Olav Engelstad

Design with Waste Wood

Masteroppgave i Industriell design
Veileder: Nils Henrik Stensrud, Pasi Aalto
Juni 2020

Masteroppgave

NTNU
Norges teknisk-naturvitenskapelige universitet
Fakultet for arkitektur og design
Institutt for design

Yrjan Olsnes

NTNU
Norwegian University of
Science and Technology

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NTNU
Kunnskap for en bedre verden

Design with Waste Wood

By Olav Engelstad

Master’s Thesis Industrial Design

Main supervisor: Nils Henrik Stensrud

Assistant supervisor: Pasi Aalto

Department of Design

Norwegian University of Science and Technology

June 2020

Preface

Many thanks to Magne Løfaldi and Mari Bøe who have been my contact poeple in Innveno. They have been essential for the development of this master’s thesis.

I also want to give my appreciations to Magnus Bøklep and Georg Solem for all the information I have recieved from their companies regarding my master’s thesis.

Nils Henrik Stensrud has been my main supervisor. Nils is a skilled designer and motivates me to create beautiful and functional products. He has a great understanding for product design and has been a big part of the product development in this master’s thesis. I would like to thank him for all the great advice he has given me over the last two years.

Pasi Olav Aalto has been my assistant supervisor in this master’s thesis, and I cannot thank him enough for sharing his great professional expertise. He has been a fantastic mentor. It is because of him that I have found such a passion for what I do.

The master’s thesis has been financially supported by Fylkesmannen I Møre og Romsdal, making it possible for me to travel to Surana and purchase the necessary tools. My best regards to Fylkesmannen for this opportunity

Abstract

Background

Our society is constantly facing challenges with over-consumption of resources. Natural resources are harvested faster than they replenish, resulting in a non-sustainable environment. Industries across the world are noticing this challenge, and new ideas contributing to sustainable development are vital for future-oriented companies. The focus of this master's thesis is to increase the lifetime of wood. The thesis is developed in cooperation with Innveno, which is a company in Surnadal. Innveno coordinates seven different companies working within the material industry, and this mater's thesis will investigate four of these companies. The purpose of this master's thesis is to find new ways to use waste material from companies within the wood industry. All of these companies have their own way of processing the waste wood, and hopefully, some of these can be enhanced.

Goal

The main goal of this master's thesis is to increase the value of waste wood from Surnadal. The waste wood is currently used as firewood for local buyers and fuel for energy recovery by local companies. This is not an optimal solution, since the wood will release CO2 into the atmosphere once burned. My goal is to increase the lifetime of the wood before it eventually is burned or disposed of. By finding new ways to utilize the waste wood, lifetime will be extended, and the value will increase.

Method

This project contains two types of design: strategic design and product design. The strategic design process is used to gather information, evaluate information, and control the scope of the project. It incorporates methods like evaluation matrix, Giga Map, analysis, interviews, and research. The product design process consists of product development, and includes the following methods: mood board, idea generation, sketching, prototypes, virtual reality, and interviews.

Result

The results are a range of furniture that can be manufactured with a high moisture level. The furniture series consists of a small coffee table, a chair and a decorative sculpture that also functions as a table. What makes this series different from other furniture is the way they are manufactured. They consist of large diameter waste wood from sawmill with a high moisture level. This does not only reduce energy, times and resources related to the drying process, it also results in products with a remarkably low carbon footprint.

Sammendrag

Bakgrunn

Samfunnet vårt møter stadig utfordringer knyttet til overforbruk av ressurser. Flere av naturresursene høstes raskere enn de fornyes, og dette er ikke bærekraftig. Bransjer over hele verden merker denne utfordringen, og nye ideer som bidrar til bærekraftig utvikling er avgjørende for fremtidsrettede selskaper. Denne masteroppgavens fokus er å øke levetiden til avkapp. Oppgaven er utviklet sammen med Innveno, som er et selskap i Surnadal. Innveno kordinerer syv forskjellige selskaper som jobber innenfor materialindustrien, og denne masteroppgaven undersøker fire av disse selskapene (som jobber med tre). Hensikten med oppgaven er å finne nye måter å bruke avfallsmateriale fra selskaper innen treindustrien. De ulike selskapene har sin egen måte å bearbeide trelasten på, og det er forhåpentligvis områder som kan forbedres.

Mål

Hovedmålet med masteroppgaven er å øke verdien til tre-avfallet fra Surnadal. Avfalsvirket brukes nå til ved blant lokalbefolkingen og industrivarme for bedrifter. Dette er ikke en optimal løsning, siden treverket vil frigjøre CO2 i atmosfæren når den er brent. Med dette prosjektet vil jeg øke trevirkets levetid, før det til slutt blir brent eller kastet. Ved å finne et nytt bruksområde for dette avfallet, vil levetiden forlenges, og verdien øker.

Metode

Dette prosjektet inkluderer to typer design: strategisk design og produktdesign. Den strategiske designprosessen brukes til å samle og evaluere informasjon, samt kontrollere omfanget av prosjektet. Den inkluderer metoder som evalueringsmatrise, analyser, intervjuer og kvantitativ forskning, i form av spørreundersøkelser. Produktdesignprosessen brukes til å utvikle produkter og inkluderer metoder som moodboard, idégenerering, skissering, prototyper, virtuell virkelighet og intervjuer.

Resultat

Resultatene er en rekke møbler som kan produseres med et høyt fuktighetsnivå. Møbeleserien består av et lite salongbord, en stol og en dekorativ skulptur som også fungerer som et bord. Det som gjør denne serien unik fra andre møbelserier, er måten møblene blir produsert på. De består av avfallsvirke med stor diameter fra sagbruk med høyt fuktighetsnivå. Dette bidrar både til å redusere energien, tiden og ressurser knyttet til tørkeprosessen. Det resulterer i produkter med et bemerkelsesverdig lavt karbonavtrykk.

Motivation

This project reflects my interest and enthusiasm for wood. Last year I travelled to Finland on an international conference called “Forum Wood Nordic”. At the conference there were many people presenting their latest work within the wood industry. Their dedication towards the usage of sustainable materials motivated me. The last year I have been focusing on using design as a tool to increase the usage of sustainable materials in general, and wood in particular. Wood is a beautiful material shaped by our planet that cleanses our atmosphere and strengthens our constructions.

This master thesis is a great opportunity for me to learn more about what it requires to develop highly sustainable products. I chose to work with this master’s thesis alone, so I could be free to investigate all the areas I found interesting.

Like many others, i am passionate about development. To develop something out of curiosity is great but being able to do so in an eco-friendly manner is even better.

I want my creations to be helpful, both to the people of our society and to our planet. I want to do as much as i can to protect the enviroment, and therefore it is important that my products or services are based on these fundamental values.

For this reason, I have chosen to learn and do as much as possible to create products out of materials others consider-waste.

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Masteroppgave for student Olav Engelstad

Optimizing industrial use of wood

Wood is a natural resource. After the discovery of concrete and steel, wood was used less as a material. In the last couple of years wood has been used more frequently because of benefits -like less co2 emissions, carbon storage and overall increased human health. Even though we are using more wood, we still use “waste wood” for material recycling and energy recovery.

This master thesis will explore the possibilities within waste wood. I will work with companies that make products out of wood look at how they can increase usable amount of wood and explore the different use cases of the rest wood. Currently the generated waste wood from production line Is often used for energy recovery. Energy recovery consist of burning the waste wood and using the energy to heat up the building. My studies will investigate if there could be other more efficient methods for waste wood, booth for the environmental and value purposes.

Proposal of areas to study:

Investigate the current procedures for waste wood at four different companies.
Investigate new procedures for waste wood.
Research different sustainable solutions for optimizing wood production.
Deliver a solution to the companies.

Ansvarlig faglærer (hovedveileder IPD): Nils Henrik Stensrud.
Faglig veileder: Pasi Olav Aalto
Bedriftskontakt: Magnar Løfaldli

Utleveringsdato: 1/9/2019
Innleveringsfrist: 4/6/2019

10/1 -19
Trondheim, NTNU, dato

Nils Henrik Stensrud
Faglig veileder

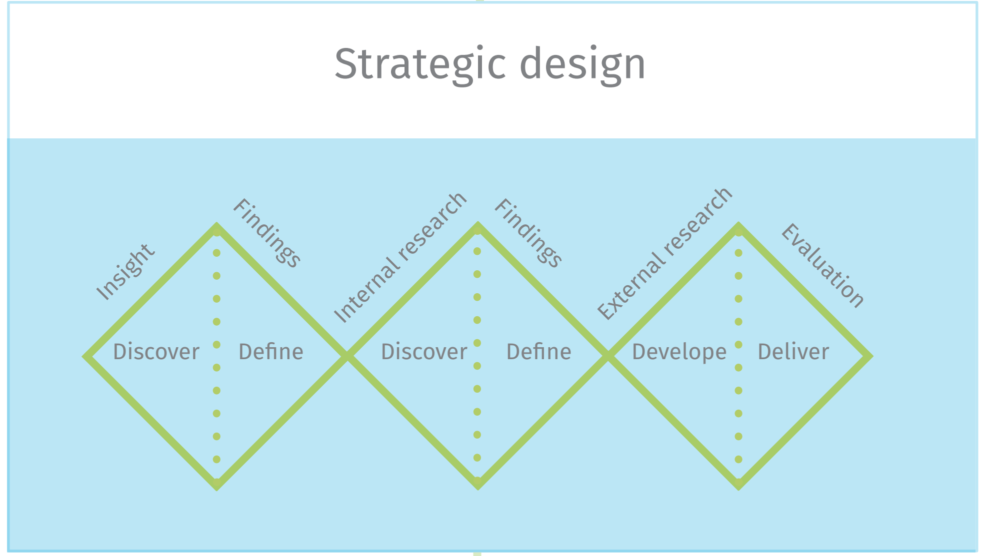
Ole Andreas Alsos
Instituttleder

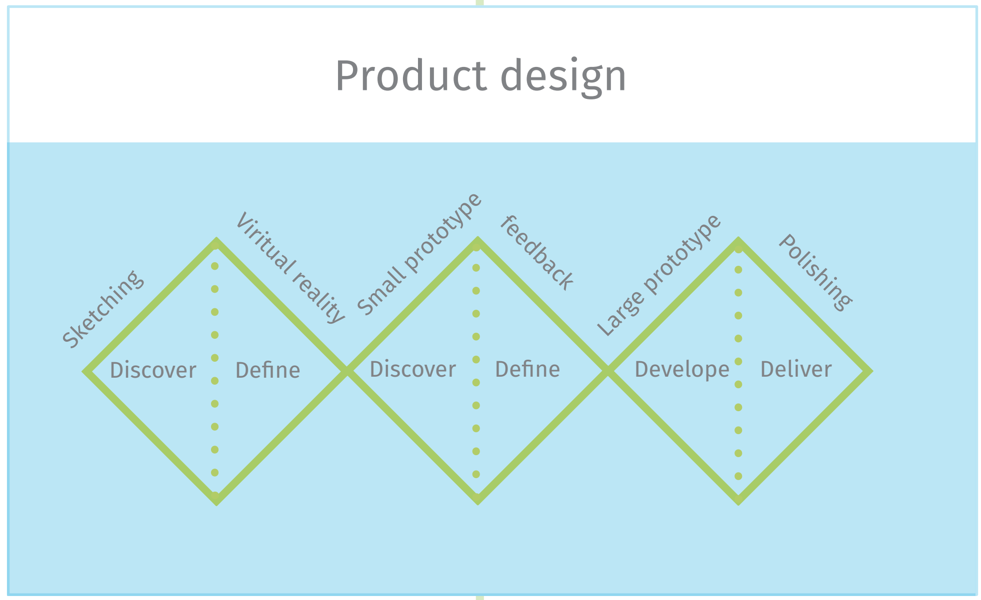
Process

I based my process on the double diamond design process, consisting of a strategic design phase and a product design phase. I used the strategic design process to discover and define the scope of the project, and the product design process included development of multiple products.

As the goal of this master's thesis was to find new ways to utilize waste material, strategic design was a key element. An important part of the strategic design was to gather the relevant information needed to improve existing procedures. The information-gathering process began with field trips, followed by internal and external research. From these early design methods, I would gather the required information to decide how the waste material would be further processed.

The strategic design process laied the foundation for the product design process. Since the results from the strategic design process were found late in the project, the product design phase had to be time efficient. Virtual reality changed the way I developed products and made me more efficient. This made it possible for me to develop multiple products in a short period of time.





Content

Strategic phase

Chapter 1

There are multiple companies to explore and investigate in this project. It is important to get a broad understanding of the companies involved, to fully utilize their potential. This chapter includes the early discoveries which led to the foundation of my research.

Insight phase

Going into this project there was a lot of questions to be answered. Understanding how the companies work was crucial. To get a greater understanding of how these companies operate and manage their waste wood, a field trip was initiated. One day was spent to go over the different processes they had for waste wood. Pictures was taken of the various-processes; questions were asked if there was anything unclear or exceptionally interesting. At the end of the field trips information was summarized, and structured to get a better overview of each of the companies. This was done to understand which areas should be focused on. Having a project consisting of two large processes, strategy design and project design, can easily get out of hands. Therefore it was important to carefully manage the scope of this project.

Discover

Talgø Møre Tre

Talgø Møre Tre is a large company with 129 employees. They produce oil pressurized wood, which makes the wood weather-proof. At their production site, I observed their waste material, which comes in large amounts and variable sizes. However, the pieces are in general very small. All the pieces of waste wood comes from imperfections in the wooden boards, which is quickly cut and separated. After their cut-offs are separated, they grind them down to chips. The massive area of chips comes from their tiny cut-offs.

Talgø Møre Tre has five different processes for their waste wood

- The fine quality chips are sold to farmers.
- Most of the cutoffs will be used to create briquettes. They sell the briquettes to Statkraft and Svorka.
- Some of the less finer quality chips is used to create Woodchips packs. These packs are sold to Felleskjøpet.
- The chips with lower quality are used to produce wooden hardboards.
- The rest is used to fuel their heating systems.

