Exploring the repurposing of cross laminated timber spillage

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Abstract

Forestry is one of Sweden’s largest natural resources and a large and important foundation for the country’s economic stability. There is a significant opportunity to evaluate material efficiency and values in the supply chain of industrialised wood-based products. This thesis comprises on handling a spill-product of a modern wood-based building material: cross-laminated timber (CLT). With the aim to increase value of this spill product through practical design iteration, material exploration and theoretical analysis. The material exploration leads to a collection of furniture and interior products which are evaluated based on commercial interest and production feasibility.
ACKNOWLEDGMENTS

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Linjon for sponsoring with line oil impregnation.
Biography

I have received a bachelor’s degree from Carl Malmsten Furniture Studies (CMFS), a school renowned for its program focusing on quality and sustainability of wood products.

My experience at CMFS made me experienced on practical design iteration and to understand the importance of it. I gained tacit knowledge about wood carpentry and learned much about Sweden’s furniture production. To work practically drives me forward in creative thinking and to explore my ideas.

Working experience after school as an industrial designer showed me a world of design not as explorative. The process of iteration and testing is crucial for design but is absent in places where it would make to biggest difference.

Joined the LIU sustainability programme in search of understanding of sustainability and how a designer’s role can contribute, but also on the sustainability of design and on the process of creation. This programme has also given me tools for designing and facilitating human based studies.
# Table of content

List of figures ...................................................................................................................... 8  
List of tables ........................................................................................................................ 8

## 1 INTRODUCTION ........................................................................................................ 10
Problem definition ............................................................................................................... 11  
Purpose ................................................................................................................................. 11  
Aim ....................................................................................................................................... 11  
Delimitations ......................................................................................................................... 11  
Deliverables ........................................................................................................................... 11  
Research question ............................................................................................................... 11

## 2 REPURPOSING ......................................................................................................... 13
The Circular economy and sustainability on repurposing ................................................. 13  
Industrial symbiosis ........................................................................................................... 15  
Supply chain .......................................................................................................................... 15

## 3 CONIFEROUS WOOD & CROSS LAMINATIONS ........................................... 17
Conifers .................................................................................................................................. 17  
Timber ................................................................................................................................... 17  
Cross lamination ................................................................................................................... 18  
Timber and CLV in the building industry ........................................................................... 18  
Timber & CLV in the furniture industry ............................................................................. 19

## 4 FURNITURE DESIGN & DEVELOPMENT ....................................................... 20
Furniture development process ......................................................................................... 20  
Design cycle .......................................................................................................................... 21

## 5 METHODOLOGY & DESIGN PROCESS ......................................................... 22
Design strategy ...................................................................................................................... 22  
Preparation for material exploration .................................................................................. 23  
Material exploration ............................................................................................................ 23  
Validation ............................................................................................................................... 23

## 6 DESIGN STRATEGY .............................................................................................. 24
Understanding of CLT .......................................................................................................... 24  
Prognosis of volume ............................................................................................................. 25  
6.4 Manufacturing costs ....................................................................................................... 27  
Design direction .................................................................................................................... 28  
CLT Primary market ............................................................................................................. 28  
Potential secondary market ................................................................................................. 28  
Furniture ............................................................................................................................... 28  
Furniture Market ................................................................................................................... 28  
Quality .................................................................................................................................. 29  
Appeal .................................................................................................................................... 30
7 PREPARATION FOR MATERIAL EXPLORATION ........................................32
   Implementation .................................................................................. 32
   Brief ..................................................................................................... 32
   Initial Concept generation ................................................................. 33
   Bar cart ............................................................................................... 33
   Bench ................................................................................................. 35
   Bowl .................................................................................................... 36

8 MATERIAL EXPLORATION ................................................................. 37
   First impressions .................................................................................. 37
   Working with CLT .............................................................................. 38
   In the machine park .......................................................................... 38
   Material characteristics ..................................................................... 39
   Concept development continued. ..................................................... 39
   Bar Cart ............................................................................................... 40
   Bowl .................................................................................................... 41
   Bench .................................................................................................. 42
   New concepts based on material exploration .................................... 44
   Dining table ....................................................................................... 44
   Dining Chair ..................................................................................... 46

9 VALIDATION ..................................................................................... 48
   Commercial value .............................................................................. 48
   Design ................................................................................................ 48
   Quality ............................................................................................... 49
   Price .................................................................................................. 49
   Feedback ............................................................................................. 49
   Results of commercial validation ..................................................... 51
   Production costs ................................................................................. 52

10 RESULTS ......................................................................................... 53
   CLT Material costs ............................................................................ 53
   Adjacent brand comparison ............................................................... 53
   Bar Cart ............................................................................................... 55
   Dining chair ...................................................................................... 56
   Dining table ....................................................................................... 57
   Bowl .................................................................................................... 58

11 DISCUSSION .................................................................................... 59

13 CONCLUSIONS ................................................................................. 60
List of figures

Figure 1 Cross-laminated timber (CLT) 10
Figure 2 Chair Penne by Lammhults 13
Figure 3 Accumulated added value and environmental burden along the supply chain (Clift and Wright 2000) 15
Figure 4 The different forces in timber 18
Figure 5 Statistics on material use for residential building industry in Sweden (TMF.se) 25
Figure 6 CLT Building Kajstaden in Västerås 26
Figure 7 Perceptual map price x differentiation 29
Figure 8 First sketches of bar cart 33
Figure 9 Bar cart first physical prototype 34
Figure 10 First sketches and models of bench concept. 35
Figure 11 Sketches exploring Bowl shape 36
Figure 12 first impressions upon arrival 37
Figure 13 CLT as a template for 45 degree planing 38
Figure 14 Split pieces of CLT Door cut-outs 38
Figure 15 Characteristics of CLT 39
Figure 16 Bar cart mock up 40
Figure 17 Final sketches of bowl 41
Figure 18 Bowl production prototypes 41
Figure 19 Park bench sketches 42
Figure 20 Model of CLT Bench 43
Figure 21 Table top pattern 44
Figure 22 CLT pattern process 44
Figure 23 table leg sketches 45
Figure 24 Table leg prototype 45
Figure 25 Chair sketches 46
Figure 26 CLT chair 47
Figure 27 Point of discomfort in CLT chair 49
Figure 28 Table legs development 50
Figure 29 Perceptual map with CLT products 51

List of tables

Table 1 Costs of production 52
Table 2 Commercial validation compared to production costs 54
Sweden has an abundant tree production and is actively looking for new ways to make products that can replace current non-wood-based solutions. There is also initiative within the forestry industry to increase the value of current wood production output (IPOS 2018). Cross-laminated timber (Figure 1) is a modern technique developed to compete with traditional materials to build at large scale, such as the combination of concrete, brick, composite and foam-based assemblies.

MARTINSONS TRÄ is a dominating manufacturer of CLT. They are situated in northern Sweden, close to the resources localising the manufacturing process by pre-fabricating floors and walls in-house. Which are then to be shipped to a building location for assembly. During this process the cut-outs of spill are not allocated to any specific repurposing method. The future for wood-based buildings is bright with CLT being a major contributor. Sweden plans to increase the production of CLT significantly in the coming future (Borgström & Fröbel 2017). The development of safe and efficient wood-based buildings is constantly improving, supporting the Swedish wood industry & the choice for sustainable, locally/regionally produced with smaller and ecological footprint.

As scaling increases the amount of spillage will become significant. For future growth of CLT there needs to be responsible thinking towards the initiative of repurposing. Key responsibilities for repurposing are to utilize the material in a way that increases its value in comparison to current form of use. This
thesis compromises the utilisation and value of the material before complete disposal.

