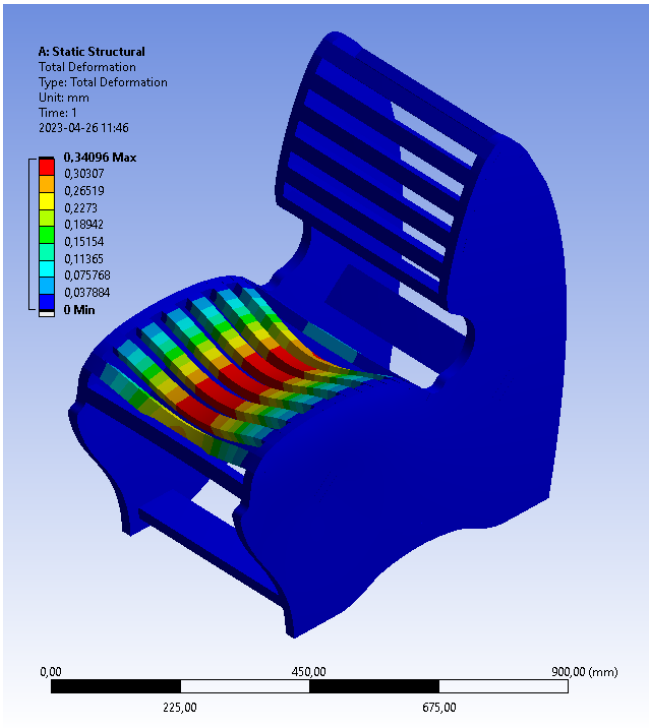

Figure 9.26 Total deformation, ANSYS Workbench.

Even though this load case is a simplification of reality the analysis delivers a reasonable result with an adequate safety margin. A person sitting in the chair will actually distribute some of its body mass force into the backrest and some directly into the ground. Heavier persons tend to have a wider bottom which will transfer a larger portion of the force through the vertical side profiles. The mechanical properties of MDF may vary with different manufacturers, however using general material data gives fair representation of how it behaves.

The maximum equivalent stress occurs in the area around the attachment points of the ribs, as seen in figure 9.24. This is reasonable, due to the fact that a large leap in cross section will result in a stress concentration. A safety factor of 4,37 assures that the current dimensions are sufficient for a robust and durable construction. In addition, the maximum deformation only reaches 0,34 mm, which in this case can be neglected. Foam and padding will also help distribute the force more evenly. In conclusion, the design is validated and will withstand normal use.

9.4.3 RISE Test Continued

RISE need samples to be able to test formaldehyde emissions from old tabletops from *Soeco*. The team located four tabletops at the *Soeco* headquarters from different producers and of different ages and cut them to appropriate size (500x700 mm). Two of the four were *EFG* produced, one from 2010 and the other 2014 or 2020. The other two were *Edsbyn* from 2017 and *Åtvidaberg Facit* from 1996. The samples were then sent to RISE in Borås, Sweden to be tested in their chamber test.

9.4.4 End Pieces

The intended modularity present in this generated framework is to connect several '*Terminal*' elements together to create a sofa. But to create the desired ends of elements a separate and different element would be needed. The team identified the need to create end pieces that slot into the same connections as on the rest of the elements. To achieve sturdy enough end pieces while still being thin and easy to store the team decided on 6 mm thick MDF clad in textile and fitted with 'bed connectors' with corresponding sheath on the element. The bed connectors were bought from *Theofils*, a business supplier for interior details. The profile was cut with a saw and afterwards the textile was stapled to the profile. Images of the process and the bed connector can be seen in figure 9.27.

Figure 9.27 End piece construction (Left) and bed connector (Right).

9.4.5 Adhesive and Textiles

The relevant requirements beyond load and construction material set by *Möbelfakta* is adhesive and textiles. The planned adhesive for the final prototype is *Casco® Cascol Indoor* and as an adhesive product it meets the requirements by *Möbelfakta*.