Kvatro

Kvatro is a medium sized company with 13 employees. They produce custom made structural bearing constructions for houses. As the bearing constructions have different sizes and shapes, so does the waste material. To make their production go faster, the wood beams are cut in every 30 cm depending on what they need. This means their cut-offs can vary a lot in length as well.

Kvatro has one process for their waste wood.

The waste material is sent to Talgø Møre Tre, where it is used for energy recovery.

Bøfjorden Sag

Bøfjorden Sag is a company with 8 employees. They mainly produce log timber which is used for log houses, and wooden decks for supply boats. Because they work with whole trees, all these products have large dimensions. Their waste material is large and can vary in sizes. Compared to the original material, the waste wood decreases in value by approximately 50%. They use waste wood to fuel a furnace, in order to save energy costs.

Bøfjorden Sag has three processes for their waste wood.

- Most of the waste wood is seperated into chips and used for energy recovery.
- Some of the wooden logs have imperfections and cannot be used to create buildings. Instead, they are sold as tracks for industrial machines.
- The rest of the waste material is cut to firewood.

Solem Sag

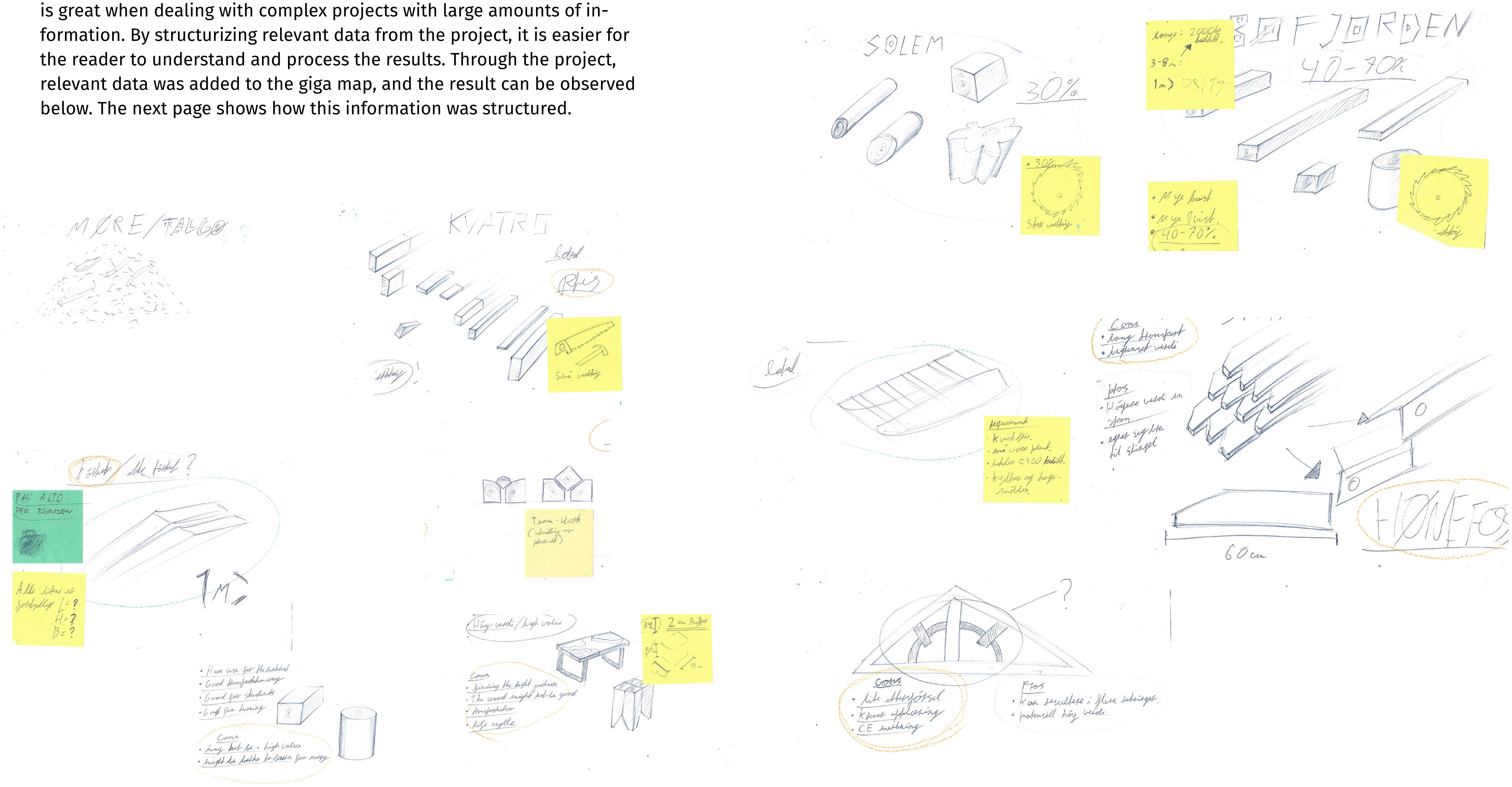
Solem Sag has 9 employees. They mainly produce log timber and solid wood. Like Bøfjorden sag, they operate with large dimensions of wood since they use whole pine trees. Their waste materials are also similar to Bøfjorden's, since they produce most of the same products. Their waste material has a 70% reduction in value. Solem Sag has no wood grinder because they end up with around 3m^3 waste materials per month. This amount is not enough to support the investments of a wood grinder.

Solem Sag has one processes for their waste wood.

- The wood is cut to firewood and sold to interested parties in the local community.

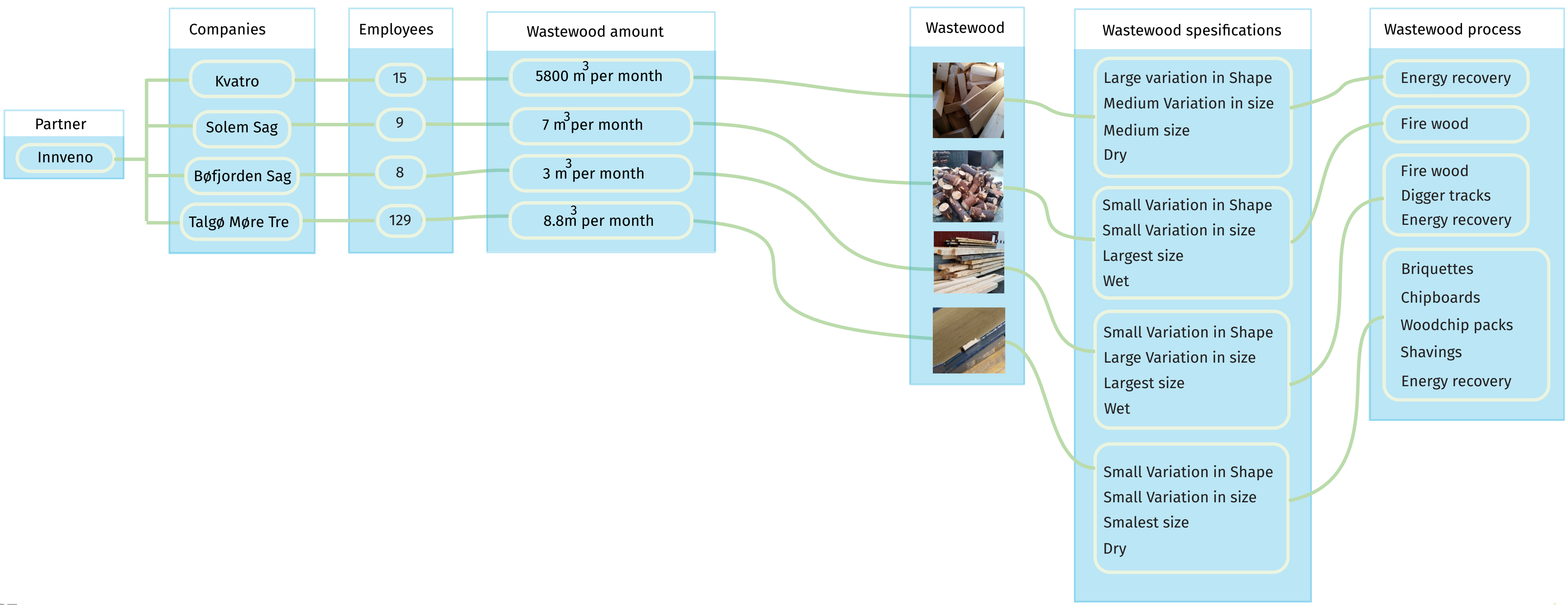
Giga map

There was a lot of information gathered at the field trip. A Giga map was created to analyze the information. The Giga map is a design process used and teached at The Oslo School of Architecture and Design. This method is great when dealing with complex projects with large amounts of information. By structurizing relevant data from the project, it is easier for the reader to understand and process the results. Through the project, relevant data was added to the giga map, and the result can be observed below. The next page shows how this information was structured.



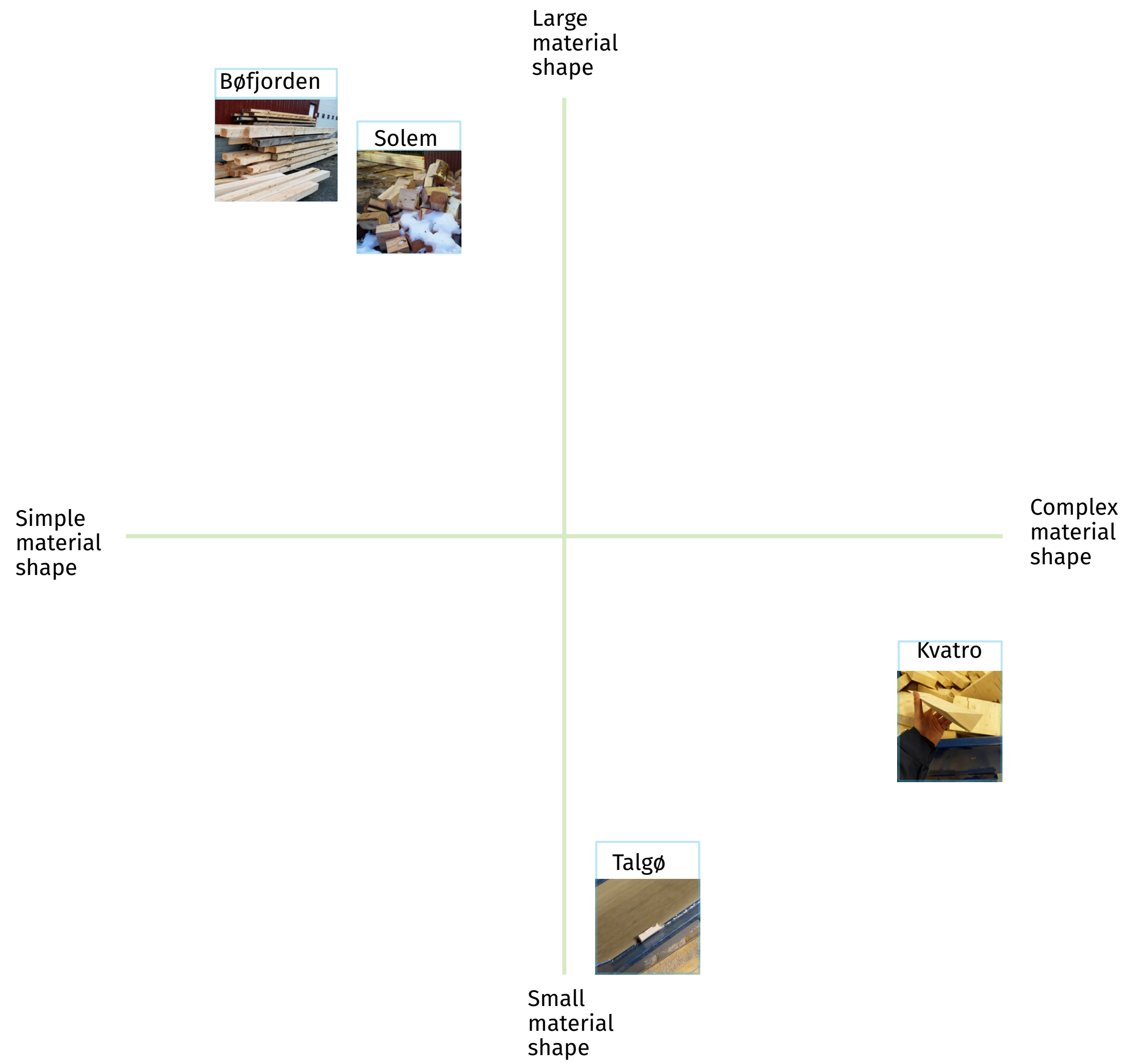
Structured Giga map

Sawmills are the first facility to process the timber. As a result, their waste timber comes in pieces with large dimensions. Both Bøfjorden Sag and Solem Sag end up with “waste” wood with dimension of over 15 cm in diameter and lengths upwards of multiple meters. Since Kvatro and Talgø Møre Tre processes wood with less size, they have a completely different process for their waste wood. It is smaller and they have a large variation in shape and size, but their amount is substantial.



Prioritation matrix

Because of the variation in size, treatment and complexity of waste wood. I saw it useful to create a prioritation matrix. The matrix would visualize the differences between the different waste materials. Based on the waste wood specification from the Giga map, the matrix visualized two different parameters, size, and complexity. The matrix indicated that the two sawmills differentiated a lot from Talgø Møre Tre and Kvatro. The sawmills waste wood was larger and simpler in shape, giving it a better potential towards other adaptations of products. It is difficult to produce products from materials with little to no consistency. This means that there is a better chance of increasing the value of this waste material. Because of this I decided to focus the project around these two companies waste wood.



Findings

The companies waste wood had been compared, and from this comparison it is most viable to focus on Bøfjorden Sag and Solem Sag's waste materials. Kvatro and Talgø Møre Tre uses their waste wood for energy recovery, because of the waste materials small size. It is hard to recommend Kvatro and Talgø Møre Tre to investigate anything else than energy recovery at this point.