Problem definition

During the manufacturing process of specific buildings, the walls and floors are cut to their shape in-house and are transported to a building sight for immediate assembly. This means that the in-house production facility is left with large amounts of by-products resulting partly from door and window cut-outs as well as other smaller trimmings. The door sizes are generally the same size due to an industrial standard, but other sections are of various sizes mainly due to the fact that windows are an architectural trait which has many sizes. The current application of this spill material is chipped and burned for district heating.

Aim

The aim is to come up with solutions that can be manufactured as commercial products, to have a variety of solutions that are dimensionally different and therefore adaptable to the varying sized cut-out.

Delimitations

The simulation of production can only be used with the resources available at the A-house, campus Valla, Linköpings University. The funds for development cannot exceed 25 000 sek supplied by LiU as part of a research project for Swedish wood development. The amount of material available is limited to 1.8 m3 which will arrive later in the project.

Deliverables

Apart from the knowledge to answer the research questions, a collection of production-ready products manufactured out of CLT.

Research question

1. What are some ways CLT cut-outs can be repurposed as new products through design and be manufactured in Western Europe?
2. How can the commercial value of CLT be increased through material exploration?
2 Repurposing

Dictionary definition of repurpose:

“To alter to make more suited for a different purpose.”

Repurposing as defined above means to obtain a different second life cycle without major disassembly or reprocessing. Unlike recycling, which does major alteration through processing such as chipping, shredding, grinding, melting etc (UNEP 2011). The CLT spillage is currently recycled through chipping. To repurpose is an initiative of upcycling, where the transformation of a by-product is turned in to something of higher value.

The Circular economy and sustainability on repurposing

Initiatives for repurposing are commonly due to dematerialisation. This is motivated by the indication that energy and material demand is growing while the awareness of virgin material resources is becoming scarcer (Georgescu-Roegen, 1977). Leading to the implication of our eco system to not surpass the capability of supporting the human demand for economic growth, requiring a shift in contemporary production, consumption and behaviour towards the environment (Daly & Townsend, 1993). For companies within the market of consumer products the initiatives of R&D lean towards material and production efficiency. Innovation in production techniques is enhancing the possibilities to manipulate material and creates new alternatives of applications. For example, the chair from Lammhults: Penne (Figure 2). With legs made out of laminated wooden tubes: a much cheaper alternative to solid wood legs, creating possibility for the producer to use high quality wood within a
product category price range not previously possible.
The topic of material efficiency is an important aspect for financial gain. Today initiatives in academia and policymakers are expanding the attention towards societal implications. Such as analysing flows and lifecycles of different product categories, approaching material efficiency on a system level. Both of these situations are example initiatives of material efficiency. Martin Geissdoerfer et.al (2017) has through extensive literature review achieved to distinguish the differences and relationships between the two concepts of sustainability and circular economy. Passing on in academia to narrow down the exact intention of research in order to contribute to the right community.

Sustainability in its modern conception originated from forestry and is based on the principle that the harvest shall not exceed the volume of the next yield. This perception has long ago lost its meaning due to the fact of growth. Overproduction is often preferred due to the existing yield can be stored and controlled for economic stability compared to underproduction which risks short term scarcity. The modern definition is broader but the general conception can be defined as an initiative in human activity preformed in a way to conserve the earth’s ecosystems, it is a balanced integration of financial, social and environmental factors to benefit current and future generations of all life (M.Geissdoerfer et.al 2017). This resolves the reason for sustainability to be such a frequently used term because it covers the entire initiative of environmental rejuvenation.

Circular economy is a more recent concept based on economic principle. It originated in the discussion on how our natural resources influence the economy by being the source for production and consumption while also creating outputs such as waste. Leading to investigations in the linearity of the economic system based on the principle that earth is a closed system with limited capacity and that the economy and environment should coexist. (M.Geissdoerfer et.al 2017)

It is a strategy for industries to invest and collaborate towards a closed loop. Prioritise allocation for regional waste prevention, resource efficiency, dematerialisation and regional job creation. It should not be seen as dystopian, characteristics of circular economy can be in initiatives to slow down or gradually close the gap in resource loops through long-lasting design, repurposing, remanufacturing, etc. (M.Geissdoerfer et.al 2017)

To summarise both concepts are defined as intentions to secure future stability, with global models that require system change and design innovation at its very core. They both benefit from interdisciplinary research and the cooperation of different stakeholders. The difference is that sustainability is dependent on all stakeholders; it is a shared adaption of lifestyle, industry and legislation. While circular economy can be narrowed down to certain stakeholders to close the loop of a specific value chain for example forestry industry and supply chain of CLT.

The act of repurposing plays a key function in that system to be a solution for both material efficiency and waste prevention. To close the loop by reducing waste and creating long lasting design is an approach for a better future based on the principles of circular economy.
Industrial symbiosis

Based on this understanding material repurposing within the supply chain is a part of circular economy and requires other incentives such as mutual agreement and collaboration between regional industries for mutual benefit known as industrial symbiosis. (Lehtoranta et al. 2011)

Supporting macroeconomic flows and stability, material and energy dependent industries need to consider circular economy an important solution for continued prosperity without the growth of virgin resource extraction. (Jackson 2009)

Supply chain

The supply chain is the material flow from extraction of virgin resources to final commercial product. In all cases of production there will be some form of waste that cannot be avoided due to material dissipation (UNEP 2011). Choosing to take initiative in finding application for wasted material is a decision currently not as easy to make for individual organisations as for example the initiative to become more effective in production processes, which can financially outweigh the loss of material.

According to Clift and Wright (2000) accumulated impact and added value over time shows that in every stage of refinement in a supply chain. As the value per unit produced is increased the environmental impact decreases shown in figure 3. In general half of environmental impact in the supply chain is from initial virgin material extraction. Much of the environmental impact during refinement is due to requirements of energy for processes. Material waste is also a factor that is the largest proportion of stage 1 and close to zero at stage 4. The unequal relations between the two are important to consider for repurposing. It provides a guideline to understand what potential there is behind each stage of the supply chain. Also, indications to what efforts are needed to reach the desired market. From the perspective of material exploration this graph is motivating that there is a lot of potential for such initiatives. Repurposing material would be of highest importance in the earliest stages of production due to the large amount of spillage, but the question is what can be repurposed and to what extent. Difficulties lie in finding a market to match the level of refinement and to explore the possibilities with a proper method of material exploration. For example, if you would want to repurpose material from stage 2 then the expected market would most likely be in the expected level 3 or 4 of a supply chain which will be require an inevitable process of refinement to reach that market. The rule of thumb is that in the latter stages of refinement, material spillage will be easier to
repurpose due to its purity. Cases are certainly always different due to vast complexity in material refinement.

The metal industry for example has a very large variety of application for the refined product. The initial waste of stage 1 would be rocks, gravel and dust from mining which is of very limited use unless the requirement of heavy processing. There is also the chance that there is no material waste and waste is purely heat energy for example. For this repurposing can still be applied through a system level collaboration between several industries to together find use of energy and material that would seem as waste to one business but an asset to another as industrial symbiosis explains in 2.2.

Based on the understanding of a circular economy the ideal is to have minimal virgin resource extraction, meaning that the first stages of refinement according to Clift and Wright may not be as important to find solutions to the waste generation. Improving the latter stages to support the avoidance of virgin material extraction. It may therefore be more relevant and easier to put efforts in to repurposing in the latter generation of the supply chain. In the case for CLT, the primary product is produced as a stage 2 in figure 3. The cut-out material is a result during transition of stage 2 to 3 when building walls are being formed in-house. The resulting product is transported to onsite assembly while the spillage is left behind. The spilled material now needs to undergo another round of stage 3 and 4 before being a finished product.

