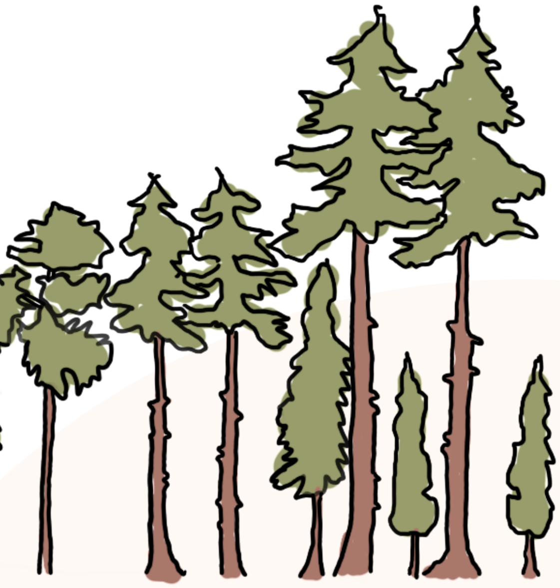
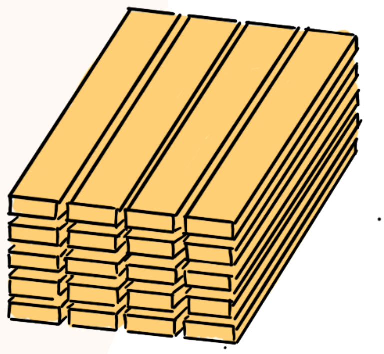
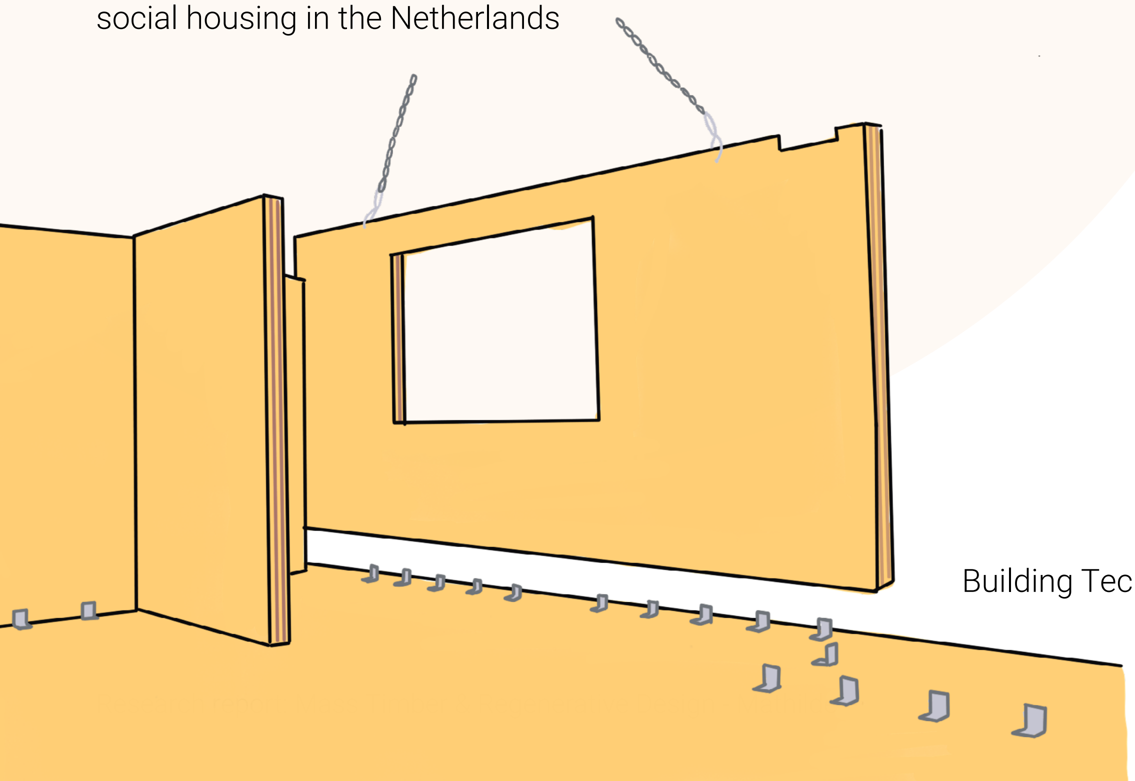


MASS TIMBER & REGENERATIVE DESIGN



a regenerative timber system from forestry to social housing in the Netherlands



Research report
22-05-2023

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Research: Peter Teeuw
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Building Technology: Gilbert Koskamp

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INTRODUCTION

PROBLEM STATEMENT

Today, the building construction sector in the European Union consumes 40% of primary materials, and the same percentage of primary energy and annually generated waste (Muthu, 2014). Making it an exhaustive industry responsible for resource depletion. The size of the building industry in the Netherlands can not be diminished as the Netherlands is in need of 600.000 new affordable houses before 2030. This according to plans of the current government (Ministerie van Binnenlandse Zaken en Koninkrijkrelaties, 2022). This need for extra housing, which is likely to increase as the population does, further increases the demand for building materials and energy. Drastic change is needed to produce the necessary housing in a way that is consistent with planetary limits.

a solution

Timber is posed as the new best thing to replace concrete. Concrete is the leading building material today and one of its main components, cement, is responsible for 8% of the CO_2 emissions worldwide (Ellis et al., 2020). Opposed to concrete, timber is a renewable resource that stores CO_2. Through prefabrication, industrialization and easy assembly, construction speed is increased and housing solutions can be produced fast. Cross laminated timber, (or CLT: usually softwood cross-glued and pressed together under high pressure joined into large boards) has similar structural properties as reinforced concrete but is five times lighter. Furthermore, timber has a positive effect on the indoor living environment (Studio Marco Vermeulen, 2020).