Because of the projects scope, and Talgø Møre Tre's optimization of their waste wood, Talgø Møre Tre was removed from further development into this project. Talgø Møre Tre is a large company with highly complex processes. It would require substantial amount of time to research new adaptations, or partnerships for their small sized waste wood. Considering that Bøfjorden Sag and Solem Sag would be the focus of this project, there would not be enough time to investigate a large company like Talgø Møre Tre. Kvatro however is still in a position for further investigation.

Chapter 2

Bøfjorden Sag and Solem Sag's waste wood had potential. The companies involved in this master's thesis might have the resources to utilize this waste material. To understand the company's capacities better, this chapter explores their internal resources.

- Internal research
- Findings

Internal research

The next step in the project was to investigate the opportunities for the selected waste wood. When evaluating a company through a strategic design process, it is important to explore the relevant internal processes. There could be a potential partnership between Kvatro, Solem Sag and Bøfjorden Sag. This partnership could lead to the development of new products. As design processes can vary quite a lot, it is important to gather other thoughts on how to approach a design method. For companies to be able to adapt new processes, two areas are investigated. These areas focus on their internal capabilities and is based on their possibilities to produce products. All relevant areas should be investigated, because internal production can be effective and cost efficient.

The two different areas are:

- Professions
(What their skills are, and their capabilities. This is relevant if they are to deal with the wood in a different way)

- Tools owned by the companies
(Whether or not the company need to buy a new machine if they were to do something else with the rest wood)

Kvatro

Tools

- 5 axis large cutting saw
- Jigsaw
- Miter saw
- Building saw
- Hammer
- Cramp pistol
- Nail gun
- Fein saw
- Drill
- Portable router
- Handsaw
- Sheet knife
- Chipsel
- Crowbar
- Wrench set
- Socket set
- Vacuum lifter
- Spreader

Qualifications

- Engineers
- Carpenters
- Furniture carpenters

Solem Sag

Tools
Parallel bench saw
Chipper & transporter
Plaining machines
Mobile log planer
Portable sawmill
Sprinkle miller
Sword cut machine
Element jig
Wood dryer

Qualifications
Carpenters
Wood specialists
Woodworkers

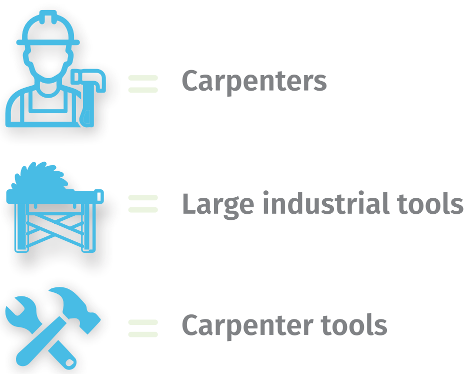
Bøfjorden Sag

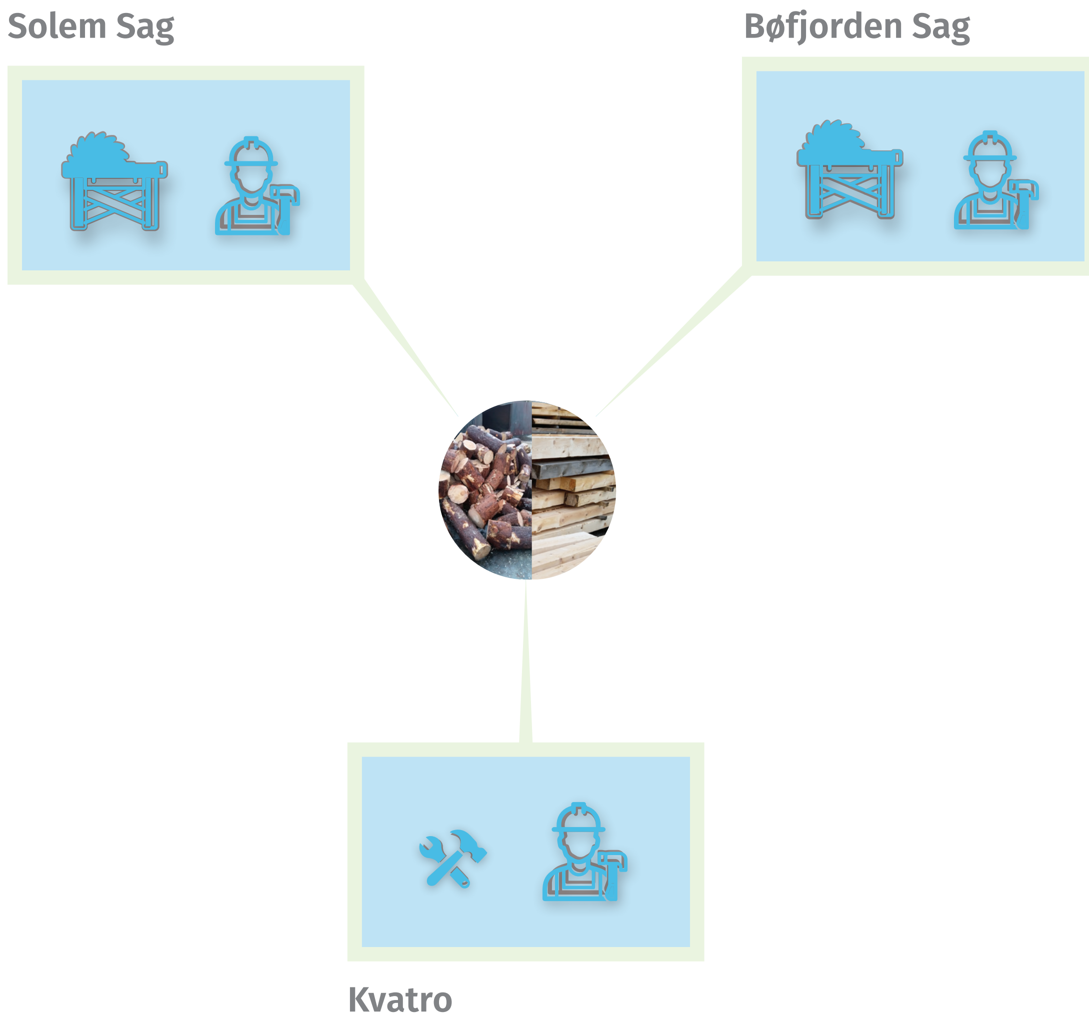
Tools
Sawline
Circle saw
Large band saw
Chipper
Bark tearer
Planer
Dry cleaver
Trimming machine
Tile mill
Lumberdryer

Qualifications
Carpenters
Wood specialists
Woodworkers

Findings

To realize what the company's internal capabilities are, their resources was categorized. What differentiates Kvatro from Solem Sag and Bøfjorden Sag, is their selection of tools and qualifications. Kvatro has tools like jig saw, router, hand saw and mitter saw to manage wood more precise than the two sawmills, and they have furniture carpenters. This means that Kvatro requires less resources to adapt their production towards new products. Kvatro could potentially receive materials from Bøfjorden Sag and Solem Sag and create a new range of products. Kvatro is thereby the first potential partner, within the companies that has been investigated.





Chapter 3

The next step of the process was to explore external applications of the waste material. It was important to study potential adaptations beyond the initial companies as these might enhance the process. In this chapter I will present my external findings.

- External research
- Evaluation

External research

Kvatro which is a company within Innveno is a potential partner. Finding out whether there are more viable partners outside of Innveno was crucial for the future of this project. To find the best adaptation for the waste wood, it is important to study external companies. There are 105 companies in Norway working within the wood industry (Treindustrien, 2020). To make sure the project only contains highly relevant companies, some criteria had to be made. these criteria's would help to eliminate irrelevant options.

There might be companies able to produce products out of the waste materials. Companies which can use the waste materials for existing products would be highly prioritized. If a company must change processes to adapt towards the waste wood, cost benefit must be within reach. Going forward, only companies which can adapt the waste wood to a current product or process is brought forward in the research. Using waste wood in other products can be difficult. Some building products demand materials with very strict certification. These certifications regard the structural integrity of the materials, and waste materials loses their original certification. (Direktoratet for byggkvalitet, 2018). The products that do not require these material certifications are:

Products with lower requirements

- Floating constructions, skate-parks, technical installations, power-plants, furniture, movable partition, temporary buildings (2 years), boats and docks.

Products with lower requirements, excel great for waste wood adaptations and will be one of the requirements for the external companies. Long transportation distances equal higher CO2 emissions and is therefore an important criteria. Bøfjorden Sag and Solem Sag's waste wood volume is 10 cubic meter per month. To make sure the waste wood generates highest possible value, the third and last criteria is economical value. This is measured though how much the material is worth in each of the product categories.

Criterias's

- Travel distance to the potential partner.
- Material restrictions.
- Material Value

Possible options

Student materials

NTNU and other universities around Norway have workshops. These workshops often uses wood as a material for students. NTNU have a partner called Moelven Limtre AS. They deliver wood to the university workshop where students can develop prototypes. The massive waste wood from the Bøfjorden Sag and Solem Sag, could potentially be used by students. Since this waste wood have a larger size than the wood from Moelven, it performs well for wood turning. As NTNU Trondheim is located 152 km away from Surnadal, they would be the closest partner.

Student materials (NTNU)	
Travel distance	152 km
Material restrictions	No
Material value	Low

Shingle

Shingle is a product used to decorate outside walls and roofs. This is popular in Norway and there are multiple companies in Norway delivering these solutions. There is a company located north of Oslo called Eilo Tree As. They inquired an interest for the waste wood, and could potentially use the waste material for their product.

Shingle (Eilo tree AS)	
Travel distance	543 km
Material restrictions	No
Material value	Low

Energy recovery

The probably most common way to use “waste wood” for companies is to fuel an energy station. These energy stations are quite effective in terms of saving cost on energy. It is an option with very low environmental value, because of the release of CO2. Kvatro already use some of their waste wood for energy recovery

Particleboard, plywood and MDF

Waste wood can be used to create wooden boards. These boards are made from grinded wood waste which is pressed together. This method requires high amounts of cut-offs. Bøfjorden Sag and Solem Sag’s total waste wood is roughly 10m^3 per month. This amount is not enough to make a process like this beneficial.

Household products

It is popular to use waste wood to create different products like lamps, wood pots, cups, cutting boards and other small products (B. Dragset, personal communication, May 26, 2020). In Surnadal there is a local cabinet maker called Trollheimen Barnekjelker, who makes outdoor furniture’s. They might be interested in a partnership, but this would result in a new range of products for the cabinet maker.

Energy recovery (Bøfjorden Sag)	
Travel distance	152 km
Material restrictions	No
Material value	Low

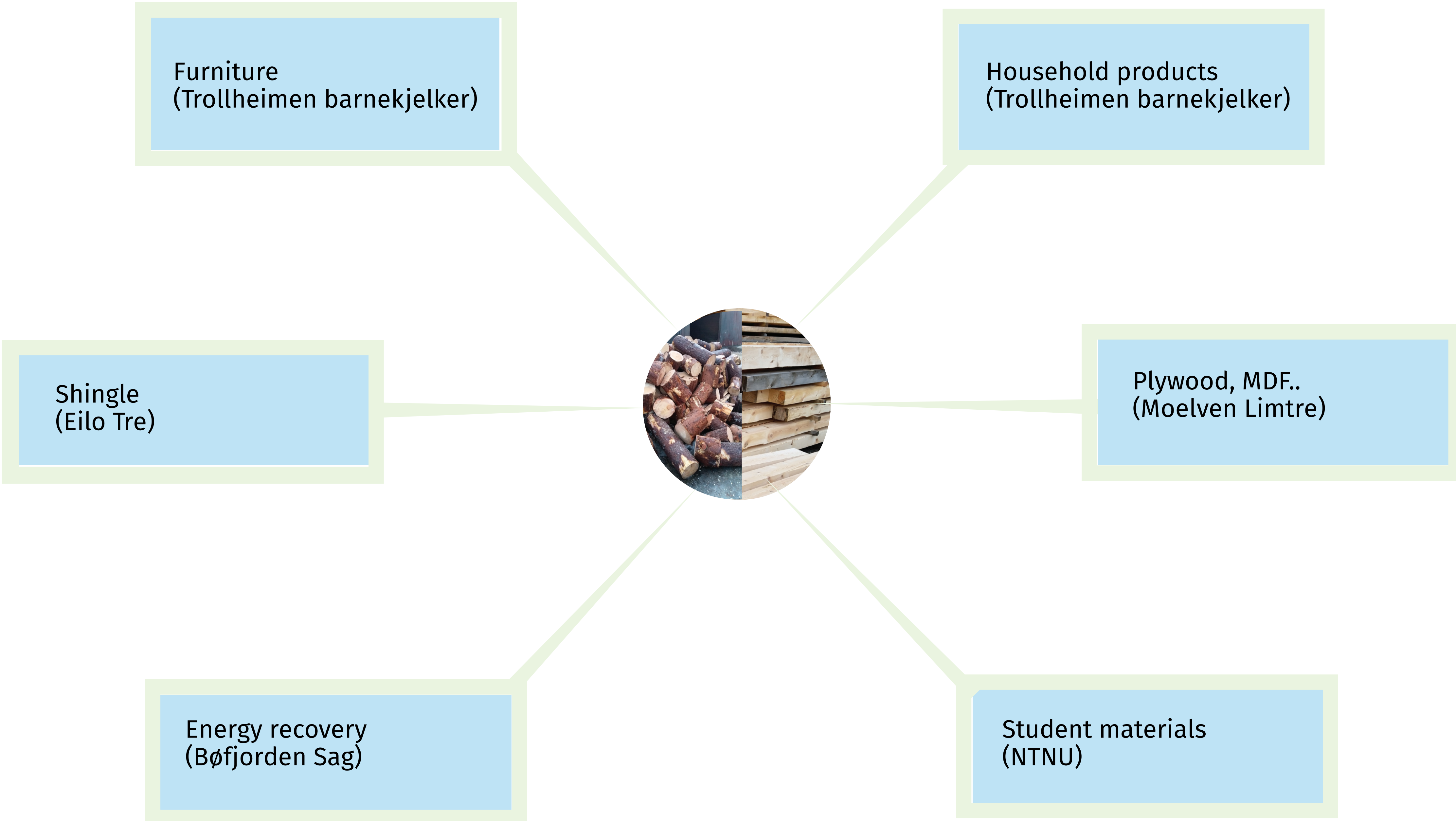
Plywood, MDF.. (Moelven Limtre)	
Travel distance	383 km
Material restrictions	No
Material value	Low

Household products (Trollheimen Barnekjelker)	
Travel distance	134 km
Material restrictions	No
Material value	High

Furniture

The most common wood materials used in furniture's sold in Norway in is oak, teak and walnut (B. Dragset, personal communication, May 26, 2020). 90 % of the furniture sold in a popular furniture store in Trondheim is Oak (B. Dragset, personal communication, May 26, 2020). Other popular wood types used in furniture's are walnut, Teak, Cherry, Maple, and Mahogany. These types of wood are hardwoods. They are less complicated to create precise tolerances with, compared to pine which is a soft wood. Pine is used for furniture's as well, but they are very rarely with knots. The waste wood from the sawmills includes knots. If the knots are used in the product, less materials goes to waste. If people where to buy more furniture made from Norwegian pine, there would be less emissions from the transportation of materials from other countries. The local cabinet maker could be a potential partner within this area. They already produces furniture's, making it an existing product category. The distance is short of 140 km.