Since the conversation with a representative from *Nevotex*, the team have been sure that the textiles used would be of their origin. As first stated in chapter 9.3.2.3, *Nevotex* offers a textile created entirely from plastics fished out of the ocean and it is the perfect candidate as textile for '*Terminal*'. The textile in question is called *Sealife* and has a ÖKO-TEX® certificate (which is a *Möbelfakta* requirement) and it lives up to the physical quality requirements directly placed by *Möbelfakta*. *Sealife* is one of the best and most sustainable textiles on the market.

9.4.6 Evaluation and feedback

The final sprint review served not only as a review of what the team had accomplished during the last sprint, but also as a review of the entire project from *Soecos* point of view.

Soeco executives are very pleased with the result of this project. They value above all else the visual attractiveness and the ease of manufacturing, since they want the furniture to sell itself through the visual component while also taking as little time and capital to produce. The visual attractiveness was the aspect the executives were the most pleased with, as '*Terminal*' is in their eyes a unique design that catches consumers attention while also being recognisable in its design as a lounge furniture. The executives however also voiced that there was a lack of data surrounding the economic aspect of the design. They are interested in seeing a thorough economic calculation made that calculates a theoretical order of an arbitrary amount of units produced, to gauge the economical viability of the product. The expectation of said economic calculation is positive as the executives can easily see ways of merging the production process with existing facilities at the *Soeco* headquarters.

The executives along with the team also gauged future possibilities of the design, such as a raw variant of the design made for outside use. Or the prospect of making an consumer assembly version as a flatpack, i.e a IKEA style of product.

Soeco executives offered the team an opportunity to continue working on this project to see it through to a later stage of completion.

10 Results and Discussion

The results of this project exist on several planes. The most apparent result is that of the concept the team has generated and refined, but this chapter will also discuss the result of the RISE testing and how the generated design adheres to Eco label requirements.

10.1 Terminal

Terminal is the result of 14 weeks of work, starting with idea generation and ending in delivery of a CAD file and description of manufacturing and assembly, as well as full scale prototypes of the concept. The design occupies a space of ≈820x770x450 mm, a volume of 24 620 cm^3 and weighs ≈20 kg. Images of the final prototype can be seen in the following figure 10.1.

The final prototype is a realisation of two types of elements from the original concept generated in sprint two and refined over sprint three and four. One of these elements is a straight chair element that when combined creates a sofa, the other is a thin end piece that is slotted in on the ends of the furniture. The connections between elements are the same and create major possibilities for future elements.

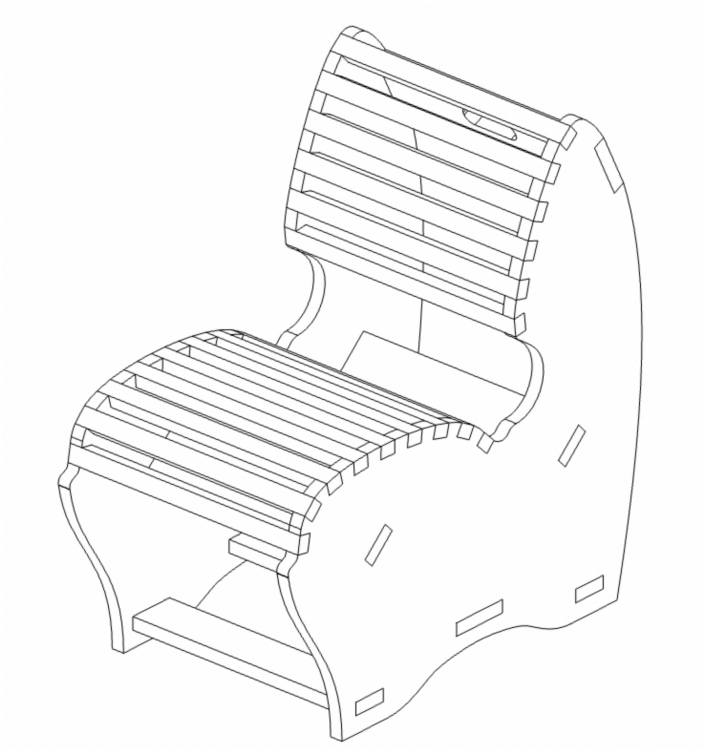

Figure 10.1: Final prototype.