Repurposing being implemented in design is an action to create an eco-effective system known as cradle-to-cradle. By dealing directly with maintaining resources leading to increased productivity instead of trying to eliminate waste (M. Braungart 2007). For effective production in late stage refinement the by-product may be insignificant for repurposing such as chips and dust and are then only appropriate for recycling or regrettably landfill.
Coniferous wood is the dominant breed of trees in Sweden. It has a long history as a material used for buildings and furniture and is the main material in CLT. Cross lamination is a traditional technique, which CLT is based on. Knowledge about these two subjects is needed to understand the decisions made during product development.

Conifers

Conifers are a type of tree most dominant in the northern hemisphere. Sweden’s most abundant tree production consists of two coniferous species: pine and spruce. It is a perennial wooden plant with secondary growth and adapts well to the cold and snowy climate of northern Sweden. The tree is built up of cells that transport moisture from the root system up the stem. This feature works the same for when applying moisture to dry wood; the end grain reveals the pores meaning end grain absorbs more moisture than side grain.

During the winter season trees grow slowly due to scarcity of nourishment. This produces a dark and hard age ring in the tree stem; the summer growth produces a thicker and lighter wood that is much softer.

Conifers produce long and brittle cells leading to the dry wood to easily produce splinters when torn.

When bark is removed, and wood is revealed to the atmosphere conifers produce a resin to protect the wood from outside exposure (Campbell et.al 2008). This resin is difficult to remove and is a problem for coniferous wood to be used for high finish products.

The process of farming trees is long and patient, requiring efforts of thinning out the forest several times keeping the best trees to grow the most. Trees ready for lumber production are around 80 – 100 years old when felled and transported to a mill.

Timber

Timber is essentially the tree stem, which has been barked, cut in to planks and rested in a place to dry. Depending on the level of moisture remaining in the timber cells it will swell or shrink depending on the seasonal surrounding atmosphere. The timber will swell in three different directions as shown in figure 4. Longitudinal and tangential is the movement of length and width while radial is the warping of broadside planks.
For outdoor application the moisture content is generally around 12-15% while indoor applications are 8-10%. The two types of coniferous timber produced in Sweden are from two types of pine resulting in spruce and fir. Spruce has branches along the entire trunk resulting in timber with a lot more twig holes compared to fir, which only has a crown and usually a clean stem. Together both have long fibres leading to a material that is light, very soft and has the tendency to produce splinters.

**Cross lamination**

Cross lamination is an old method of creating structurally stable sheets of wood. The most popular occurrence of this is in the form of cross-laminated veneer (CLV e.g. Plywood). Where sheets of veneer are glued in opposite fibre direction, creating a strong sheet with complete dimensional stability. The sheets are glued in even layers creating a balanced force. Impacts affecting this balance will alter the structural integrity of the product and can lead to mainly radial movement. For example, applying paint to only one side of CLV would lead to the sheet warping.

**Timber and CLV in the building industry**

Spruce is the main wood material used for building buildings due to it being of a lower quality to fir and not directly exposed to the observer when building buildings.

The folk housing 1690 – 1900 was the peak for artisanal wood building in Sweden. Building houses with heartwood, early buildings are log cabins while more developed buildings using logs for a frame and wood panelling with insulation. At this time brick roofing was mainstreamed due to easier construction compared to traditional wood-based roofing.

In the shift of the century of 1900 the brick industry peaked mainly for masonry and roofing but also other applications as piping systems. Houses of this time still threw on artisanal knowledge in building houses of brick and stone requiring skills of craft.

During this time Alfred Nobel invented the rotisserie lathe and the mass production of CLV became a popular material for inner walls that could fit insulation.

Post WW2 mid 1900s there was a building scarcity in Sweden leading to the political initiative to a program of improvement. This initiative led to a massive expansion in housing districts in Sweden. At this time efficiency was very modern and the style functionalism. This style was also financially beneficial for building at large scales due to minimal requirement for quality handiwork since the building techniques were more forgiving using plaster, concrete and factory-made components.

The building industry can be seen as a representative of societal progression and we
can see that the current progression has moved away from artisanal craft due to its expense to more effective and cheaper mass production.

**Timber & CLV in the furniture industry**

During the Swedish folk era coniferous wood was the most popular material due to its availability. Most furniture was built out of fir due to it being easier to shape because of fewer twig holes, which leads to harness and difficulty to process with hand tools.

Fir has continued to be a material choice in Sweden all the way to the 50s where it was the prime time for the material. Heavily applied in Scandinavian design for interior panelling and furniture. At the time in Finland where there was a higher abundance of birch the CLV with birch veneer started being used for furniture. This became a much cheaper solution for creating bent wood details compared to steam bending.

After the popularity of plastics during the 60s fir the interest of fir was lost and its yellow characteristics from ageing was seen as unappealing. Today fir is classified as a cheaper variant of wood seldom exposed directly but offers function of stability in for example stuffed furniture and for cheap CLV also as support in larger pieces of furniture. Typical Scandinavian design does no longer represent the wood production of coniferous wood but instead heavily focused on deciduous wood sorts such as birch, ash and walnut, which are scarcely grown in Sweden.
In this chapter I present the basic knowledge that is commonly present in the industry and in my process for creating product with the intention for feasible and profitable production.

**Furniture development process**

For a large furniture production company there are a series of steps taken for the initiative to create and release a new product. These steps are induced for the designers to actively collaborate with production and company reviewers to ensure everyone is on the same page. This is a method embraced to design products for commercial purposes.

The steps of development are as follows:

1. Identify opportunity for new product
2. Generation of product ideas
3. New product information given to designers
4. Designer activities
5. Initial review
6. Iteration (steps 3 – 5)
7. Mock up
8. Intermediate review
9. Development Iteration (steps 7-8)
10. Final product review

(Bumgartner 2001)

The reason for iteration in the design process (step 6) is for the designer to translate the feedback from initial review to the task managers and achieve a desirable product. This can also be the self-iteration with the designer to reach a satisfied point completion for the next step. Development Iteration is due to the testing and analysing the need for technical adjustments for feasible full-scale production, affecting the design, which needs to be reviewed. A furniture designer should be aware of construction limitations and production availability to ease the strain on this process for development team and to reduce risk of change to initial design. They should also have awareness about how materials can be manipulated and how the costs of such manoeuvres will affect the commercial price. This knowledge should be reflected upon during the first step of concept generation.
Design cycle

Concept Sketching

Upon initial identification of products, the designers’ role is to interpret those in forms of sketches. These sketches are based on the designer’s expertise and industry knowledge. Depending on the company and the project, the information given to the designer can vary. If too much specification on a product is defined this can limit the level of creativity for a designer.

Refinement

After the first phase of sketches the results are presented to a product development committee for the decision on what ideas will be carried on to the stage of CAD where technical drawings and renders can be performed. In some cases, a render can also be part of the sketching phase to assist in product characteristics.

Mock-up creation and evaluation

The technical drawings are translated to physical samples featuring front, top and side views. The initial prototypes seldom feature functional capabilities. More advanced mock-ups to test function are produced in a customised fashion do not resemble the full-scale production.