Furniture (Trollheimen Barnekjelker)	
Travel distance	134 km
Material restrictions	No
Material value	High


Furniture
(Trollheimen barnekjelker)
Household products
(Trollheimen barnekjelker)
Shingle
(Eilo Tre)
Plywood, MDF..
(Moelven Limtre)
Energy recovery
(Bøfjorden Sag)
Student materials
(NTNU)

Furniture (Trollheimen barnekjelker)

Travel distance	134 km
Material restrictions	No
Material value	High

Household products (Trollheimen barnekjelker)

Travel distance	134
Material restrictions	No
Material value	High

Shingle (Eilo Tre)

Travel distance	543 km
Material restrictions	No
Material value	Low

Plywood, MDF, etc. (Moelven Limtre)

Travel distance	383 km
Material restrictions	No
Material value	Low

Energy recovery (Bøfjorden Sag)

Travel distance	152 km
Material restrictions	No
Material value	Low

Student materials (NTNU)

Travel distance	152 km
Material restrictions	No
Material value	Low

Evaluation

Based on the criteria, developing furniture together with Trollheimen barnekjelker would be the most viable option. This place I located close to Bøfjorden Sag and Solem Sag. Furnitures can have a high material value, as the value to material mass is higher than the other options and there are no material restrictions connected to furniture's. This can also be a positive drive towards usage of waste wood in the furniture industry. There are vast amounts of pine in Norway, but it is mostly used in cabins. Using more pine in furniture's could potentially lead to a more sustainable furniture industry for Norway.

Complete Giga map

The internal and external investigation lead to the discovery of Trollheimen Barnekjelker. They would be the best suited partner and completed the Giga map and the strategy phase.

Household products (Trollheimen)

Travel distance	134 km
Material restrictions	No
Material value	High

Plywood, MDF.. (Moelven Limtre)

Travel distance	383 km
Material restrictions	No
Material value	Low

Furniture (Trollheimen barnekjelker)

Travel distance	134 km
Material restrictions	No
Material value	High

Energy recovery (Bøfjorden Sag)

Travel distance	152 km
Material restrictions	No
Material value	Low

Student materials (NTNU)

Travel distance	152 km
Material restrictions	No
Material value	Low

Shingle (Eilo Tre)

Travel distance	543 km
Material restrictions	No
Material value	Low

Partner

Innveno

Companies

- Kvatro
- Solem Sag
- Bøfjorden Sag
- Talgø Møre Tre

Employees

- 15
- 9
- 8
- 129

Wastewood process

- Energy recovery
- Fire wood
- Fire wood, Digger tracks, Energy recovery
- Briquettes, Chipboards, Woodchip packs, Shavings, Energy recovery

Wastewood

Wastewood amount

- 5800 m^3 per month
- 7 m^3 per month
- 3 m^3 per month
- 8.8m^3 per month

Wastewood spesifications

- Large variation in Shape, Medium Variation in size, Medium size, Dry
- Small Variation in Shape, Small Variation in size, Largest size, Wet
- Small Variation in Shape, Large Variation in size, Largest size, Wet
- Small Variation in Shape, Small Variation in size, Smalest size, Dry

Product phase

Chapter 4

Before the product design could begin, there were important areas to investigate within the waste wood. Waste material can have flaws and limitations. This chapter explains the complicated specification of the waste material.

Technical elements

The waste wood from the Bøfjorden Sag and Solem Sag have a moisture level of around 16-20 percent. Wood used for indoor furniture's, have a moisture level of around 7-11 percent depending on the area's moisture level (Brown, 2009). If wood with a high moisture level is used for indoor products, it will start to shrink (Eckelman, 1998).

The high moisture level in the waste wood is due to their application. The original material is used as a construction material for houses. In this application it is important that the wood have a moisture level of around 16-20 percent (M. Bøklepp, personal communication, February 13, 2020). At this moisture level the wood stabilises better, because the wood is used for an outside application where the moisture level is higher than what it is inside (M. Bøklepp, personal communication, February 13, 2020).

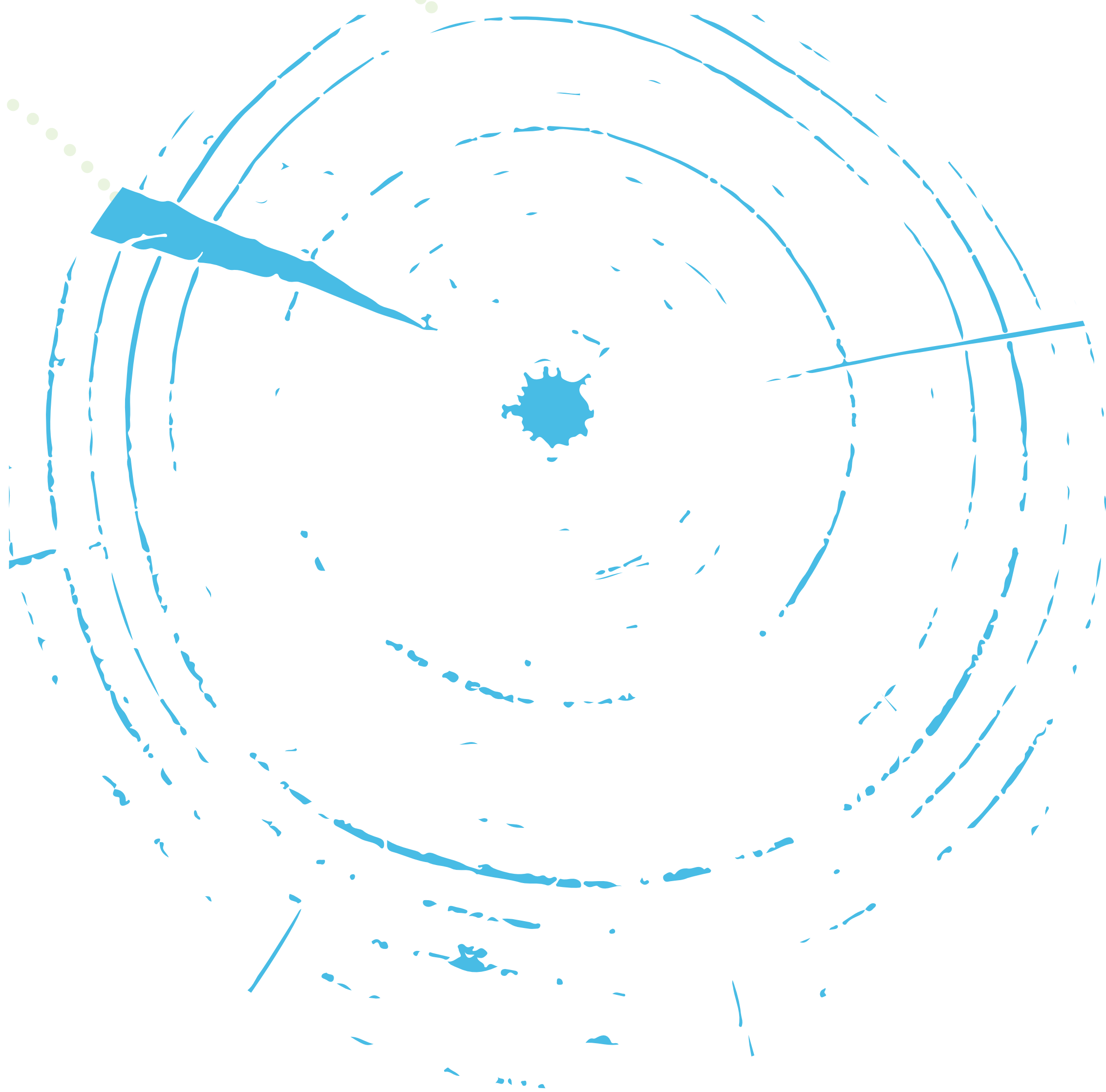
At NTNU in Trondheim there are people with a large amount of knowledge about wood. Originally the products would be developed together with the furniture carpenter from Trollheimen Barnekjelker in Surnadal. Because of the technical issues of the waste wood, and NTNU's expertise. I saw it more useful to have the furniture's developed at NTNU. Once the furniture's were developed, Trollheimen Barnekjelker or another furniture carpenter could produce the products.

Shrinkage

When wood is brought inside, the temperature increases. The water inside the wood dries and the wood will shrink (Eckelman, 1998). Each of the blue rings consists of many wood molecules. Each wood Molecule shrinks independently, resulting in shrinking of the entire wooden rings.

When this happens, cracks in the wood will increase their size. This is because the outer rings reduce their size more than the inner rings. The cracks will then have a triangular shape (Eckelman, 1998).

If wood with a high moisture level is used for indoor products the cracks will increase their size until the wood has reached a stable moisture level content (M. Bøklepp, personal communication, February 13, 2020).



Drying

The two sawmills use heating systems to dry the water inside the wood. These systems are called kiln drying (M. Bøklepp, personal communication, February 13, 2020). They do this to hit the target of 16-20 percent moisture level. This translates to four weeks in the heating systems.

The waste wood can also be heated in these systems together with their prioritized wood. Each of these heating cycles is four weeks, and then these ovens have long breaks before the new cycle is started. This means that the waste wood cannot go down further than 16-20 percent moisture level. If 8-9 percent would be achieved these ovens have to run continuously for eight weeks, which is too costly for these companies.

Instead of heating systems, Air drying is also commonly used (Salas & Moya, 2014). This is a much less time efficient method (Rietz & Page, 1971). The waste wood used in this project can have diameters upwards eight inches. This can require multiple years to fully dry

Waste wood observation

For a greater understanding of how wood with a high moisture level behaved, Bøfjorden Sag sent some of their waste wood to the university. The transportation consisted of fourteen individual pieces of waste wood and had the measurements listed in table.

Measurements		
Depth	Width	Height
16 cm	21 cm	156 cm
16 cm	20 cm	156 cm
16 cm	21 cm	103 cm
16 cm	16 cm	116 cm
16 cm	16 cm	106 cm
16 cm	16 cm	80 cm
16 cm	16 cm	81 cm
16 cm	16 cm	80 cm
16 cm	16 cm	70 cm
16 cm	16 cm	51 cm
21 cm	16 cm	54 cm
20 cm	16 cm	36 cm
20 cm	16 cm	34 cm
16 cm	8 cm	64 cm
18 cm	15 cm Average	84 cm

Since most of the wood is twisted and uneven, the average size of the waste wood pieces ends up with a different size after being planned. One cm of the width and depth was therefore removed, as a buffer. This led to a 15cm depth and width, as most of the materials width and depth were 16 cm. Since the length of the pieces differentiate, the products that will be produced should be based on the size that is most accessible. This will ensure maximum usage of the waste wood pieces. The shortest piece delivered had a height of around 34 cm.

To verify the moisture level of the wood, samples was taken. These samples were done with a measuring tool from the university, and the gave following result.

Moisture level after	
0 days	19 %
7 days	19 %
14 days	18 %
21 days	19 %
28 days	19 %

Chapter 5

Design processes often differentiate from each other. This chapter visualizes my thought process and methods used to design the products.