It is because of this that timber sparked my interest as (one of) the solutions for a future proof building industry of which I will become a part. That, and the fact that timber allows you to build something tangible with your own two hands and a few tools. A very rewarding process. The 100%TREE workshop in Amsterdam, pictured in figure 1 below, in the summer of 2022 is where a team of 40 students, including myself, from all over Europe, built a shelter from 8 locally sourced trees.

Fig. 1 100% TREE photo credit Jonathan Andrew.

the problem with this solution

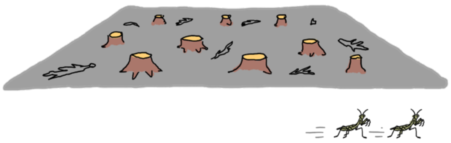


Fig. 2 Clear cutting and biodiversity loss.

I am not alone in my fascination with timber; many news articles claim that building with timber is the future. But the availability of suitable timber is not self-evident. Neither is its sustainable image. Pictured in figure 2, if the production forest where the timber is sourced is not carefully managed, monoculture plantations and clear cutting can lead to biodiversity loss and a soil degradation (Liu et al., 2018). In *Building from Tradition* Elizabeth Golden argues that in the past "working directly with accessible resources led to an understanding of their limits and capabilities" (Golden, 2017). While today's construction methods, that rely on global supply chain logistics and economies, have replaced the builder's direct connection to the site and building process (Golden, 2017). This missing connection could be explained by the world view of western science, which, according to Robin Wall Kimmerer "sets human beings outside of "nature" and judges their interactions with other species as largely negative" (Kimmerer, 2014).

This disconnect between our natural resources and our building practices is made extra visible in times of conflict. Due to the war in the Ukraine, the timber import is put to a full stop, resulting in shortage in the rest of Europe (Redactie Het Houtblad, 2022). Here it is made clear that we depend more on the global market than on our own capacity to produce. We have outsourced our connection with the the living environment. In his book The Patterning Instinct, Jeremy Lent argues that metaphors, particularly those relating to human interaction with the living environment, have a significant role in determining the pathways human societies take. The philosophy of Rene Descartes, which supported a "conquest of nature" metaphor, and Francis Bacon's notion of "nature as a machine" have since come to dominate the global economy. Lent makes a strong case that developing a metaphor of people as being embedded inside a web of systems is necessary to sustain our future on this planet (Lent & Capra, 2017). Which leads to the idea of regenerative design, developed by Sarah Ichioka and Michael Pawlyn. They argue in their book *Flourish* that we must go from mitigating negatives to maximizing positives by acknowledging that humans are part of nature and move beyond a sustainability paradigm towards a regenerative paradigm (Pawlyn & Ichioka, 2022).

the real problem

The real problem is that human beings see themselves as outside of the natural systems, leading to destruction and degeneration, and that careful reconsideration of the entire timber system is needed in order to make building with timber not just another way to exploit natural resources.

OBJECTIVE AND RELEVANCE

It is clear that building with timber is part of our future, the added value of this thesis is to research how building with timber can help us shift from a sustainable paradigm towards a regenerative paradigm through providing housing for all. This thesis departs from the belief that humans are a part of nature and leads to the objective of this graduation project which is to strengthen our interdependent relationship with all living species.

design question

This objective leads to the following design question: **How to introduce a regenerative timber system, from forestry to social housing in the Netherlands?** This multidisciplinary design challenge will be approached from two different disciplines to obtain a more complete understanding of the workings of the system. By me as an architect and by my fellow student Yael von Mengden as a landscape architect. Where Yael will focus on the research on (production) forestry, I will focus on the research on timber housing, as illustrated in figure 3. Together we come to see how the system can work as a whole. To sketch a future where instead of outsourcing the material production, and its negative impact, as has been the trend the past century, we bring the production back, closer to home, to be able to take responsibility for its (positive) impact.