Product planning

Evaluating the mock-ups from a sales perspective. Retailers accepted price is not defined at this point but in the furniture industry a price category is generally defined in the initial specification. Making product differentiation very important in every price category and a focus feature to evaluate in this step.
5 Methodology & design process

In this chapter I describe the layout of my method, what studies have been performed and my approach to how CLT cut-outs can be repurposed as new products through design manufacturing in Western Europe and how the commercial value of CLT can be increased through material exploration. The method is separated into three sections: A pre explorative process consisting of design strategy and material analysis, the empirical study of material exploration and lastly a validation of the collected results.

Design strategy

The design strategy is an analysis of the current market application and characteristics of CLT. This information is gained through interviews with relevant stakeholders. Calculations of costs and volume is preformed to understand potential scale of the applications designed. A Strategy defining the desired domain of application is preformed and perceived through literature & user studies.
Preparation for material exploration

Based on insights from the design strategy and my experience as a furniture designer this chapter presents the thoughts and actions made in time before the possibility to physically work with the desired CLT. Initial concepts are defined based on the design brief through sketches, CAD and model building. Some concepts reach an early model of mock-ups as defined in chapter 4.

Material exploration

This part of the chapter is an empirical study on testing limitations and applications of CLT. Based on my background as a furniture designer and carpenter many decisions are made based on tacit knowledge. I am exploring ways to embrace the quality and character of CLT, which differs from the quality of wood it is made out of. This process is very dependent of practical involvement and the experience of carpentry which itself is a wordless discipline. Based on iterative design through play (Zimmerman 2003) I produce and evaluate the development by spending a lot of time in the workshop sketching, prototyping with the intention to “play around” with the material.

Validation

The validation is conducted by validating the commercial and production values. The commercial value is determined by conducting user studies based on the perceptual framework defined in the design strategy. A calculation of production costs is preformed based on the costs defined in the design strategy.
6 Design strategy

In this chapter I analyse of the theoretical potential for the door cut outs from CLT production and create a strategy for appropriate application.

Understanding of CLT

CLT is made out of coniferous trees cultured in northern Sweden. The trees are around 80 – 100 years making them young and fast grown. The material is cross-laminated from sheets of edge-glued fir and spruce. Similar to the plywood but on a larger scale, making it much less prone to swelling and shrinking like regular timber. The cross-fibre structure makes the material Ideal support in large flat surfaces.

Its current function serves the purpose of self-insulation walls, floors and roofs for all types of buildings. The maximal size produced at Martinsson TRÄ is 3.5 x 6 meters. Currently architects are not used to designing buildings with CLT and therefore create buildings that produce a larger amount of spill cut-outs than necessary.

The thickness available from Martinsson varies between 60 – 400mm with 120 – 150mm being the most common for current building projects as it is sufficient for the insulating and carrying purposes needed. The centre layers of wood are of lower quality compared to the exterior wood, which is sometimes fir of a medium quality. It is a solid wood-based material with a cross-fibrous structure consisting of four total layers and the layers consist of two thicknesses. The thinner thickness is part of the exterior layers. Altering this structure may affect the structural stability of the material in a similar way as CLV.
Based on conversation with Peter Jacobsson R&D Martinsons trä more characteristics are revealed:

- Cross-laminated end & side grain makes it difficult for a fine-planed surface and risks long term wear of machinery.

- Creating uneven dentation in larger parts of a piece of CLT risks the possibility for warping due to uneven forces.

- The door cut outs weigh roughly 80kgs each making it difficult to transport within a workshop.

- The door cut-outs have a hole of 40x40mm in the centre for the supplier used for lifting the pieces.

Prognosis of volume

The prognosis of volume can determine the amount of material limiting mass production. This prognosis will estimate the future growth of spillage.

At Martinsons TRÅ the data on CLT is not very well recorded but according to product management the current total spill for one year’s production is roughly 2%. In 2018 the company produced 20 000 m³, creating 400m³ of spilled product. From this 400 m³ there is a very small number of cut-outs that are door cut outs or the same size. Currently all spill is chipped and sold for incineration.
In a recent housing project Kajstaden in Västerås shown in figure 6. CF Möller designed an apartment building completely built out of CLT. This building consists of 8 floors and based on the floor plans 15 door sized cut out per floor totalling in 120 cut-outs. One standard door cut-out is 900x2000x120 mm equalling 0.216m3.

According to Daniel Wilded at Martinssons trä the amount of modular wood and frame systems has increased from 10.9% as indicated in the figure 5 to 15% in 2018. There are 64 000 newly built apartments in 2018 (SCB). 15% of these are built out of wood (qualified guess by production chief at Martinssons), which equals: 9600. 1/4 – 1/3rd of those buildings being out of CLT with a qualified guess of 50% is for condos.

Based on Martinsons trä 1/4 of these projects are CLT equalling 2400 buildings. 50% being condos meaning 1200 buildings with an estimated average of 120 door cut outs per building = 144 000 cut outs of CLT in 2018.

From 2016 to 2018 the amount of wood buildings has increased by more than 200%. If the wood buildings grow by 50% for 2020 (which is expected) the amount of door spills out of CLT will be:

\[ 144 \, 000 \times 1.5 = 216 \, 000 \text{ door cut outs in 2020 equalling } 46 \, 656 \, m^3. \]
6.4 Manufacturing costs

The costs of manufacturing are based on the machinery in allocation to Linköpings University. The park has two sections, one specified for metal and one for wood, both equipped with sufficient machines to accomplish all basic shapes in their respective material. It has a 5 axel CNC machine for milling wood, requiring programming and installation to run properly.

The direct costs of manufacturing in the workshops are based on the salary provided by Linköpings university and is fairly standard for similar workshops in Sweden the material cost is based on the current disposal of the spill which is chipped for burning. One m3 of solid wood is equivalent to 2.5 m3 of wood chips. The current market value for 1 m3 of wood chips is 250 sek / m3.

Fixed Cost

<table>
<thead>
<tr>
<th>Cost</th>
<th>Cost per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood workshop employee cost</td>
<td>700 sek / hour</td>
</tr>
<tr>
<td>Metal workshop employee cost</td>
<td>800 sek / hour</td>
</tr>
<tr>
<td>CNC cost</td>
<td>700 sek / hour</td>
</tr>
<tr>
<td>Material price per m3</td>
<td>(0.216 x 2.5) 250 = 135 sek/cut-out</td>
</tr>
</tbody>
</table>

Variable costs

- Employee efficiency
- CNC programming
- Machine maintenance
- Production optimisation

To reduce the time of manufacturing the amount of handwork needs to be kept at a minimum. It is optimal to avoid complex cuts and joints that can’t be effectively manufactured in larger scale. This includes mainly sanding, sculpting, assembling and surface treatment. Working with CNC is a very useful to achieve complex shapes but will also need sanding for a good finish and time for programming. From my experience working for production-based organisations, the production costs impact the commercial price by a factor of 3. This should account for the indirect costs to run a business such as marketing, sales and administration and will be included in my final calculation of the commercial price.
Design direction

This section defines my strategy for what types of products to focus on designing.

CLT Primary market

CLT was developed for the building industry. The technology originated in Germany around the 1990 and has grown in popularity across Europe since then. CLTs advantages to traditional building are being lighter, fire resistant and modular. Creating advantages for building in certain areas where cement its main competitor cannot be applied, such as above tunnels (Bonnischsen 2018). As mentioned in the prognosis the majority of CLT buildings are residential apartments.

Potential secondary market

The source of spillage is dependent on the continued prosperity of CLTs primary market. Meaning that if a production is to be implemented it would completely rely on the collaboration of the primary producer. By choosing a market that can be complimentary to the primary market can increase the relationship with the primary producer. Specifically, products that suit the specific buildings made out of CLT, this can result in the option to make packaged deals with the primary market producer. Possibly even to place a production facility close to the origin of the spill product, creating a more circular system with the two facilities collaborating in industrial symbiosis.