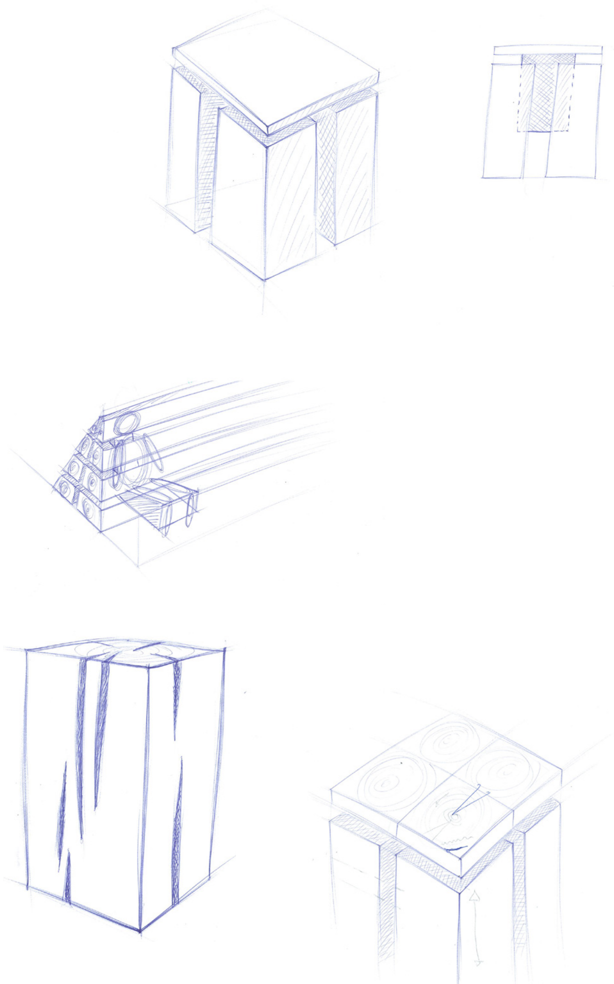
- Moodboard
- Sketching
- Viritual reality
- Small scale prototypes

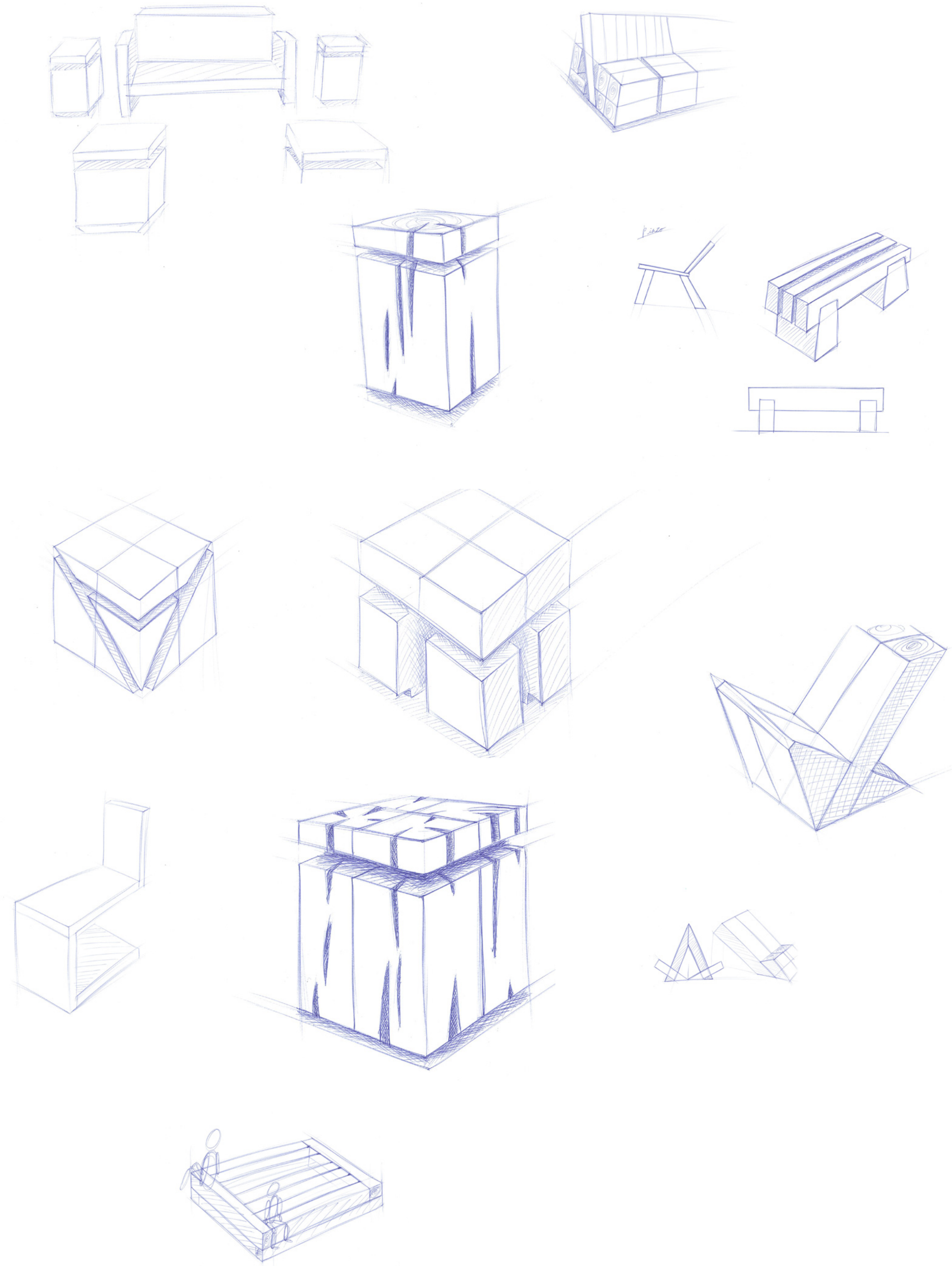
Moodboard

The pictures in this mood board represents products and textures that has been used as inspiration for the idea generation. Mood boards is a great tool to use when you want to visualize the though process behind your design. I developed an interest in wood products with very distinct and sharp angles. As wood is a soft material compared to metals, it is easier to shape and made it less troubling to explore my ideas. As the waste material had large size, I wanted to create massive products. Massive products with sharp angles can look exclusive and could help the waste wood look more attractive.

Sketching

Based on ideas associated with the mood board, sketches were produced. These sketches were discussed with designers and architects, and carpenters from the design and architect department at NTNU Trondheim. This was initiated to explore shapes, manufacturing capabilities and to gather thoughts from different minds. As sketches were created to explore the sharp angels, I came across an optic illusion that would make the wood look like it was floating. This idea lead to a range of different ideas.

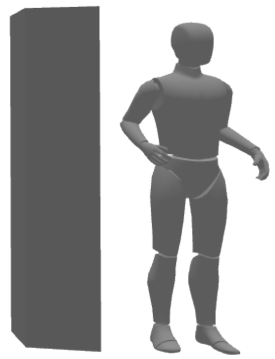


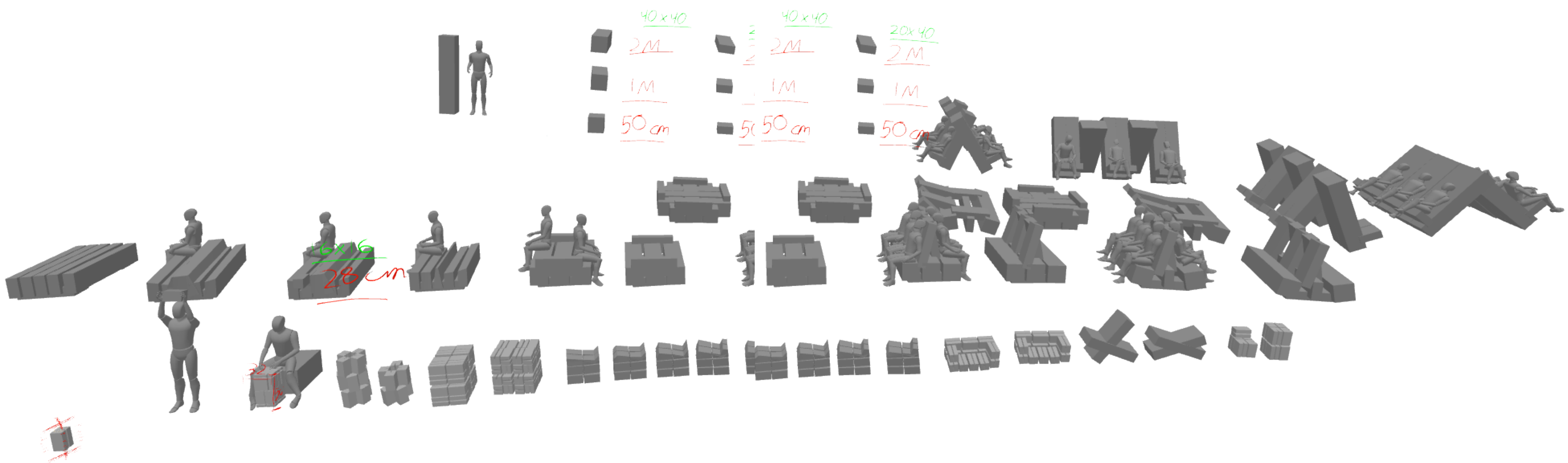


Viritual reality

Virtual reality is a tool which can make idea generation and prototyping phase very efficient. It has the potential to save substantial amount of time and give superior overview of complex products. This is possible since the software makes the user able to copy, place, change, and adapt all the shapes created in the software. These shapes can be scaled to a cad model of a human, making it possible for the users to have a near perfect intuition of a products shape and size.

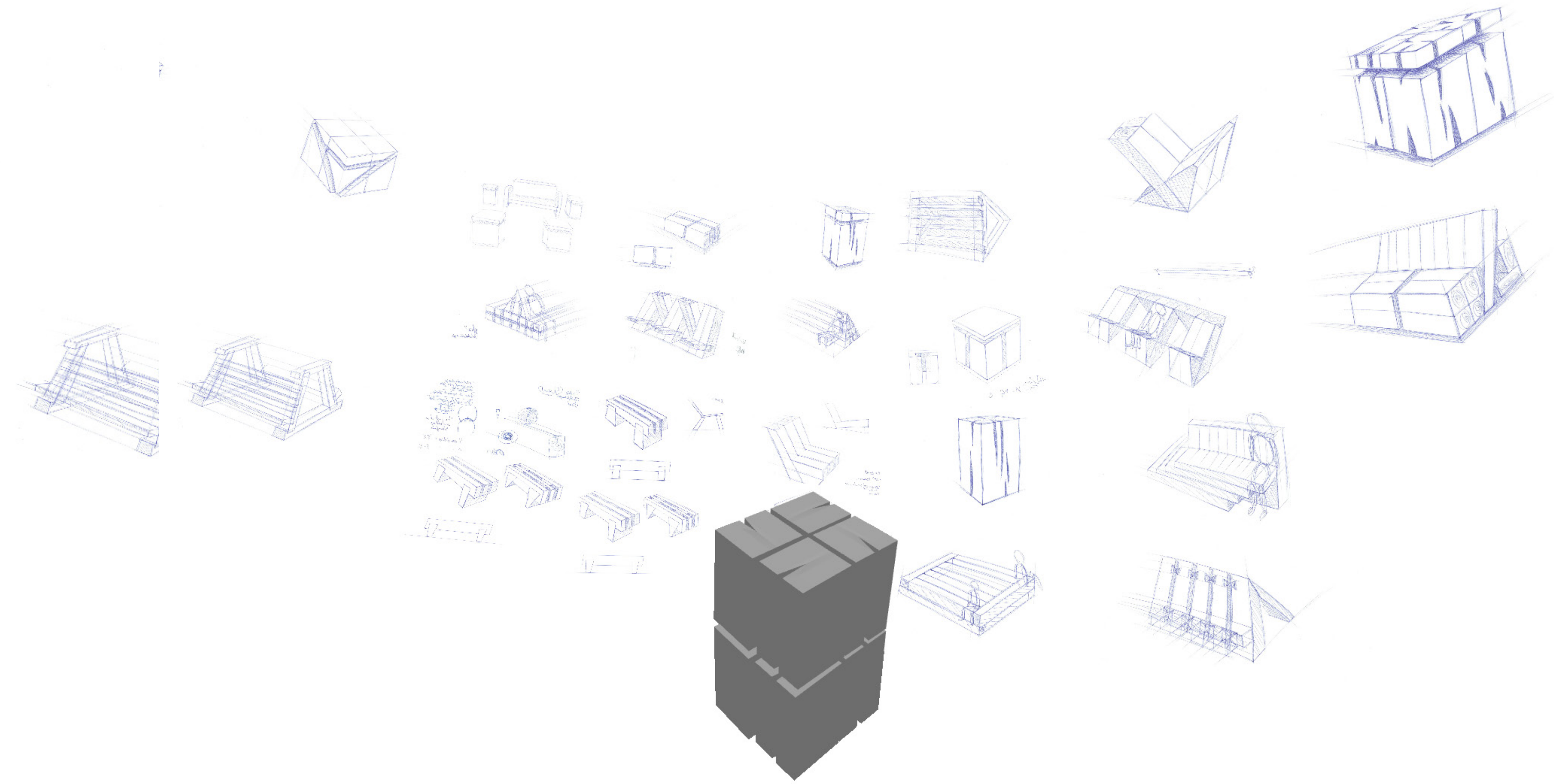
The optimal size of the waste wood was discovered in the waste wood observation. A cad model was created with this size and imported into Virtual reality. All the ideas from the sketching phase could then be explored. Over 36 different models were created, exploring shapes, assembling methods and sizes.





All the drawings which represented the different ideas, could be imported into the virtual reality software. The drawings were imported into the system to enhance the idea generation process. The models could be created in the system while observing the initial thoughts.

This feature made the product development phase quicker and led to new designs and ideas that were based on the important technical elements.



Small scale prototypes

Virtual reality works as a great tool to generate ideas and observe shapes. Creating physical prototypes is still necessary to illustrate your thought process to other people. It is possible to illustrate the products created in VR through screen sharing, thought this is a time-consuming, and less effective method. The ideas which was found interesting from virtual reality was created as small prototypes and brought to the projects supervisors to be discussed further. The prototypes below represent the evolution of my ideas for a coffee table.