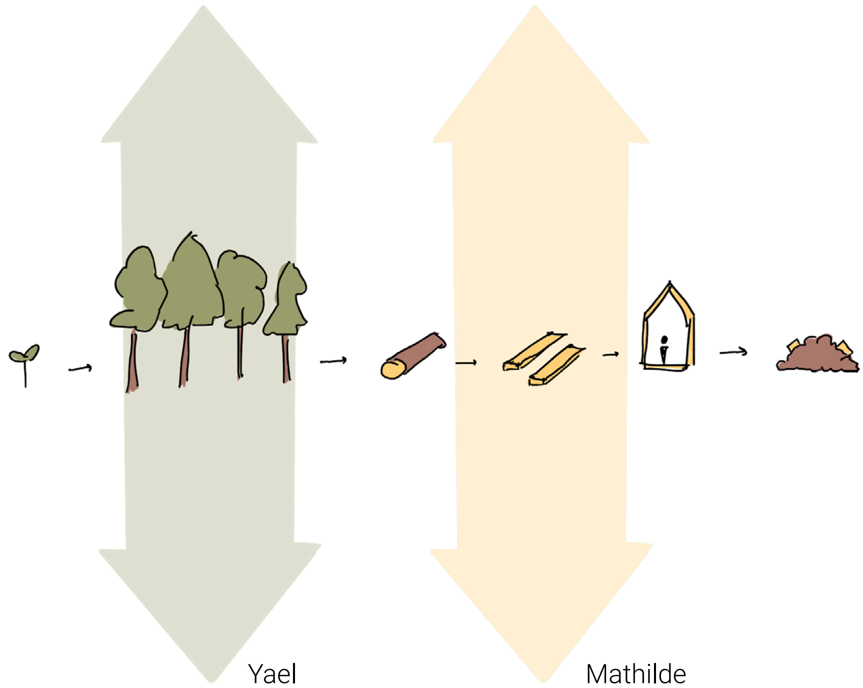


Fig. 3 Research focus Yael (forestry) and Mathilde (timber construction).

RESEARCH QUESTION

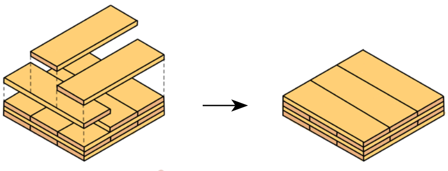


Fig. 4. Cross laminated timber

Ever since its invention in Switzerland and Austria in the 1990's, cross laminated timber (CLT) has been on the rise, see figure 5 (Studio Marco Vermeulen, 2020, p.15). The highly engineered timber product allows for the construction of high rise buildings. CLT is made by glueing together dried boards of timber and glueing them together under alternating 90 degree angles, figure 4. Through this cross laminating similar strengths to concrete are achieved. The resulting panels can then be used as floorslabs, loadbearing walls, or cut into beams and columns. Different ways of laminated timber products are also referred to as mass timber (Swedish Wood, 2019).

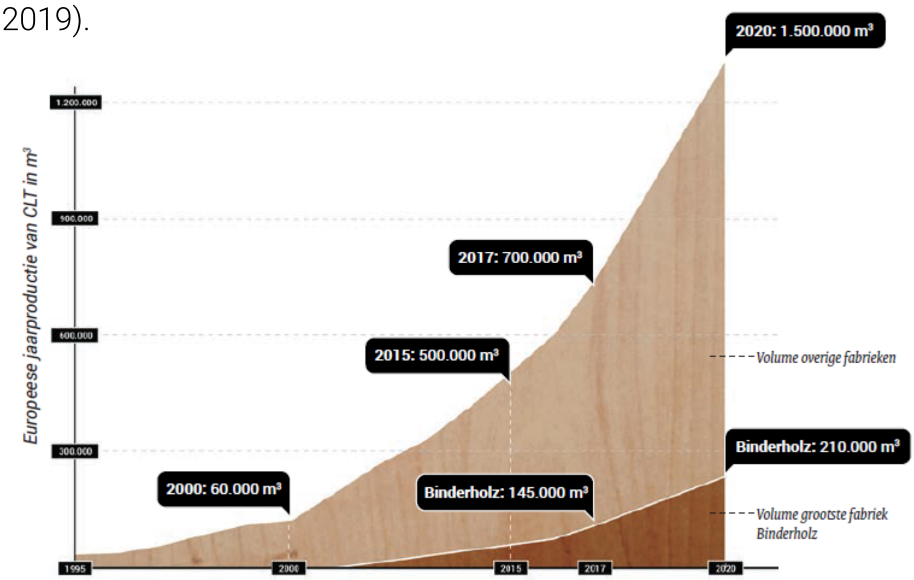


Fig. 5. Increase in CLT production (Studio Marco Vermeulen, 2020, p.15)

Another form of building with timber is in timber frame onstructions. In the Netherlands a proven building method. Here, a characteristic post and beam construction is to be filled with insulation material.

Seeing the booming production of CLT, this research sets out to explore the possibilities of CLT as a a regenerative solution in the specific context of providing housing for all. Leading to the research question: **How can a CLT construction contribute to the regenerative design of social housing in the Netherlands?**

Let's start with defining the terms of the research question:

CLT CONSTRUCTION

This research focusses on the load bearing elements of the construction where CLT can be an alternative to the highly polluting concrete. Besides the loadbearing construction elements, the façade, insulation and foundation are also of importance but for time related reasons this thesis only covers the loadbearing construction. The consequences of using a CLT loadbearing construction on these other construction elements will be mentioned. The most common tree species to be used for the construction of CLT is the spruce tree. The life of the spruce tree will be central to the storyline.