Furniture

Based on the understanding of a platform application (Lugt 2008) it can be translated that CLTs primary use in the building industry would promote its reliability as a material. This becomes a form of advertisement, making the material recognised as reliable in adjacent markets.

It is important to choose a market that is not materially indecisive, furniture is a good place to start due to the acceptance of innovative material is high and there are few risks in testing the application. The furniture industry is material-cost insensitive because there is a high tolerance for trying out new materials (Johnson & Langdon 2002) and it is complimentary to CLTs primary market.

Many circumstances of repurposing are process intense, resulting in a range of products classified as concept pieces heavily focused on appeal in the form of art. These are usually too expensive in relation to similar products serving the same function. (W. Walhout et.al
2013) My ambition for CLT is to design products that can be produced effectively. They should be equally or more appealing than similar products of the same price.

Furniture Market

The perceptual map (figure 7) is based on an online survey of 30 participants. In the survey, participants got the task to grade furniture brands on the level of quality and design. I created this map to show result of the perceived values of current furniture producers that are wood-based and to some extent and active within the Scandinavian market. This value is based on the average decision. The map shows in X what scale the perceived price & quality is, 1 being the lowest and 10 being the highest. And on Y the type of design a brand may represent 1 being refined and 10 being high differentiation.

*Figure 7 Perceptual map price x differentiation*
In figure 6 I have also found a gap in price and quality, which I find suitable to aim for. This gap is marked with a dotted line and once my products are finished, I shall create a validation based on the framework of this study to see if I have reached this quality.

Choosing to create a versatile array of applications is a strategy to repurpose as much of the cut-outs as possible. For this to be achievable on a larger scale I must continually look at material and production flow optimisation as an important factor throughout the design process.

I must optimise the design dimensions to fit within the cut-outs. I will focus on continued model making in the design process to understand material properties, scale and production moments. With the understanding of workshop costs, I need to act both as the task manager and designer of a furniture company (Chapter 4). In the end I will validate the final production and perceived values of the finished products. The perceived values of quality and design differentiation will be placed on the same map and matched with the adjacent brands to evaluate the price differentiation.

Quality

In commercial product design, the first step when defining a new product is to specify the price market. Defining this early on will affect the choices of material and processes that are appropriate for a profit. Based on the accumulated added value and environmental burden along the supply chain from primary resource model (Clift and Wright) the same effect can be predicted for the refinement of CLT spillage to become new products. The more elements of machinery and effort will be more costly but should simultaneously affect the quality of the final product. But since CLT is in a late stage of refinement, the quality of this material is close to its peak. To explore the possibilities of CLT I choose to not limit myself to a direct budget of production but instead on the position shown in figure 6. This still means I am aware of the costs of production, which is play its part an instinct in the early stages of designing.

Appeal

Intentions to create a modern appeal and function of high relevance and quality is strategy for differentiation and leaps risk of limiting market share due to the expense in product development & manufacturing costs. To focus on designing a product for manufacturing efficiency by avoiding quality materials and quality functions is a cost-based strategy. It will also limit the product to another end of market share based on price and limitations in quality.
The knowledge creation from designing products based on a material will lead to conclusions where the appeal is a secondary decisive and the structural integrity is what is primary. But based on the understanding that research is design (Stappers & Jiaccardi. 2017) to play with the barriers between these two factors is what would be the major knowledge contribution in this project. Pine and fir have a reputation as a material that is very robust and has always been designed in that way. I seek to challenge that appeal both visually and technically by exploring the possibilities of CLT. The understanding of this can be backed up through empirical research evaluating a design (research through design: Stappers & Jiaccardi. 2017). Testing prototypes to get feedback on function and appeal.
Eight door cut-outs have been ordered from Martinsons trä. The transportation time is difficult to predict because the company does not usually handle these kinds of special requests. To save time I try to prepare concepts based on the theoretical knowledge about CLT and from my personal experience with wood and furniture design.

Implementation

The first step for the concept generation was a design brief based on inputs from the analysis. This brief is defined with the purpose to explore CLT's potential as a product outside its primary use and to narrow down the direction of design to furniture of appliance products. According to the supplier the eight door cut-outs are roughly 200 x 90 cm. with half of them consisting of pine exterior and the other half of a low-quality fir. The total thickness is 12cm.

Brief

Aim
Design and develop a collection of furniture / interior products consisting out of CLT. The products designed need to match the size of cut-outs effectively for serial production and to avoid spillage.

Market
The market aimed for this product is the same as CLT based housing; broadly Europe and more specifically Scandinavia.

Design & Quality
The desired design and quality are defined in the perceptual map of figure 6.

Price / costs
The product range can vary from premium furniture to lower quality. The costs of manufacturing need to be efficient and adaptable to mass production. The price of products will need to match those of adjacent competitive brands in figure 6.
Initial Concept generation

In the absolute first phase of generating concepts I went very broadly on the direction of ideas. I was focusing on modular products such as shelving systems, outdoor noise barriers and modular stair solutions. But these kinds of products are hard to build and present individually and are dependent on their surroundings. I instead began focusing on individual products and furniture. I began sketching concepts based on my understanding of cross lamination, the dimensions of the CLT and on the characteristics of pine. My focus was on using CLT as a large flat surface to be a major contributor to the structure of the products. I developed three concepts based on the brief. These are described below:

Bar cart.

![Figure 8 First sketches of bar cart](image)

This idea came from the increasing trend of drink trolleys that have become more popular over the past couple of years. After observing several variants at Stockholm furniture fair, I found them to be lacking in solitary style, which I personally believe such a product need. I came up with the idea of combining a cabinet and drink trolley in to one style. With the CLT being the three shelves shown in figure 7. The CLT thickness shall be cut in half creating a 60mm thick shelf. Thus, creating a solid foundation to support the walls and fillings. An element of curiosity and elegance is added by having the walls be transparent and revealing the inside, this also makes the product look less robust. The walls are suggested with solid wood, in this case pine to match the CLT. When opening the bar cart its shape turns in to a miniature bar transforming the product and creating a space to prepare and serve drinks. This function requires wheels and hinges which I will find standard fittings for.

I create a first mock-up of this product to understand the size and fittings. Specifically, I focused on how to fit the beams as walls. Since the height of the shelves make it too big for CNC and my desired width of the insertions are much thinner than any mill, I created...
a template that made it possible to create them on the table saw. Only requiring one cut per hole creating a 3.5mm gap which can be seen in figure 8. The regret of this is that those beams need to be of the highest quality pine to avoid knots. This will affect the final price.

This prototype also revealed that the shelves have a tendency to let the entire product to twist. This problem is less prone to happen when the true CLT shelves are in place but to avoid the problem I decided to attach a thick front beam shown in figure 8 that will also indicate where the cart can be opened.
This design was based the mission of how to take full advantage of a single door cut-out. I explored concepts of benches and shelves used for indoor and outdoor purposes. By splitting the material once there would be very little effort required to produce this product. By adding wheels to the benches/shelves depicted in the sketch of figure 8, it will be easy to move the heavy object in the room.