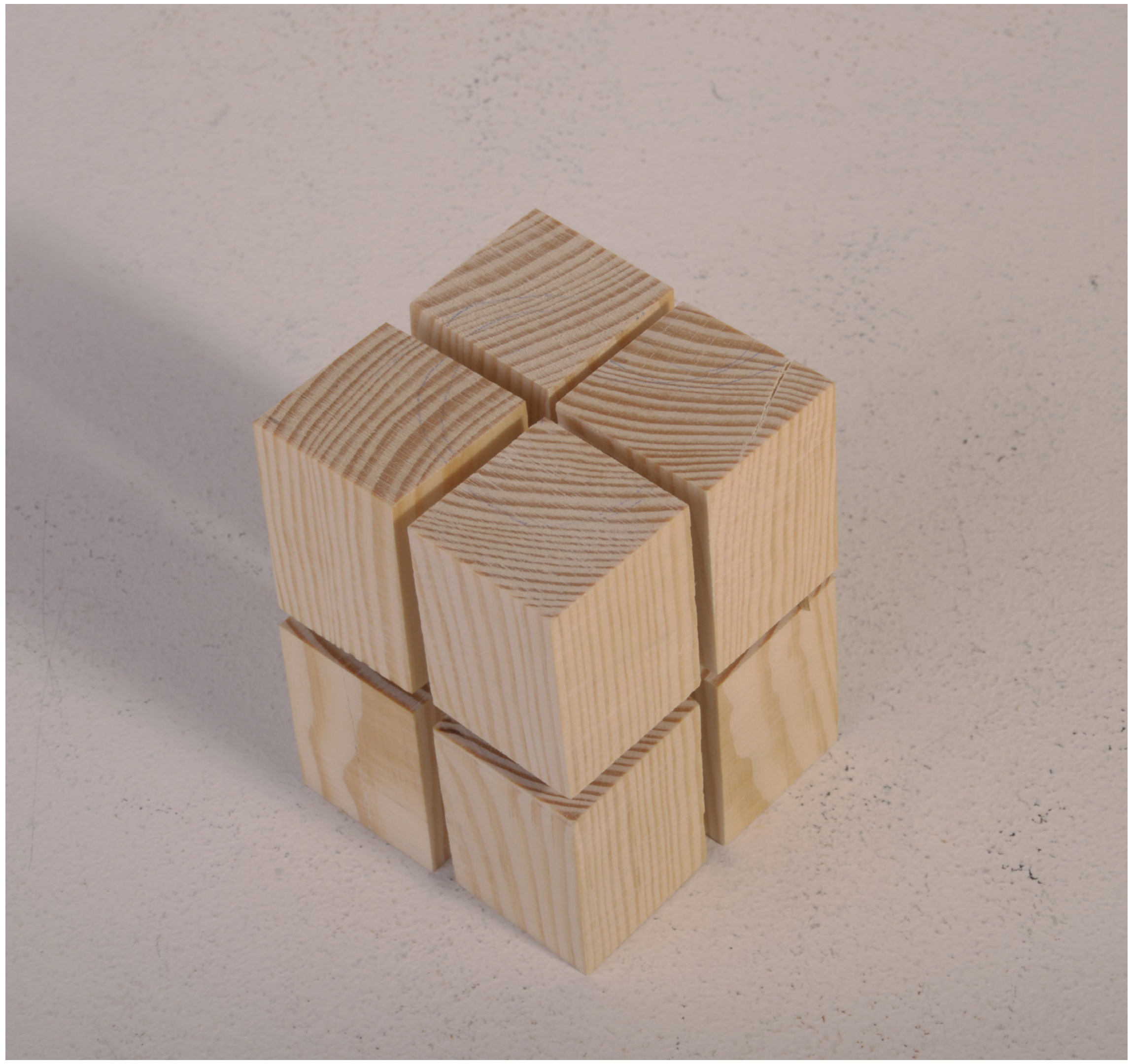
Chapter 6

The technical elements of the waste material could cause problems under production. It was important that the right production method would be used. This chapter includes important feedback from experts, which influenced the design and production method.

- Workshop 1.0
- Workshop 2.0
- Full scale prototypes

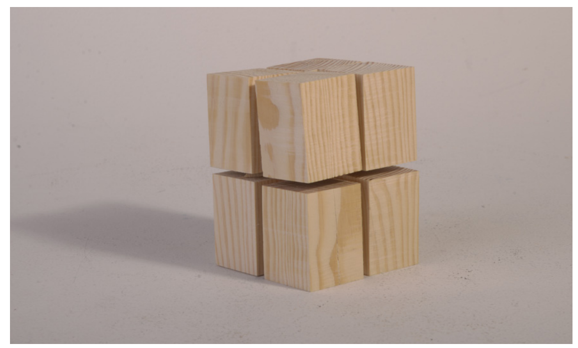
Workshop 1.0

After creating the small-scale prototype, two separate workshops were executed. The first one was done together with two carpenters from the architect's workshop at NTNU. The point of this workshop was to find out how we could create an indoor product made from wood with a high moisture level. The thoughts from earlier processes were presented, and the carpenters from the university workshop could quickly explain how the product could be produced. Since the material will as the moisture level is reduced, it was important that the composition of the product did not hinder the shrinkage process. The pieces of wood could be assembled by wooden plugs in the products core, allowing the outer edges to move freely.



Workshop 2.0

The second workshop was done together with Martin Høgh. Martin Høgh is a designer and teacher at NTNU. The goal of this workshop was to hear his thoughts around the interesting visual impression. His advice was to investigate how the empty spaces of the product could be a visual attraction. This had been experimented with by artists in the 1960’s. People like Dan Flavin, Donald Judd, Ellsworth Kelly and Larry bell. All these people are using light, shadows, and straight lines to create different visual impressions. Since the product is heavily influenced by the distance between the pieces, I saw it relevant to investigate this further and se the different possibilities. we discussed the potential of the product further and Martin saw it useful to create a full-scale prototype. A full-scale prototype with the actual cracks would give a better representation this. It was very hard to visualize this in a small prototype where the cracks were hard to recreate.

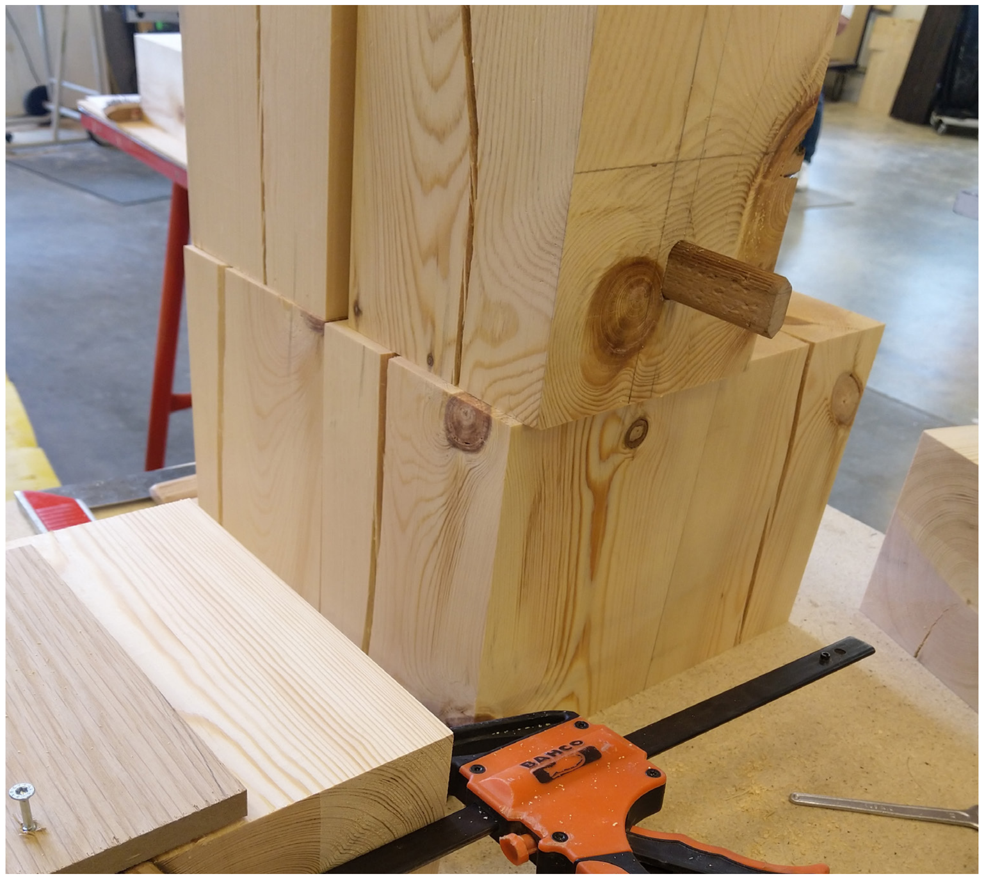


Full scale prototypes

After discussing with Martin, Jorge, and Pete. Waste Materials were prepared for the construction of the first full scale prototype. This prototype gave insight into the production method, and how the visual impression between the pieces would look. The full-scale prototype would also allow for a closer observation of the movement in the wood. As the wood movement is higher in the early stages of the drying process, most of the shrinking would happen within few days after construction. It is also important to assemble the product quickly once the materials are prepared. Assembling a product with changes in tolerances is not optimal.

Prototype number 1

As discussed with the carpenters from the architecture department at NTNU, the best way to produce the product would be to use wooden plugs. To speed up the production of the product, a domino machine was used. Domino machines create perfect holes with ease of use. These holes are made for specific types of plugs, that are compatible with a Domino machine.



The wooden domino joints are a mass-produced element which differentiate allot from the natural looking pine. The domino joints look more like a technical element, while rest of the product expresses a more natural look. Based on these findings a second prototype was made. This prototype was the same size as the previous one, just with joints made from pine.

Prototype number 2

Prototype number two required more time to manufacture as the wooden pine joints had to be manufactured into the desired shape. This process is time consuming, compared to the finished domino joints. Instead of using a domino machine to drill holes into the wooden block, a stationary wood drill was used. The holes depth was reduced to 39 from 40 millimetres and the pine plugs kept the same length. This would increase the size gaps with two millimetres. Tiny differences in gaps like these can make big differences.

Prototype number two looked more like a finished product. The pine joints had a better coherence with the product compared to domino joints. This prototype's gap increases of two millimetres, made a difference, giving the product more of a presence. The gap accentuates the sense of mass of each individual volume. The overall product made more sense. In terms of practicality, wider gaps are justified by how the product meets the user's hand and fingers. Prototype number 1 did not have room for fingers between the gap, and it drew unwanted attention to the risk of getting fingers stuck. The total size of the gap was now around 22 millimetres, and this gave the product a more relaxing feeling. As this design asks to be read as a pure composition of volume, rhythm, proportions and pauses, the optimal gaps are balanced between these two parameters

Prototype number 1

Prototype number 2

Chapter 7

A project can always face unpredictable obstacles and changes. It is important to be adaptable when these interferences appear. In this chapter I will present how Covid-19 affected this project, and how I dealt with it.

- Covid-19
- User servey
- Results

Covid-19

After finishing the prototypes at the university workshop, Covid-19 hit Norway. The university was under lockdown and the rest of my prototype phase changed. Continuing the prototyping phase at the university was not possible. The tools required to continue were too expensive to buy, and the project had to change direction temporarily. This master thesis focus was originally on what the sawmills could produce out of waste wood and physical full-scale prototypes was crucial considering the technical issues of the waste wood. The future of this master thesis was discussed together with the supervisors. The master thesis focus would be to gather more information about the marked for low emission products. This could strengthen the thesis and, also give valuable information about products made from waste wood.

User survey

To many people, how the furniture matches their interior style is an important factor. However, they do not necessarily know a lot about the particular product (B. Dragset, personal communication, May 26, 2020). To investigate whether or not there was a market for low emission products, a user survey was created. Since the products developed in this master's thesis is based on waste wood, the overall environmental CO2 emissions are far lower than what it would be from a product based on new materials.

The servey included four pictures of the second prototype, as well as a competing product from Turkey. The product from Turkey is a typical popular coffee table with an attractive design, and the renders illustrate potential use cases. It was important that the competing product had accessible information of its CO2 emissions.

EPD & LCA

A way to show a product's CO2 emissions is through an Environmental Product declaration (EPD) or Life-cycle assessment (LCA). These show the total energy required to harvest or produce the materials for a product. They show how much impact these factors have on the environment, as well as how much energy is required to manufacture and transport the product. These numbers are estimated in CO2eqv.

The Turkish table included an EPD, which allowed me to compare CO2 emissions from the two products. The next step was to perform a user survey to find out how much the environmental impact of the products affects the potential buyer.

Calculations

In order to compare CO2-emissions, relevant data for the two products had to be acquired. The transportation emission from Turkey to Norway had to be calculated, as this is not included in an EPD. To calculate the transportation emissions, it is required to know the emissions from the vehicle transporting the goods. A commonly used transportation truck in Europe is a 32 tonne EURO truck (Saunders, 2014). This truck has an emission of around 80g CO2 per kilometre. The distance from the production place in Turkey to Trondheim, Norway is 3713 kilometres, and the weight of the product is 11 kilograms.

Transportation equation
80g co2 x Km x Ton

Transportation emissions	
80g co2 x 3713km x 0.011 tonn	= 3267.44g co2eqv

Total transportation emission for the product is 3,26 kg CO2eqv, If the product is transported with a 32-ton Euro truck. The overall emission of the Turkish product from the EPD (without transportation to Norway) is 66.1 kg CO2eqv. In total (including the transportation to Norway), the CO2eqv of the Turkish product is 69.1kg CO2eqv.

To complete the research for the user test, CO2 emission regarding prototype two is necessary.
Prototype two does not have an LCA or a PDA. The necessary data had to be acquired to calculate the emissions for prototype two.
The product is made from waste wood, this affects the equation when calculating the emission number. (J. Saunders, personal communication, March 16, 2020).
The CO2eqv from the product only requires the CO2 emissions from the manufacturing and transportation of the finished product (J. Saunders, personal communication, March 16, 2020). Calculating the emissions related to harvesting of the raw materials is not necessary. This is because they are already accounted for in the production of the product where the raw materials are considered the waste wood.

Production equation
Manufacturing emitions + transportation emitions

Manufacturing energy is calculated by adding the energy required to produce the product.

Manufacturing information		
Tools	kw	Time
1 x Table saw	5.5	30 min
1 x Band saw	2.2	30 min
1 x Planer	3	30 min
2 x Industry fans	0.3	30 min

To calculate the emissions from manufacturing, the kw from the tools must be multiplied by the time they are used, and by the grams of CO_2 released per kwh.