SOCIAL HOUSING

While multiple European conventions mention the right to housing, the Dutch constitution only mentions that the “promotion of adequate housing is the object of government concern” (Grondwet, 2022, art. 22, para. 2).This is also called an ‘obligation of effort’ but the government can not be held accountable if not everyone has a house. With the current demand of affordable housing in the Netherlands the government has plans to build new affordable homes. Using timber in the construction of social housing provides the opportunity to move beyond iconic projects for the lucky few. To make optimal use of the benefits of wood, volume is needed and timber building will infiltrate mainstream housing on a large scale (Lente, 2022).

Social housing is the subsidized construction of housing intended to be rented on a non-profit basis to people with a low income. The average area of a social housing unit in the Netherlands is 85m2 (Stuart-Fox et al., 2022). Social housing in the Netherlands is bound by a maximum rent. Thus the development, must be cheap. This research will not work with exact costs but instead look at the relative factors that come into play determining the costs. Looking at the entire building cycle the amount of material needed, construction costs and the residual value of the construction will be considered.

The construction costs of highrise buildings are much higher than lowrise buildings, mostly due to safety requirements (Kooiman & den Breejen, z.d.). Typical low to mid rise social housing in the Netherlands is pictured below in figure 6.

Besides construction methods, regulations also form an important factor in providing housing for all. At the moment it can be cheaper to rent two individual houses than to share one house with two people due to the national rent supplement for lower incomes. In addition, the Dutch enjoy a relatively large living area per person compared to their neighbours. The average living area here is 53m2, compared to 46m2 of our neighbours in Germany (Centraal Bureau voor de Statistiek, 2018) (Statistisches Bundesamt, 2018).

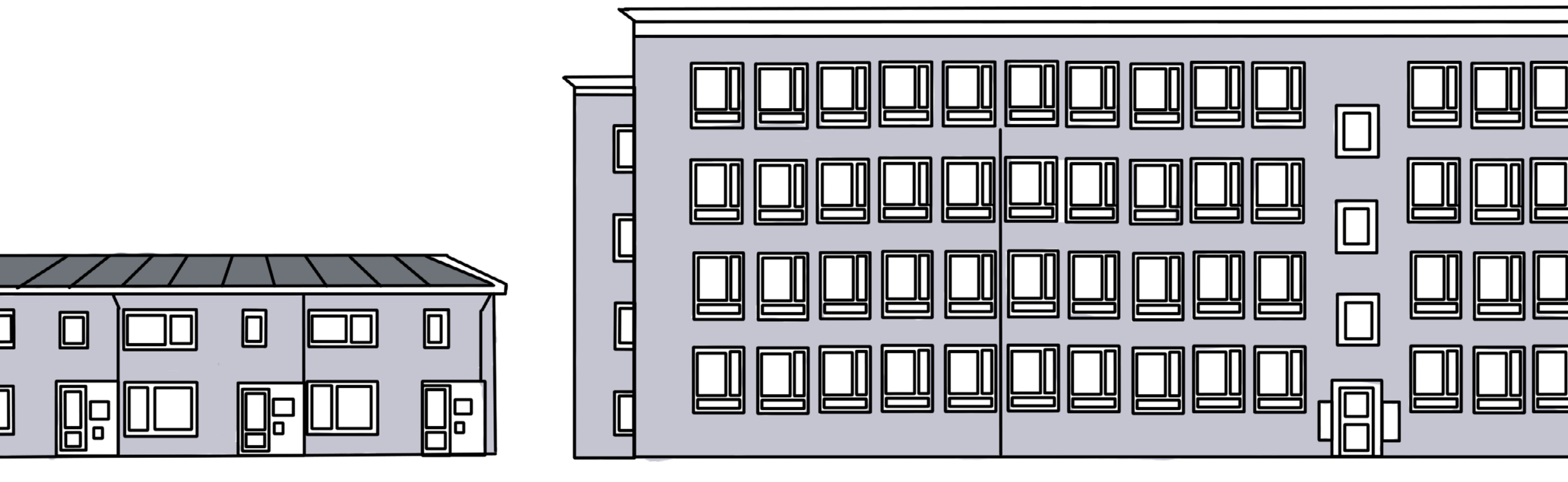


Fig. 6. Typical social housing: left: row houses. right: portico appartments

REGENERATIVE DESIGN

In their book *Flourish*, Sara Ichioka and Michael Pawlyn define regenerative design as 'that which supports the flourishing of all life, for all time" (2022, p. 14). Or in other words regenerative design aims to use design and construction as positive forces to restore natural and human systems, rather than merely minimizing the negative effects of new development. Where humans co-evolve as an integrated part of nature.

Donella Meadows, author of the book *Limits to growth,* which is seen as the start of the sustainability movement in the 1970's, has analysed the effectiveness of places to intervene in a system, so called 'leverage points'. Little effective is intervening at the 'material flows and nodes of material intersection.' Which would be minimizing our impact through material use, energy consumption and CO_2 emmisions and waste generation. The most effective way to change a system, according to Meadows is to "alter the mindset or paradigm out of which the system arises" (Meadows, 2012). It is now our task to move beyond a sustainable paradigm, towards a regenerative one. The current western conviction that human being are outside of or above nature needs to be replaced with the conviction that we are an integrated part of nature.

nature connectedness

Nature connectedness "is a measurable psychological construct that moves beyond contact with nature to an individual's sense of their relationship with the natural world" (Nature Connectedness Research Group, n.d.). According to Lumber at al. the way to restore the human connectedness with nature is through tuning into nature with the senses and focusing on its beauty, among others, we can reestablish our connection to it. Realizing our interconnectedness with nature will lead to more pro-nature behaviour and enhanced mental health (2017).

framework

research criteria

Ryn and Cowan made a framework for integrating human design with living systems. Their book *Ecological Design* challenges us to design buildings and landscapes restore our natural systems rather than just slow down the rate at which they are deteriorating (Ryn and Cowan, 1996). The section below explains how the five pillars of this framework set the research criteria for CLT and regernative design.