10.2 RISE

The samples sent to RISE have spent several weeks being tested and the official results of those tests can be seen below:

Maximum value of formaldehyde emissions allowed by Möbelfakta is 65 % of the European standard E1 (0,1 mg/m^3), which equates to 0,1*0.65 = 0,065 mg/m^3.

Manufacturer	Emissions
EFG 2014/2020	0,008 mg/m^3
EDSBYN 2017	0,021 mg/m^3
EFG 2010	0,014 mg/m^3
ÅTVIDABERG 96	0,045 mg/m^3

These results show that MDF from old tabletops at *Soeco* has formaldehyde emissions below the allowed limit according to *Möbelfakta*. Making it plausible to use as raw material for the design created in this project. The report later generated by RISE can be directly used when applying for a *Möbelfakta* certification. Naturally these results are a small sample size of all tabletops present at *Soeco,* but the impressive results show that the likelihood of tabletops not meeting requirements are low.

10.3 The Requirements of Eco Labels

As can be read in the previous paragraph the material the team uses for the design will meet the formaldehyde requirement from *Möbelfakta.* As can be read in chapter 9.4.2 '*Terminal*' has a more than acceptable safety factor against the load requirement. Other miscellaneous requirements are fulfilled as well, like adhesive and textiles.

The team believes that '*Terminal*' and *Soeco* live up to the social, environmental and ethical requirements set by *Möbelfakta*. *Soeco* is an abbreviation of 'social' and 'ecological' and the company works hard to go above and beyond with their social, ethical and environmental work. Their business works with reused and refurbished furniture instead of newly produced ones. '*Terminal*' falls neatly within that existing work and although it is a newly produced product it is made from reused materials and continue the environmental focus.

10.4 Discussion

Working in sprints gave the team deadlines to deliver progress for, which moved the project along in a good pace and proved a valuable spur for both team members. It also gave the reward of progress, never letting the project become boring. Combining sprints with Double Diamond also gave the sprints themselves goals to achieve and proved a good framework for such a work ethic. The methods used from Ulrich and Eppinger prove their usefulness within this project and how good those methods are, could this project have benefitted from following Ulrich and Eppinger to its entirety instead of sprints according to Scrum? Maybe, but in the end the results were good and the team had enjoyed the process of sprints combined with Double Diamond and a little bit of Ulrich and Eppinger.

In the end the final prototype is not as modular as the original generated '***Cobra Solid***' concept. Modularity was a important need and goal of this project and the team did not deliver as many elements as earlier intended. The reason was the timeframe of the project causing the team to focus on only the straight simple element, to be able to produce something viable and physical before the presentation and deadline. The team however believes that the concept produced is a solid modular frame that has great potential for future elements, and delivering something that can be improved greatly upon with future elements is a more than good tradeoff for not delivering more different elements for the deadline.

Working with the intent to adhere to eco label requirements have given a clear red thread to follow throughout the project. Every decision made needed to be grounded against the requirements, keeping the team realistic and efficient in making the right decisions.

Focusing on one construction material, in this case MDF, gave the team both challenges and solutions. Challenges in the shape of workarounds for complex needs of which usually are solved with other materials, and solutions in the shape of easy decisions regarding default material usage.

Throughout the project the team leaned on the expertise present at *Soeco* to expedite the process and make decisions without the need for user research. Of course the data gathered from user interactions give the superior information, but

since the product produced in this project has a unique consumer and user interaction, the experts understanding of the market and furniture products was deemed a good fit for producing the intended product. The point of interest here is that the consumer, user and product maintenance are all different people (public procurers, citizens and cleaners), and gathering data from all these sources is a large task, too big for this project. The Anthropometric study performed in this project also serve as a substitute for user research, since the data gathered from anthropometrics is from user research already done by other institutions regarding comfortability.