Manufacturing equation
kw x time x g CO_2 per kwh

How many grams of CO_2 is emitted per kwh is individual for each country ("European Residual Mix," 2019). Norway produces vast amounts of hydropower (NVE, 2019). Hydropower is a way to generate energy with very low emissions. This is often referred to as green energy. In average Norway produces 18.9g CO_2 per kwh (NVE, 2019), this number is low because of hydropower (NVE, 2019). In theory this number could be used in the calculation, however Norway uses energy from other countries (NVE, 2019). which means that the energy Norway buys, does not necessarily come from hydropower.

The European residual mix is a calculation of the average origin of electricity sold without documented origin in Europe ("European Residual Mix," 2019). Since it was unclear where the energy used for producing prototype two came from, the European residual mix was then used. The average gram per kwh for the European residual mix is 520g per kwh in 2018 (Saunders, 2014).

Manufacturing emissions							
kw		Time		g CO_2 per kwh			
5.5	x	30 min	x	18.9	=	1430g CO_2eqv
2.2	x	30 min	x	18.9	=	572g CO_2eqv
3	x	30 min	x	18.9	=	780g CO_2eqv
2 x 0.3	x	30 min	x	18.9	=	78g CO_2eqv
Total						2860g CO_2eqv

As the manufacturing emissions were calculated, the only missing number was the transportation emission for prototype two.
To make the comparison fair, the same transportation method is used for prototype two.
The emissions from a 32-ton euro truck is 80g CO_2 per kilometre (Saunders, 2014). The distance from Surnadal to Trondheim Is 151km, and the weight of prototype two is roughly 22 kilos.

Transportatin emissions	
80g co2 x 151 km x 0.022 tonn	= 253.68g co2eqv

Adding the manufacturing emissions and transportation emissions to the production equation leads to following emissions for prototype two.

Production eqaution
Manufacturing emitions + transportation emitions

Production emissions	
2860 CO2eqv + 253.68 CO2eqv	= 3187g CO2eqv

Both products CO2eqv was calculated, and all the data required to initiate the user survey was acquired. The total CO2eqv per product is the following.

Terna

Total CO2eqv = 69,3kg CO2eqv

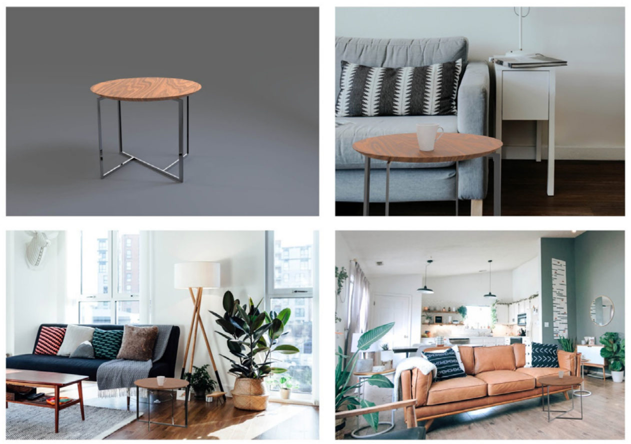
Prototype two

Total CO2eqv = 3,1kg CO2eqv

Two separate surveys were sent to different groups of people. The first group got a survey with pictures of the two products. They would have to choose which one of these products they would have in their living room. The second group received the same type of survey, except they were presented with the amount of CO2eqv each product emits.

Product number 1

Product number 2

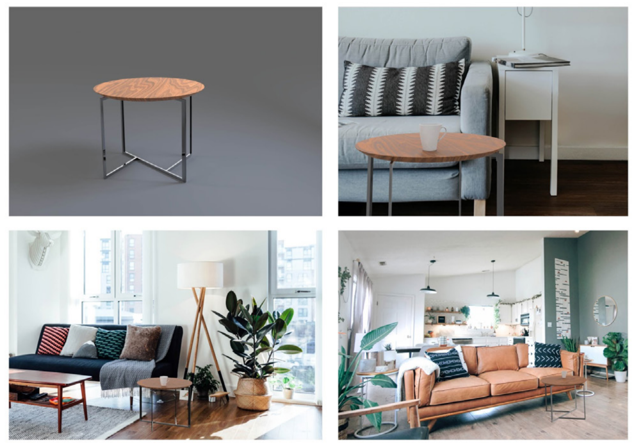


Product number 1

The product emits 3.1kg CO2eqv

Product number 2

The product emits 69.3kg CO2eqv

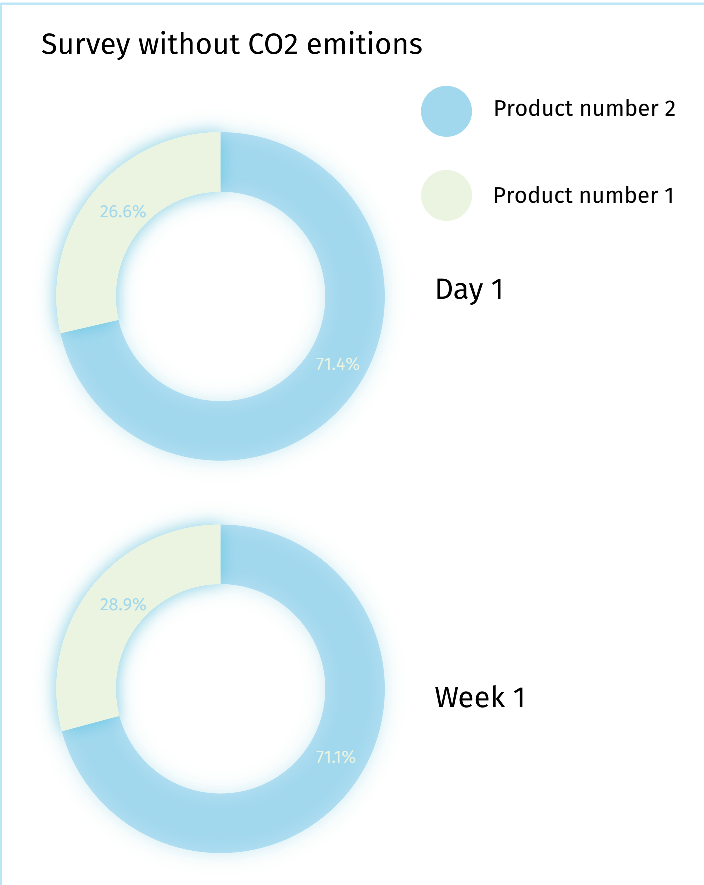


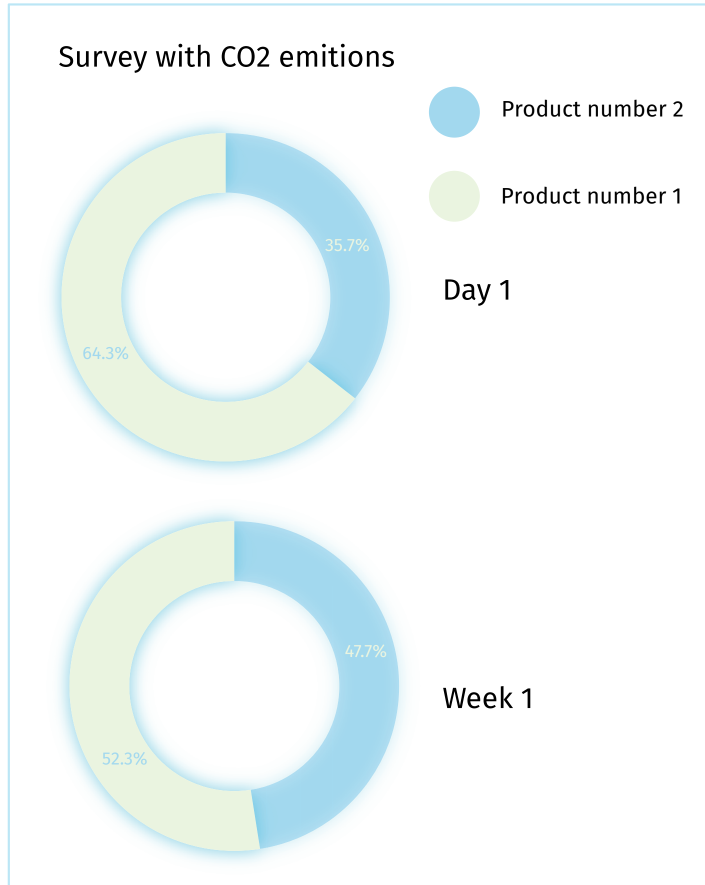
Results

The two surveys received different results. After sharing the user survey for over one week, 124 responses had been acquired. The survey without listed emissions had 38 responses and the survey with listed emissions had 86 responses. The amount of people who would prefer prototype number 2 increased with 23.4 % once the emissions were listed. Almost twice as much, compared to results when the emissions were not listed. This was fascinating as the numbers were expected to change, but not at such a large extent.

Product number 2

Product number 1





"The wooden sculpture looks better"

"I would choose the most enviromental product. but if i was in a store and this was not listed, i would chose the one which apeals the most to me"

"Natural and real design"

"Lowest emitions"

"I love wood"

"Because the table was very different and very cool. Can it be bought?"

"Enviroment and design"

"It had the lowest emitions, and it can be used as firewood"

"Interesting and beautiful"

" i would choose the product that would fit my interior the most, co2 emitions is not a criteria when buying furniture"

"New design"

On the bottom of the survey, the users had the possibility to explain why they chose the product. These comments were interesting to read, as there were many different opinions about the products. The surveys were sent people within the health, architecture, business, and furniture industry. It was intriguing to see people's interest in the developing product and this motivated me to continue develop products out of waste materials.

However, as some people also pointed out, if they were in a store to buy one of these products and CO2 emissions were not listed, they would choose the product based on its appearance and look. Even if the CO2 emissions were listed in a store, people might still buy the product with a higher CO2 emission. In other words, it is not sufficient to produce a product with a low CO2 emission if the product does not appeal to somebody.

Chapter 8

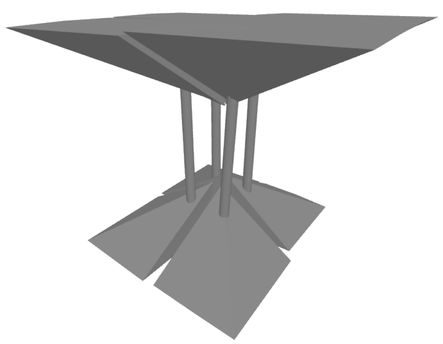
After Easter, this project had gotten prioritization at the university workshop. The product development could continue, but the deadline for the project was close. This chapter shows the true benefit of a virtual reality software when time is at the essence.

- Product development phase 2.0
- Product development phase 3.0
- Product development phase 4.0

Product development phase 2.0

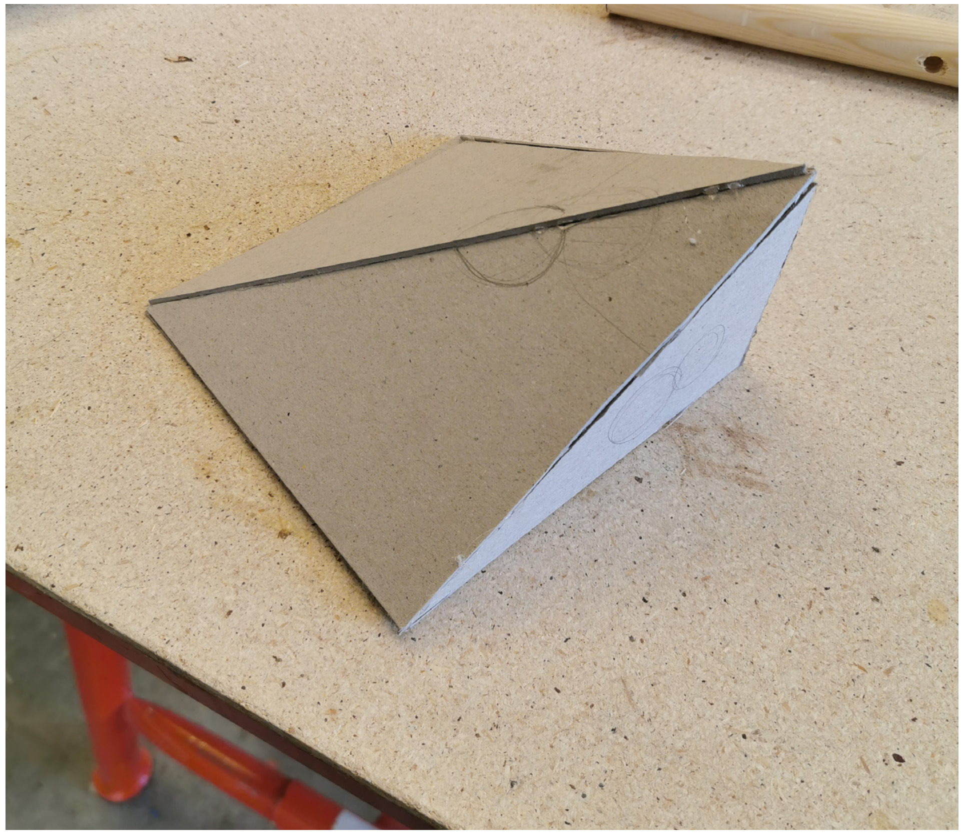
Viritual reality 2.0

The user survey lead to more ideas and thoughts. These ideas and thoughts were ready to be explored, as the product development phase continued. There were comments regarding the product's weight from the surveys, and I saw it relevant to investigate a coffee table with less mass. If the wood did not have a high moisture level, this would not be a problem. Since the moisture level makes the wood shrink, it is more prone to lose its structural integrity when its mass is reduced. In the previous virtual reality session, prototypes of a coffee table with lower mass had been generated and was therefore no need for a new sketching phase. These designs were based around the same principle as prototype two. Sharp angles, space between the pieces and a small lift from the ground.



Small scale prototype 2.0

After Seeing the complexity of the product in virtual reality, it was decided not to create a small-scale prototype. This would require allot of time, which were not at my disposal. Instead, a quick cardboard model of one assembly piece was made. This was done to make sure the assembly pieces would have sufficient mass to support the locking mechanism of pine plugs.