1. Solutions grow from place.
Traditional cultures that depended on their immediate surrounding for their survival celebrated the interdependence with the living world, weaving practices of sustainability into everyday life (Ryn and Cowan, 1996).

Can CLT be produced within a local interdependent system? In this case in the Netherlands, with trees that are well suited for this land and climate.

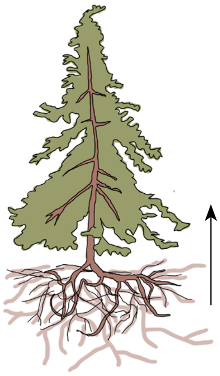


Fig. 7 Solutions grow from place

Illustrated on the left in figure 7, where the tree is rooted firmly in the ground and extracts the necessary nutrients from its immediate surroundings to be able to grow.
2. Ecological accounting informs design.
Tracing the complete set of ecological impacts, along the entire building chain, is a prerequisite for ameliorating those impacts (Ryn and Cowan, 1996).

In the case of CLT this means assessing the environmental impacts along the entire chain of construction. From tree, through the production, construction, use, and finally disposal of the material. And to take responsibility for any shadow costs and side effects.

Fig. 8 The stereotypical view of 'wild nature'.

3. Make nature visible
"We have rendered both nature and the consequences of our own technologies increasingly invislbe, effective design helps us to inform us of our place within nature. Weaving nature back into everyday life breaks down the destructive dichotomies between the built world and wild nature" (Ryn and Cowan, 1996, p185).

In which ways can CLT help make nature visible. Or sensible, through sight, smell and touch. Help us think as nature as closer to home than the stereotypical image of 'wild nature' as pictured on the left in figure 8.

The two final pillars of the framework are not taken account in this research but will be part of the design project: 'To design with nature' and 'Everyone is a designer'.

THE NETHERLANDS

The Netherlands will set the boundary for the geographical scope of this research project. This is done to make the research feasible and because a local system reduces transport emissions and can strengthen local ecosystems.

METHOD

This research makes use of three types of research methods to come to an answer of the research question chain analysis, interviews and literature study. The first two methods will be elaborated on below:

CHAIN ANALYSIS

The aim of this project is to take responsibility for the impact of the building materials along the entire chain. Because of the importance of the production chain as described above in the introduction, this is taken as the starting point of the research. Looking at this process, from cut spruce tree, to timber boards, from timber boards to cross laminated timber, from CLT panel to someones home, and from a home to fuel for the incinerator, a number of parameters are distilled that determine how CLT can contribute to the regenerative design of social housing. These parameters are used to asses CLT construction in comparison to another popular timber building method; timber frame construction.

INTERVIEWS

In order to gain relevant and current information intervies are carried out with different stakeholders in the timber chain. The interviews are informal and almost in all cases carried out on location, shown in figure 9 below.

Jan Oldenburger

Director and senior advisor of PROBOS; knowledge organization dedicated to sustainable forest management in the Netherlands and abroad.

Lambert van den Bosch

Director of Heko Spanten; sister company of Houthandel Lambert van den Bosch. Specialist in the construction, manufacture and assembly of glued load-bearing timber structures.

Cas van der Zanden

(short meeting) Tutor TU Delft, Architect and builder of WitteHaai, extreme CLT projects.