Many types of bench like models were explored but mainly for indoor use because CLT is not meant to withstand outdoor weather due to it not being a treated wood. For interior use I find that the products may be too clumsy and take up too much room.
Bowl

The intention of this design was to find an application for smaller size of spilled material and to perhaps create a collection on a single cut-out. The intention of design is for the product to be completed with minimal manufacturing effort. Here the bowls are in a square shape, which can be effectively cut out of the raw material. Then the concave shape is milled out with CNC, this would be time consuming but on a larger scale cheap due to not requiring manual labour. The bowls are meant to come in a set of different sizes. The purpose is to be a decorative object rather than a functional utility bowl. In figure 9 I explore primarily the concave shape.

*Figure 11 Sketches exploring Bowl shape*
8 Material exploration

At the arrival of CLT I started prototyping the first concepts using the material. In this progression I further understood the qualities of CLT and how its characteristics affected my designs. Many of these characteristics were understood based on my tacit understanding of wood. Below I will go through the fundamentals.

First impressions

Upon arrival my first impressions of the material are documented in figure 10. The material is very large and extremely heavy, storing this material is difficult in a smaller workshop. Not all cut-outs are the same as documented in figure 10 one sheet has a large piece missing. Finally, in the centre and on some of the sides there are large holes.

Figure 12 first impressions upon arrival
Working with CLT

I realised that the eight sheets of CLT is an abundant amount and I could use them for more than just products. The vast dimension makes it useful for several purposes in the workshop such as creating templates and modifying rests. The material is very good for making mock-ups of large solid shapes in the CNC. An example is moulds for carbon fibre, which today is created with lots of layered plywood at the university.

In the machine park

Using CLT in the machine park gave the insight to its adaptability for larger scale production. Firstly, the cut outs from Martinsons TRÄ are heavy and ungainly to maintain when moving between machines. Each piece had a measurement of 2200 x 950 x 120 mm, weighing roughly 80 kg. To ease the mobility of the product, using a chainsaw I split the sheets in half: 40% were cut down the long end and 60% on the short end. The short end cuts could be carried around and handled on all machines singlehandedly but required a lot of strength to do so. The long end pieces always required two people.
In the process of refining the material through sawing, planning and cutting I noticed that due to the sheer size of the material, I am pushing the machines to their limit. Starting with the bandsaw, to cut the thickness of this material effectively we needed to switch to the thickest band saw blade, which can only preform straight cuts. It is also difficult to be accurate sawing long pieces. To avoid this problem, I decided to do a steering cut only 40mm deep on the table saw through both sides of the material, creating a thinner amount of solid wood to cut through and providing a visible straight line to follow. This was no problem for the table saw and minimised strain for the band saw but made the procedure of cutting the material more complicated.

On the Table saw the height limit of the saw blade is 124mm. With CLT being 120mm there is a big risk for backlash or burning if cutting too fast or not applying enough pressure when cutting smaller pieces. The finished cuts look good if nothing goes wrong. Overall it is an intimidating experience to cut the full thickness for the material.

When using the jointer and planer their maximal width is 550 and 900mm. This means that both split dimensions of CLT can be planed but it is very close to the measurement limit. When jointing 90 degrees the sides of end and side grain need to be planed. Planing end grain wears the planning knives faster than normal and can be expensive in the long run.

Material characteristics

The age ring quality is what I determine as a higher quality building material compared to what is used for framing houses. This is based on a higher age ring density and thinner summerwood. The CLT is covered with knots and occasionally pockets of resin appear which has a tendency to seep out. Both of these factors are common indicators for low quality coniferous wood and is not usually used in the modern furniture industry. The knots can easily chip off when planing leaving large chunks of sharp holes in the material.

Since the wood has moisture content of 15% there is a chance of shrinking over time when if cut to thinner dimensions, this mainly affects the radial dimension but does not cause bending due to the cross lamination. Even when dry the wood is very soft and easily marked from a harder material. Planed end grain gets crushed leading to a rough feel rather than a smooth planed finish. So, all end grain needs to be finished with sanding.

Figure 15 Characteristics of CLT
Concept development continued.

In this section of the chapter I develop the design of the initial concepts from chapter 7 based on the improved understanding of CLT.

Bar Cart

I now build a mock-up of one half of the cart using the CLT shown in figure 14. The thickness of the shelves needed to be adjusted to 45mm for even proportion of the three layers after splitting the CLT if I would not do this there is a chance for the layers to bend.

The CLT in this product required several moments of preparation before assembly. They needed to be planed individually to create the perfect proportions between layers. Additionally, the top layer needed an additional split because the beams stop halfway as shown in figure 14. I tried to make these holes by hand at first, but it was too time consuming and the wood is too soft for being chiselled.

Total time of build was roughly 16 hours including building templates. I only used bandsaw, planer and table saw to create this product. The amount of CLT used from the original spillage is two squares of 450x450mm. The CLT is important for serving as a stable frame for the vertical walls to support on. With the structural stability and thickness of CLT it is possible to glue thin vertical dimensions without risking warping. I also chose to add brass wheels, hinges and a brass guard on the bottom two shelves. The finished product is a very nice result but the time and effort to build was very costly. Total time of cutting and assembling parts was 12 hours, while the metal bending and assembling took 4 hours.
I decided to stick with one size due to it being easier to adjust to one single sheet of CLT. I chose to work with a 250x250mm square after observing this in real life scale. The sketches in figure 17 show the type of shapes I want to try and mill in the CNC. In total there are 4 shapes that I will test.
In figure 18 you can see the 4 variants of bowls I milled out in the CNC. The bottom two designs had their concave shapes too close to the edge leading the large pieces flying off during milling. This could be avoided by milling from a larger piece, giving more support that can then be cut down to the right shape. But it would still be a fragile edge. The top two bowls however worked much better and remained whole. I will choose to continue with the circular design because it visually counters the square shape and feels more like a bowl. 

I chose to do minimal finishing on the inside of the bowls because it is labour intensive and difficult to reach due to the tight concave shape, which cracks the sanding paper. Instead I sanded the exterior to a very smooth finish to contrast the inside. 

In total one bowl took one hour to produce, consisting of 20 minutes of cutting and 40 minutes of CNC and sanding. The milling program has a lot of room to be optimised.

Bench

After some research on different types of wood impregnation, the alternative of line oil impregnating came up as a very eco-friendly method. I came in contact with a producer in Sweden who had the same interest of trying this out on CLT. The problems that could occur is for the glue to release, which did not happen leading to the test being a success. This led to the continuation of developing a bench for outdoor use.

In figure 19 I begin testing types of designs specifically for outdoor use. My intention is still to use one whole door cut-out for one bench. I also aim to minimise the production. Initial thoughts were to make the entire bench out of the same material, but this would mean
that it will not fit on one door cut-out if I want a back rest. I chose to design a bench with the seat and back rest out of CLT and with a metal leg structure. This will also protect the wood-based material from trapping moisture if it would be in contact with the ground.

This product would be built with minimal effort and the CLT requires only 3 moments of preparation before assembling. These include cutting, planning and milling a radius on the edge all of which can be performed in the workshop. Working with these dimensions equivalent to the full scale of the door cut out it will be very labour intensive and require two people to perform.

With legs of metal in this case intended to be water-cut out from a single piece of steel and welded together. The line oil impregnation is a very traditional and expensive process for outdoor protection but causes fewer burdens on the environment and lasts a lot longer compared to the standard chemical impregnation.

The CLT preparation is expected to take 2 hours and leg structure an additional 3 hours. The line oil treatment currently costs 30 000 /m3 and the amount for one park bench is 0.7 m3 = 21 000kr.
New concepts based on material exploration

During the building of the concepts previously presented I had time to discover new ideas that could be made with CLT. The origin and development of these ideas are explained below.