Full scale prototype 2.0

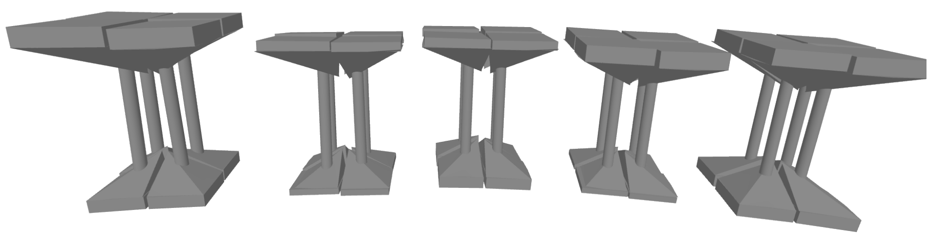
The product was not manufactured with the recision required. Some of the important 90-degree angles on the product was therefore not acquired. This resulted in problems during the production, and the pieces did not align perfectly. Since the product was lighter and each wooden piece had less mass, the wood moved more than the larger product. The surface on the coffee table were uneven after just a few days.

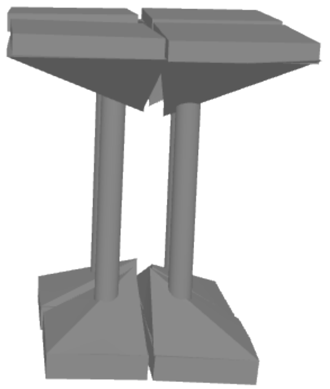
The sharp corners combined long pine shafts, gave the product a strange look. The pine shafts were too long, resulting in a table looking more like a pillar. The Virtual reality model was designed from material with a larger size than the available material. Once this was discovered, the software files was optimized. The next iteration would not have the same flaw.

Product development phase 3.0

Virtual reality 3.0

As the previous product had errors, some VR models with more mass was created. The higher mass would reduce the woods movement and increase the products structural integrity. How much this would affect the product was unclear. The new iterations were based on the correct material size, making it possible to create. As there were few adjustments to the product no small-scale prototypes were created.





Full scale prototype 3.0

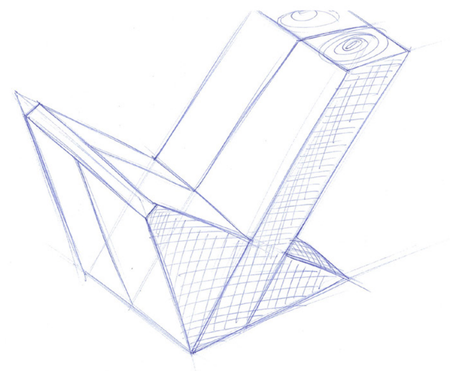
Three centimetre in thickness to the lower parts of the product and two centimetres of thickness to the upper part of the product was added. This is where Virtual reality as a tool works exceptionally well. The product felt more completed and expressed the essence of a table more than a pillar.

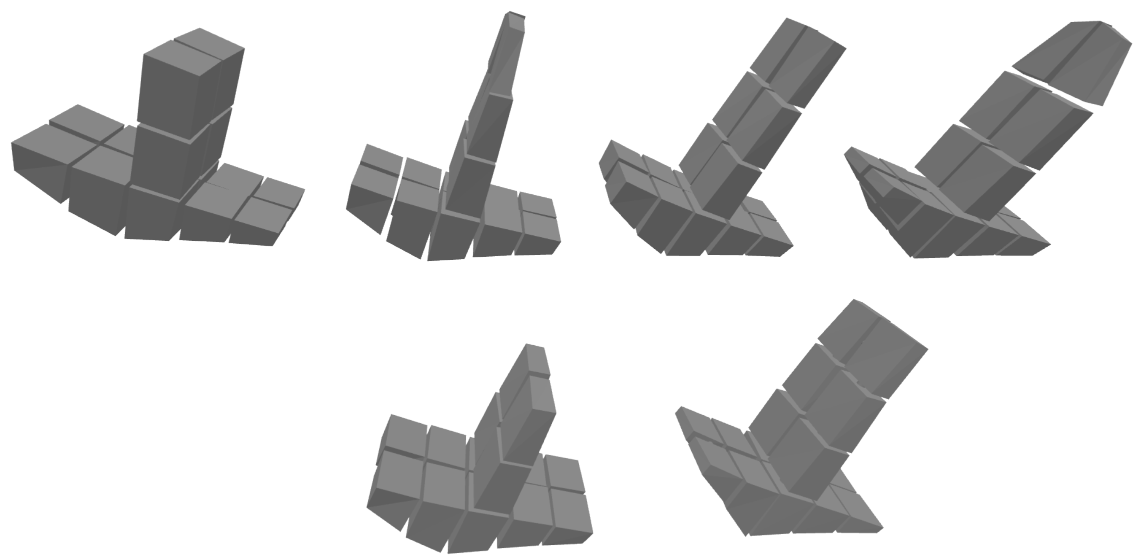
After a short amount of time the wood started to move. The previous large coffee tables which is built by massive pieces, support and represents the movement of the wood better than this construction. They have larges cracks which supports the design. On this product cracks seems to be fault instead of a design element.

Product development phase 4.0

Virtual reality 4.0

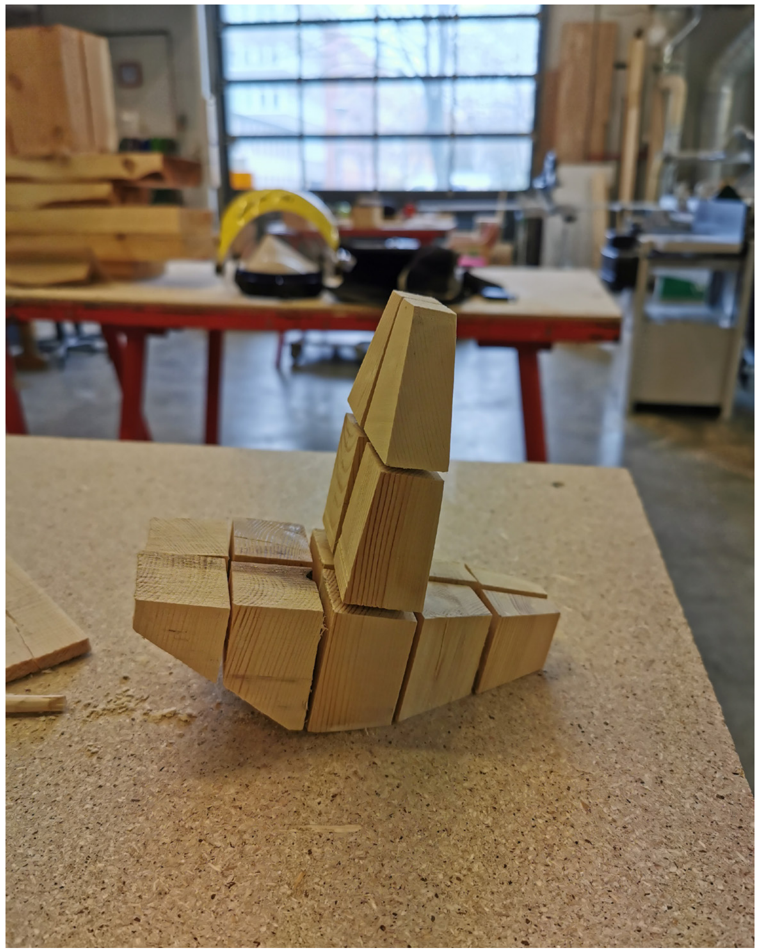
Earlier in the project, some sketches of a lounge chair had been developed. At the time when the sketches were made, too many limitations within the waste wood was yet to be resolved. Now that these problems were resolved, I could adapt this method to a lounge chair. This chair would be based on the same design Principle as the first coffee tables. Heavy and large pieces of wood with natural cracks. The previous sketches were explored and imported into VR. When creating furniture’s that is heavily affected by the human body, Virtual reality brings exceptional possibilities. A digital model of a human can be imported into the software which allows the user to measure the products, towards a human body. This process is precise and gives the user great understanding of the products before they are created.





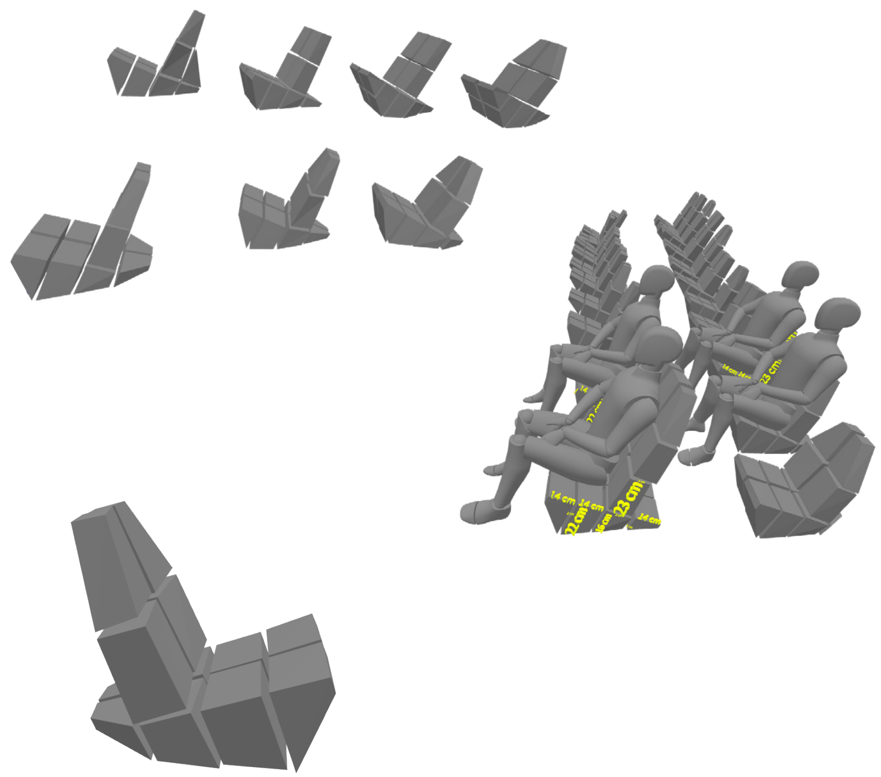
Small scale prototype 4.0

A quick model was created to visualize the idea. Feedback received from supervisors regarded issues with the mass distribution. The lounge chair would tilt forward, as there was nothing to support the weight of a person. The feedback was taken into consideration and a second virtual reality phase was initiated.



Virtual reality 4.1

The mass was changed, and some pieces were adapted to support the weight of a human body. The shape suddenly looked very appealing. I knew this shape had to be experimented with. Minor changes were done to different variations, until nothing could be removed without destroying the products playful expression. A full-scale prototype was created once there was nothing more to adjust.



Full scale prototype 4.0

I was very pleased with the result. The product represented a playful shape built by natural material with a technical element allowing the material to breathe. Small pieces of felt were added to the seating area to increase seating comfort. I wanted to experiment with colours and textures, but there was not enough time.

Pictures

Conclusion

The project included a wide range of different processes. Combining strategy design and product design in a master's thesis can quickly get out of hand, as they bought require a lot of time. The Giga map compressed large amounts of valuable information into a more manageable size and allowed me to see all the possible adaptations for the waste material. Both the internal and external research could be compared through the Giga map, making sure that the right adaptation was chosen.

The technical elements of the waste material made it complicated to work with. NTNU had the necessary knowledge required to develop the products, and remarks from designers and architects assisted in the development by giving architectural and artistic life to the products.

The Covid-19 pandemic was an unexpected source of influence on the master's thesis and resulted in valuable findings. The course of the process was changed by incorporating a user servey. This survey showed that several people would prefer to buy furniture with a lower carbon footprint. This information strengthened the reason to create furniture from waste material. The waste materials could be imported into virtual reality, accelerating the idea generation process, thought process, and prototyping of the products. This ensured a more productive development and led to the exploration of many interesting new ideas.

Reflection

At first, I was concerned with how the limitations of the waste material would influence the products. What really baffled me was the potential of the large diameter waste wood. As the materials were delivered to the university for development, it was hard to visualize the type of products the waste material could turn into.

Virtual reality has been a fantastic tool when it comes to exploring ideas. Before using virtual reality, I explored ideas by making quick sketches and then small-scale prototypes. These small-scale prototypes led to new ideas or changes, which ended up in a new small-scale prototype and so on. This is a time-consuming method, and ideas might be lost in the process.
In an ordinary design process, the material is not limited by access or quality. However, these designs are limited by the waste materials. Waste materials comes in specific shapes and sizes and can have defects. These defects can make the production of a product difficult. Being able to visualize the waste materials in different shapes, makes it easier to generate new ideas. Without Virtual reality, these solutions can be much harder to come across.

Final Comments and future research

This project has been very interesting to me. I am passionate about natural materials like wood, and fascinated by how technology can be used to optimize design processes. It was exciting to observe how Virtual Reality could strengthen the development of a product, especially when the products come from highly sustainable materials. I believe that technologies like VR have the potential to enhance many areas within waste wood design, and I would like to continue expanding my knowledge of these promising technologies.

The results of this master's thesis are products developed from waste materials. I believe that knowledge of how design can enhance multiple industries by optimizing processes will be a useful tool in the future. To help enhance the waste industry, I would therefore like to continue to develop my knowledge and promote the usage of waste materials

The products were initially intended to be developed in cooperation with Trollheimen Barnekjelker. However, due to technical issues of the material, this changed. As waste material has more complicated specifications than common materials, more knowledge is required to use this material for product development. This type of Information can be gathered through a master's thesis like the one in press. Furthermore, knowledge of waste material can contribute to laying the foundation for services that others might need. The municipality, for instance, struggles with lagre amounts of waste material from the building industry. Products built from waste clearly have a marked, and I would love to be a part of that evolution.

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Olav Engelstad

Design with Waste Wood

NTNU
Norwegian University of
Science and Technology