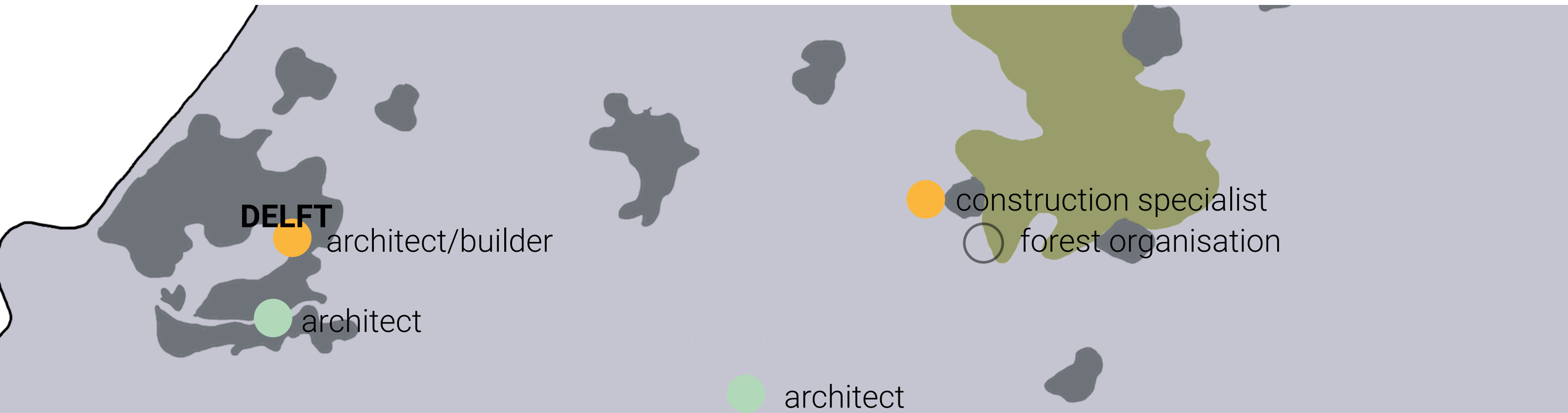
Annemariken Hilberink

Partner of Hilberink Bosch Architecten, architectural office mostly housing, private as well as projectbased. Robust architecture with sensory experience.

Marco Vermeulen

Partner of Studio Marco Vermeulen; a design studio for architecture, urban planning, landscape and design research.

Fig. 9 Location of the interviews



FINDINGS

PARAMETERS

The following parameters are identified as being of influence for the production and use chain of CLT:

Input:
tree species

Production:
material efficiency
energy consumption
additives

Construction
construction efficiency
construction speed and cost
architectural consequences
wall build up

User experience:
sight, smell, touch

Deconstruction
reuse
cascading

End of life

The parameters are listed in chronological order. Two notes must be made from an architectural research perspective:

1. All parameters are connected and cannot be approached seperately. The parameters at the beginning determine and influence the parameters further down the chain. For example the material efficiency of the production and the used additives determine largely the (dis)ability to deconstruct.
2. Subsequently, while the role of the architectural designer is usually most present around the construction and user experience phase the interconnectedness of the parameters pleads for an architect, or a team of architects with knowledge on all parameters and their interdepence.

HOW TO READ

This research is presented as an interactive report. Please open this document in Adobe Acrobat to view the PDF. The different buttons show more information, an example or a side note. They also direct the reader from and to the CLT production chain, central to this research. Please read the instructions below carefully to ensure not to miss anything.

- Click to expand pop up
- Click to minimize pop up
- Click to go to page with research findings
- Click to show timber chain content
- Click to hide timber chain content
- Click to go back to the timber chain overview

It is also possible to read this report from beginning to end, in order, or skip to the conclusions right away by clicking **here.**

Please think carefully before you print this research.
The trees needed for this report could be used for a higher value application.

I lived in the woods;
I was killed with a hard axe.
As long as I lived I was silent;
Now that I am dead, I sing with a soft voice.

Spruce with a finer grain and narrow, regular annual rings can be used for the bottoms of musical instruments including violins. At some point, in French musical instruments, the musician was reminded of the previous life of the tree and found this poem in the instruments case (translated from: Fraanje, 1996, p. 257).

FROM SPRUCE TREE TO HOUSE: THE STORY OF CROSS LAMINATED TIMBER

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INFORMATION

BY-PRODUCTS

ALTERNATE PRODUCTION METHOD

INTERVIEWS

INPUT

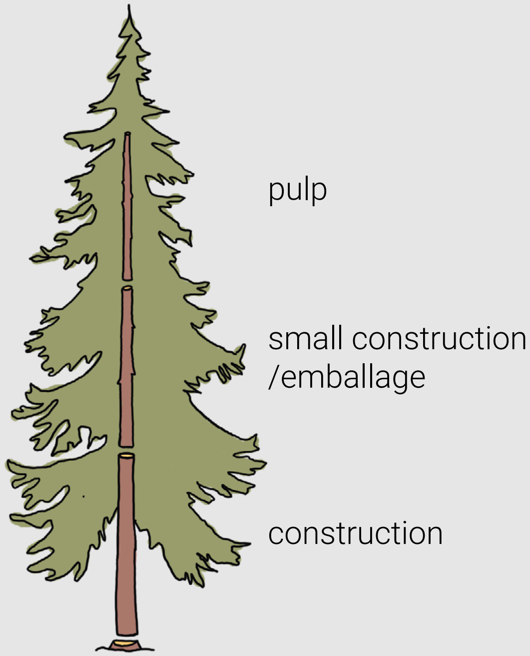


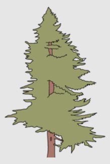
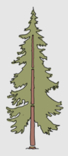
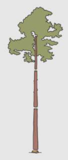
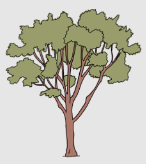
Fig. 10 Parts of a spruce tree

Fig. 11 Section of a tree

This story starts where the living life of the spruce tree ends; after the cut. The tree is cut into parts and processed to become suitable construction material. Because of its ability to glue well, the light weight and relatively high strength, spruce is the main type of tree used for CLT (Wigo Group, 2022). The average spruce takes 50 years to grow (Fraanje, 1999).However, the spruce is not native to the Netherlands (most spruce trees grow in forests in Germany, Scandinivia and North Eastern Europe) and for an ecosystem to thrive, diversity is needed. The presence of indigenous trees is of great importance to the quality of the ecosystem, according to WUR (2019). Most trees native to the Netherlands are decideous trees, but for mine working constructions many coniferous trees were planted a century ago which, when cut are now being used for low value applications (Studio Marco Vermeulen, 2020). At the moment Staatsbosbeheer is phasing out the coniferous trees and planting more native decideous trees. This section looks at which various tree species, growing in the Netherlands, could be used for the production of CLT.