10.4.1 Individual Contributions

Henrik and Marcus have been diligent in sharing all work evenly and making sure both team members were handling an even workload. The question is not what each individual member contributed, but what parts of the project the team spent a different amount of time on. Both team members contributed to research, concept generation, CAD designing, prototype creation, report writing and the presentation.

The only parts of the project with uneven work distribution was CAD design and report writing. While the workload between both member was the same, Henrik spent more time on report writing than CAD designing, while Marcus spent more time CAD designing than report writing.

11 Future improvements and goals

As previously stated the executives at *Soeco* were interested in seeing an economic evaluation be made for an arbitrary number of units to more accurately gauge the economic viability of '*Terminal*'. This economic evaluation would be one of the next steps of a continuation of this project and would entail talking production price with a workshop for using a CNC mill, evaluating material costs and manufacturing/assembly costs like employee time investment etc.

For the CAD design of the original concept '***Cobra Solid***' simple renditions of angled corner pieces were made as an example of modularity with the design. One future goal of a continuation of the project would be to create construction concepts for these angled corner pieces. This would give more options to what constellations of '*Terminal*' are possible and would contribute to the competitiveness of '*Terminal*'. There is also a possibility to create custom connectors instead of buying pre made bed connectors, these custom connectors would make the act of connecting elements easier.

Since the team decided to use wheels and feet for the design, new possible load issues could become relevant. The wheels used for the final prototype where from *Theofils* and with four physical connections with the ground these wheels would be under heavier load than the ribs on which users sit. More specifically, the beams on which the wheels and feet are attached to would experience a heavy load. An important future goal would thus be to do a thorough FEA analysis of the wheels, feet and bottom beams.

When creating the upholstery for the final prototype, just prior to the final presentation, the upholsterer at *Soeco* advised that for future iterations of the design there would be a need for beams along the outer edges of the bottom. These beams would be needed to create a more solid foundation for the upholstery to attach to and add to the robustness and quality of the textile feel.

12 Conclusion

The team is along with the executives at *Soeco*, pleased with the outcome of the project. '*Terminal*' is an innovative and sustainable concept that the team feels has a bright future which might ebb out into a real product on the Swedish furniture market.

The tests performed by the team and in cooperation with RISE has given credit to the possibility of one day applying 'Terminal' for a Möbelfakta certification. As the team has worked hard in adhering to their requirements.

The team is hoping that this project might inspire other producers to take a second look at the materials they posses and work towards more sustainable furniture.

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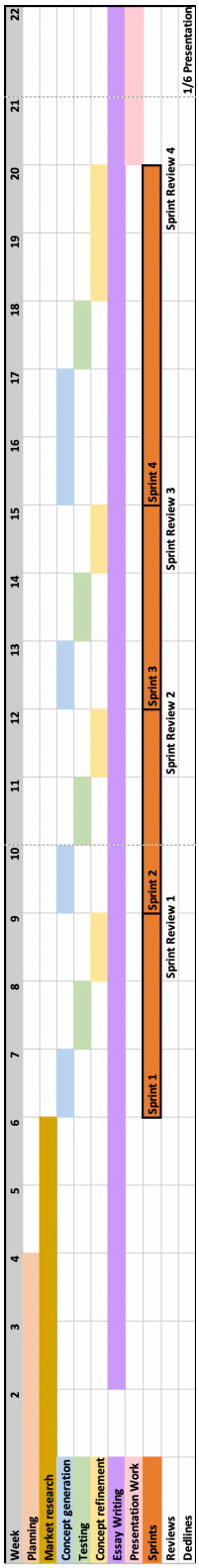
Appendix



A.1 Initial Gantt Chart.