Dining table

The idea of creating a table was always interesting to me because it would seem fitting for the materials structure. The problem was that it was too heavy and upon splitting the material the opportunity to make a large table seemed to have disappeared. After cutting some pieces for the bar cart, I picked up the trimmings and saw that an interesting pattern could be made from making cuts of the CLT and flipping them on their side as shown in figure 22.

![Figure 22 CLT pattern process](image)

This pattern of exposing the end grain and side grain created interesting stripes that would be very process intense to create from scratch thus lifting the opportunity of refining the specific product of CLT further which was thought to be very difficult based on the argument presented in chapter 2.3.
Using half, a full-length door cut out resulted in a table top of the pattern shown in figure 20. The size of one half is 930x2000x40mm, which is suitable for a large dining table. The structure of this top varies from standing grain to laying grain, which is a weak point if exposed to too much down force. This means that the legs need to be very supportive for this table to be steady. There is no need for steadiness on the long side of the table but only the short side since that is where there is no crossing support. Also, with the cross lamination being cut in to thin dimensions there is a risk for radial and tangent movement.

To allow for movement the legs need to be joined to the table with enough margins for travel. This is performed with a threaded insert and bolts through the leg structure with a big enough hole for the movement not to interfere with the bolt. I decided to make the entire leg structure also out of the same pattern since it seemed playful to over exaggerate such an interesting pattern and would mean the product is made 100% out of repurposed CLT. Total building time for this product was about 6 hours including glue time. The legs and table are basically built in the same way so everything can be produced effectively.
Dining Chair

The origin of the chair came from a stool that was meant to test different types of surface treatment. This plan was phased out by the prioritisation of developing concepts instead of surface treatment. But the idea of creating a seat remained an underlying interest while developing all the other prototypes. Working with CLT for other concepts tests the limits of structural integrity and I came to the realisation that pins are twice as sturdy in CLT compared to regular solid wood if inserted deep enough to cross at least two layers. The chair I designed takes advantage of this feature. Based on the traditional folk style chair the “pinnstol” where the pins are fastened to the seat and a top frame for support. Due to the thickness and cross-laminated feature I do not need the same amount of support for my chair design shown in figure 25. I created two types of backrests. Finally, I decided to go with the closed shape because it will be more comfortable and the concentration of weight from leaning will be more evenly dispersed on all pins.
With the CLT being 120mm I chose to exaggerate the curve of the seat to make it lighter and for a unique shape not as common in other solid wood chairs. The backrest pins will be fastened deep in the seat and this stability will be increased due to the cross lamination. The seat in this chair currently required a lot of CNC shaping for both sides making it quite expensive. It is difficult to say if CNC could be avoided but the chances are not likely due to the complexity in pin angles and depths, as well as the angled and large concave seating shape which is too large to be milled on a table mill. I designed this chair to test the limits of CLTs structural and dimensional stability. With all the pins being free in the opposite end, the seat can warp freely without affecting the structure.

The total building time of this product came to about 5 hours. The CNC time was 2 hours and there is a lot of room for optimising the program. Preparing legs and backrest took 2 hours. The seat needed to be sanded afterwards together with the final assembly, which took another 1 hour.
9 Validation

This chapter goes through my method of validating the production cost and commercial value of the concepts I have produced. With the help of participants, in an interactive exhibition the evaluation is meant to bring forward opinions on the characteristics presented in the perceptual map of brands (Chapter 5.3) so that my products can be compared to those brands. I will also evaluate the production feasibility and costs of production to compare with the perceived commercial value.

Commercial value

To test the perceived value of my products I will perform live testing with a survey for participants to complete. I will base the framework of this study on the perceptual map on brands made in chapter 6.5.3, which are evaluated in two axes, the X-axis on the price and quality and the Y-axis on the level of design differentiation. These brands are of furniture and products within the same domain as my designs. The goal for this study is to place my products within this map to compare their qualities with the brands. There are three categories in this framework to validate for the commercial market: Price, Quality and Design. Together these will give me enough understanding of how the commercial market may perceive these results.

Design

Based on understanding what designers are interested in when creating a product, the top three topics are: sensorial properties, intangible characteristics and technical properties (Elvin Karana 2007). With the sensorial properties being of highest priority it is most fitting for the participants to be able to interact with my products on a physical level. This will give more accurate answers on the perceived values. For this case the questions regarding design shall be used to orientate the level of differentiation in each product.

With the help of kansei engineering I have created a set of kansei-words that assist in scaling the differentiation on an axis between two categories such as:

Familiar – Unique
Traditional – Contemporary

This data can then be translated to numerical results that can be placed on the y-axis of the framework.
Quality

The quality of these products will be measured on a scale of ten. I have chosen to focus on the quality of appeal, which can mainly be judged by observing the products and quality of finish, which requires physical interaction. To place these within the framework I will simply calculate the average sum of both factors, which will be a number between 1 and 10 that can be placed on the x-axis. But this will only show the quality not the quality/price.

Price

To determine the price of these products I will create a slider with two points of reference to existing similar products. These will go from the cheapest alternative I can find to one of the more expensive. The participant will place an indication where on the axis they perceive the product in the room in terms of design value.

I chose to use references that are recognised by most, but it is still difficult to find something everyone will recognise. It is also difficult to compare an image to a physical product. So, to back up this I also chose to give the participants a set of price alternatives similar to the scale of price comparisons.

I choose not to compare the results of this within the framework of the perceptual map since there is no scale for the price for specific products. But I can compare the perceived prices of my products to those within the brands that match the same level of quality and differentiation. The commercial value of a product should three times more than what it costs to produce.

Feedback

In addition, since I was present in the room, I got the opportunity for a lot of reflections of the design of my products. Some of these I annotated with sketches during the conversation leading to understand the problem and how to solve it. These are shown and presented below:

Chair

For people of larger shapes there is a risk for front edge of the seat to cut in to the body shown in figure 25. A solution for this is to create a larger radius on the front edge.

Figure 27 Point of discomfort in CLT chair
Table

The legs of the table obstruct a lot of room beneath the table. Currently you can only sit 8 people around it shown in figure 26. If the legs were pushed further out to the edge there could be room for one more seat alongside.

![Figure 28 Table legs development](image)

Bowl

The bowl was the least interesting product for many. In comparison the rest of the collection it did not fulfil the same standard of design. People found it difficult to place as it was too clumsy for a utility bowl and not refined enough to be a solitary designed object.

Bar cart

The bar cart was a hit and the most desired object to personally own. There were many comments on that the high quality of design did not match the low-quality material. CLT seems inappropriate for this type of furniture where high fit, feel and finish is expected.
Results of commercial validation

As shown in figure 29 the CLT concepts are almost in line with the initial boundary previously set. Most of which was reflected upon when talking with the participants. Like the bar cart which is perceived of the highest quality and differentiation. This makes sense because it is a new type of product and I put the most amount of time in building it. The products that follow are the chair and table, both of which are on the same level of perceived quality but the chair being perceived as a more differentiated product. This may
be because of the backrest being very different compared to what that which is associated to a pin chair. While the table shape which is modern but not different, what is different is the surface pattern which lifts the design above most brands. The bowl scored lowest on all features; this may be because it is difficult to place, since most people associated it as a utility bowl and then concluded that it was too clumsy for that purpose.

Production costs

Below is a table showing the final costs of manufacturing each piece of furniture. Each centre column is presenting the mount of hours it took to create the product. The total cost is the total amount of hours times the manufacturing costs (700 sek).