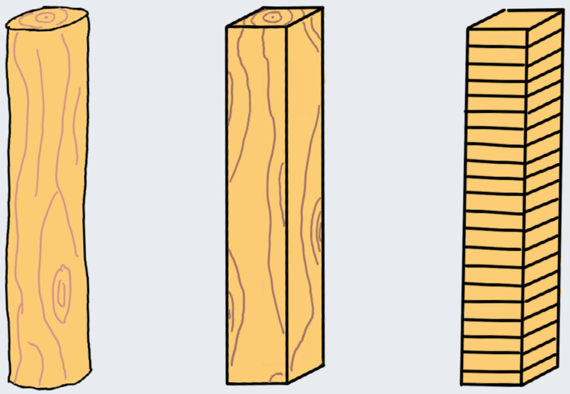
In table 1 on the next page multiple tree species are analysed that are suitable for the construction of CLT. Here, their growth rates, important for the urgent housing deficit, size of the tree, strength, durability, which means susceptability to rot and insect attacks are stated. Furthermore, it is stated if the wood is also used for timber frame construction, unlaminated and possible other applications within a home. Most of the information was found in the book *33 Boomsoorten* by Peter Fraanje; an extensive overview of all tree species growing int he Netherlands suitable for production (1999).

For the production of CLT the largest, most lower part of the tree trunk is used, illustrated in figure 10. The most durable wood is found in the hardwood, shown in figure 11, and thus also preferable for constructions. The other parts of the tree become pulp, or palletwood, etc. Different coniferous trees can be combined in the production of CLT. The industry of engineered wood products is a risk averse industry. Since CLT is relatively new, and there are a lot of prejudices against building with timber relating to constructional integrity and fire safety, the industry can not afford to make a misstep. Therefore, according to the interview with Probos, at the moment, mainly two tree species are used, spruce and pine. These tree species are readily available in large quantities in Europe and their properties have been researched extensively. In addition, the large quantities of these tree species make a reliable influx of raw materials resulting in a steady output of engineerd wood products necessary to make ends need financially (interview summary available in appendix A).

tree species	(latin name)	tree type	growth rate	dimensions	strength	durability (heartwood)	laminated	solid	other	remarks
European Larch	Larix decidua	Coniferious tree/softwood 	Fast (40 years) Annual growth: 10,5m3/ha	H: 30-40m. D: 0,5-1m	C14, C18, C24, C30 (4). Similar in properties to pine but heavier, harder and stronger.	II-III: One of the most durable coniferious tree species in Europe. Larch sapwood is less susceptible to blue mold than spruce sapwood and much less so than pine sapwood. Can be used outdoors untreated.	x	x	frames, façade, interior, staircases and rooftrusses, foundation pole	Larch wood ranks above pine in utility value, but below that of larch, Douglas fir and pinus. Takes twice as long to dry as pine. Does not work, warps fairly quickly.
Douglas fir	Pseudotsuga	Coniferious tree/softwood 	Medium (75 years) Annual growth: 125m3/ha	H: 40-60m. D:1-2 m	C14, C18, C24, C30 (4)	III: Can be used outdoors untreated.	x	x	frames, façade, interior, foundation pole	Fir is known for laying down a consistently high proportion of strong, dense summerwood, which is what makes it such a good structural timber (9).
European spruce	Picea abies	Coniferious tree/softwood 	Medium-fast (40-60 years)	H: 35m. D: 0,6-1,2m	C14, C18, C24, C30 (4)	IV: Unlike other woods, spruce sapwood is considered equivalent (in durability and other properties) to heartwood for most applications after drying. Not to be used outdoors untreated.	x	x	frames, doors, staircases, floors, interior, furniture, foundation pole, façade	Easy to process
Scots Pine	Pinus sylvestris	Coniferious tree/softwood 	Medium-slow (80 years)	H: 30m. D: 0,6-0,9m	C14, C18, C24, C30 (4) Less resilient and tough than spruce and pine and therefore less suitable for long joists.	III: Sapwood very nondurable.	x	x	frames, door, floors, interior, fences	Disadvantage compared to silver fir and spruce is the strong perspiration of resin. Easy to process.
Silver Fir	Abies Alba	Coniferious tree/softwood 	Medium	H: 30-45m. D: 0,4-0,9	C14, C18, C24, C30 (4)	IV: Little resistance to insect attacks. Susceptible to blue mold.	x	x	frames, door, staircases	
Poplar	Populus	Decideous tree/ hardwood 	Fast (15-25 years) Annual growth: 15m3/ha	H: 15-25m. D: 0,2-0,5m. Average yield: 1-2m3 lumber per tree	C22 (4) In terms of mechanical properties as strong as spruce .	V: For indoor use it is durable but outdoors it does not last long.	x (2)	x	floor	Dries relatively quickly. Wear-resistant and difficult to ignite. Strange that poplar wood is hardly used in construction in NL.
Birch	Betula	Decideous tree/ hardwood 	Medium (50-60 years) Annual growth: 8-15m3/ha	H:18-21m. D: 0,5-1m	?	V	x (3)		Floor tiles	Untreated not suitable as construction wood, decays too quickly in moist air
Elm	Ulmus	Decideous tree/ hardwood 	Medium	H: 35-40 m. D: 0,9-1,4 m	Elm is barely inferior to oak in quality as construction or work wood.	IV	?	x	door, staircase, furniture	
Robinia	Robinia pseudoaccasia	Decideous tree/ hardwood 	Fast (40 years) Annual growth: 9,4m3/ha	H: 25-30m. D: 0,6-0,9m	D30 (6)	II: Known as one of the most durable woods in Europe.	x	x	frames, door, staircases, façade	
European ash	Fraxinus excelsior	Decideous tree/ hardwood 	Medium (60 years) Annual growth: 8,4m3/ha	H:20-30m m. D: 0,4-0,9 m	D40 (4)	V	x (CLT in development) (7)	x	roof, doors, staircases, floor	Heavy, hard but excellent to work with. Highly underrated in construction, grows fast, is hard and has beautiful markings.
Chestnut	Castanea sativa	Decideous tree/ hardwood 	Slow (60 years) Annual growth: 14-17 m3/ha	H: 15-25m. D: 0,6-1m	D24 (4)	II: High tannic acid content accelerates corrosion of metals but allows untreated outdoor application.	x (CLT in development) (7)	x	Frame, Door, furniture, façade, roof, floor.	Easier to process than oak
Beech	Fagus sylvatica	Decideous tree/ hardwood 	Slow (50-80 years)	H: 30m. D:0,8-1m	D35, D40 (4)	V	x	x	Threshold, stairs, floor,	Very good to glue. Expands a lot in contact with water. Not to be used outdoors. (8)
Oak	Quercus patraea	Decideous tree/ hardwood 	Slow (150 years)	H: 18-30m. D: 0,6m	D18/D24/D30 (4)	II-III: Keeps well when dry or continuously in water.	x (CLT in development) (7)	x	Frames, doors, floor,	Steaming reduces shrinking and swelling. Wood works in one direction, can cause cracks (8)
	source	(Fraanje, 1999) unless stated otherwise			4: (Houtdatabase | Houtinfo, z.d.) 6: (Foreco Houtproducten, z.d.)		2: (Studio Marco Vermeulen, 2020) 3: (HASSLACHER, z.d.) 7: (Buckland Timber, z.d.)			8: Interview Heko Spanten, 2023 9: (Pollan, 1998, p.143)