Table 1: Costs of production

<table>
<thead>
<tr>
<th>Product</th>
<th>Metal workshop</th>
<th>Wood workshop</th>
<th>Assembly</th>
<th>Surface treatment</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td></td>
<td>4200</td>
</tr>
<tr>
<td>Table</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td>4200</td>
</tr>
<tr>
<td>Bar cart</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td></td>
<td>11600</td>
</tr>
<tr>
<td>Bowl</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>700</td>
</tr>
<tr>
<td>Bench</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td>24500</td>
</tr>
</tbody>
</table>
10 Results

CLT Material costs

Chair
450 x 450 mm = 1/8 of a solid door cut costing = 17 sek

Table
½ straight cut & ½ side cut for a whole table = 135 sek

Bar cart
900 x 450 = ¼ of a door cut = 33 sek

Bowl
250 x 250 = 1/24 of a solid cut out = 5 sek

Adjacent brand comparison

Figure 30 Adjacent brand to product map
In figure 30 the four products are matched with each brand that is similarly perceived. The reason for matching the bowl with MIO is because it was the least favourable product and for that I wanted to be compared to a brand that is also less favourable. The adjacent brand for the table is StolAB, which is not visible in the figure. Based on this I studied the assortment of the same products within each brand and summarised the price range. The results comparing this price range, the production costs and perceived product prices can be seen in the table below:

<table>
<thead>
<tr>
<th>CLT product</th>
<th>Production + material cost (sek)</th>
<th>Perceived price (sek)</th>
<th>Competitive brand*</th>
<th>Price range (sek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dining Chair</td>
<td>3517</td>
<td>2500 - 3500</td>
<td>Cassina</td>
<td>6 500 – 20 000+</td>
</tr>
<tr>
<td>Dining Table</td>
<td>4335</td>
<td>10000 - 15000</td>
<td>StolAB</td>
<td>7 500 – 19 400</td>
</tr>
<tr>
<td>Bar cart</td>
<td>11633</td>
<td>5000 - 8000</td>
<td>Artek (Vitra)</td>
<td>30 000</td>
</tr>
<tr>
<td>Bowl</td>
<td>705</td>
<td>200 - 500</td>
<td>MIO</td>
<td>30 - 899</td>
</tr>
</tbody>
</table>

* Based on the placement of price quality in figure 30

Looking at this table you can see one product that stands out, which is the table. Firstly, the perceived price 2-3 times higher than the production + material cost, which is great results meaning I have created additional value. Secondly the perceived price is on point with the price range of the competitive brand meaning a healthy competition focused on design differentiation rather than price. Looking at the bar cart and the bowl I can see that in both cases the production costs surpass the perceived price. In the case of the bar cart the adjacent brand is Vitra which does not have a similar product, but Artek which is owned by Vitra does have a famous serving cart designed by Alvar Aalto, yet I do not think it is comparable by it is my only reference in matters of price. In the case for the bowl there is clear not enough that this product will be commercially successful. Finally, the chair is an interesting result. The current production cost for producing one chair is equivalent to the perceived value, yet the competitive market value is twice as high. This leads me to conclude that the chair is still an interesting product to continue to develop.
Bar Cart
Dining chair
Dining table
Bowl
Discussion

CLT spill as a material for furniture

Cross laminated timber has a large potential as a material for furniture application. But only to a certain extent of quality. Due to the large amounts of knots and the low-density wood it cannot be as exposed compared deciduous wood. It is also difficult for precision cutting and sculpted features. Yet it is a reliable and cheap source of solid wood specifically for large dimensions which is seldom available in furniture due to the cost of virgin solid wood resources. It is a very durable and robust material with characteristics that can provide a quality otherwise not attainable for furniture and other products within a certain price range.

Building with CLT

Due to its size and weight CLT is difficult to deal with in a workshop. It requires a lot of space and ideally a specially designed workshop where the machine park is planned based on the succession of refinement. The machines should also go through a quality protocol to ensure the wear from working with CLT does permanent damage to the machines and affects the quality of output of CLT based products. The softness of the wood leads to minimal wear but the resin is acidic and bad for metal. Also, the dimensions for cutting are on a limit to the tolerance in the current workshop used. Ideally a majority of these cuts can be performed at the main factory at Martinsons when the actual cut out of door holes are made. If the CLT was made from a non-coniferous wood its application in the furniture market would be much broader.

Production

By introducing CLT to the furniture industry it can potentially disrupt other suppliers of material which are used for similar purposes. Purposes such as template material or sheet material of larger thickness that does not require a high amount of quality can be replaced today. By further developing the concepts I have proposed or new furniture concepts there is a chance to create a market for furniture consisting of large volumes of wood at a cheap price, potentially disrupting similar markets of a higher premium.

The current prices of production are only examples of producing a single piece in LiUs machine park. Meaning there is a lot of room for optimisation in production and higher volume means there is potential for all the products to be a lot cheaper to produce.
Discussion of Method

From my development iteration, iterative play with CLT led to the risk of offsetting other responsibilities such as the quality of verification and literature studies. I prioritised my time in the workshop because it was the absolute most stimulation part of this process.

Material exploration

The iteration of building physical prototypes and making adjustments is time consuming and generates a lot of information that needs to be reported but I found that my documentation does not justify my efforts. The lack of documentation also affects the amount of knowledge that can be shared, since most of it is tacit, annotated video footage would have greatly improved this.

When it comes to the phases of my methodology, I have found that the pre material exploration process would not have been necessary. To directly begin with the material may have produced more results that are specifically tailored to the CLTs characteristics. Then again due to the serendipitous findings for the dining table, this may not have happened if I did not start building the bar cart. I think that the more important lesson to learn from this is that for material exploration you have to start somewhere.

Validation

The perceptual map created was based on a study of 30 participants. It is questionable to this being counted as a quantitative study due to those numbers and with more people the results may have been different. Also, by joining price & quality there was no way to evaluate them separately which may had been useful.

The validation study consisted majorly of university students. It would have been interesting to use a bigger variation of people, which would have given more “real world” results.
13 Conclusions

Answering research question one:

What are some ways CLT cut-outs can be repurposed as new products through design and be manufactured in Western Europe?

The production mock-ups show that CLT can be repurposed at least to the extent presented. Based on the results I conclude that the dining table is a product most suitable for market release based on the perceived value being twice as high as the production and material costs, accounting for enough profits for an organisation to administer and market the product. I also conclude that the chair has enough potential for production optimisation to be a way to repurpose CLT cut outs.

Answering research question two

How can the commercial value of CLT be increased through material exploration?

The table is a very suitable example in answering this. Because the pattern created through re-assembling CLT as shown in figure 22, has proven create a feature that to greatly increase the perceived value as shown in table 2. This pattern would be more process intense and costly to create from scratch meaning using CLT in this way is a method of adding value. The production of this feature was a result from material exploration and is therefore a suitable answer to this research question.
CLTs future potential

Comparing to the initial use of CLT spill product (chipping & incineration) I find the applications developed to be an extension of the martial lifecycle. Eventually they will also lead to the same end of life purpose but has before that time contributed to more. As I currently see it there is huge potential for applying CLT door cut outs to a different purpose than incineration. As shown by answering the second research question, there is a lot more value in the material to be taken advantage of and the potential to develop even more solutions I think is colossal.

Future for material exploration

I have found that the process for material exploration has been an important part of the design process to achieve innovative results. Also, to research and understand the supply chain of a material should be included in the exploration process. The knowledge created from this will be both tacit and explicit. By recording an explorative process with media would greatly assist in transferring this knowledge to others. Finally, I believe that material exploration is very important to develop solutions for a more circular economy.
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