PRODUCTION ENERGY

Fig. 12 Production energy in MJ/m3



Already back in the 1998 when CLT was just invented Peter Fraanje wrote his dissertation on the required energy for the production of a timber beam. Here Fraanje compared the energy input for round timber, squared sawn timber and glue laminated timber, summarized in figure 12. (Note: here the timber boards are not laminated crosswise but parallel).

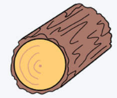
For the round and square timber, drying requires the farmost relative amount of energy; two-thirds and two-fifths respectively. For the glue laminated timber three-quarter of the energy is needed for the drying and laminating: 2500 laminating, 1300 for kiln drying (Fraanje,1998).

The timber has to be dried to 10% +/-2% moisture content to in order to be glued together (Oldenburger et al., 2020b). This means that the timber is placed in a room of 70 degrees celcius for 2 week. According to Lambert van den Bosch, from Heko Spanten, timber construction specialist, the timber for a simple timber frame construction would not necesarily need to be dried. Saving an substantial amount of production energy (interview summary available in appendix A).

side note:

According to the Carbon Based Design research by City Forster, the majority of the emmissions comes from the daily life of the inhabitants and not the production and construction of the building itself (2022).This stresses the importance of an integral approach towards our emmisions.

PRODUCTION - Efficiency from log to timber



For the production of CLT the heartwood is cut out of the trunk of the spruce tree. The sapwood is used for lower value applications, just as the brances and part of the trunk with too small of a dimater for the timber needed. Timber boards for CLT are typically 170mm by 5000mm (Oldenburger et al., 2020b). According to CLT manufacturer Pollmeier, the efficiency is similar for the all the tree species they use, however, there is a difference in efficiency between cutting methods, a rotary saw used for CLT has a lower efficiency than a stationary saw producing sheets of veneer that are then glued together (Pollmeier, personal communication, 2022). More information on this alternative cutting method can be found on page 15, or click on the log in the top right corner, under alternate production method.

Of the logs large enough to use, a whole lot more than sawnwood is extracted. A sawing pattern is shown in figure 13. First the log is debarked, the bark is used for ground coverings or biofuel. The debarked log is then sawn resulting in chips, destined for the paper industry, panels and biomass; sawnwood, which is on its way to become CLT; sawdust, used for energy pallets, mdf etc. and shavings, which can become particle boards, MDF, biomass etc. The exact efficiency differs per source, but the numbers are around 40-60%.from log to sawnwood, shown in figure 14 below (Forest Product Conversion Factors | UNECE, 2020, Swedish Wood, z.d., Oldenburger et al., 2020a).

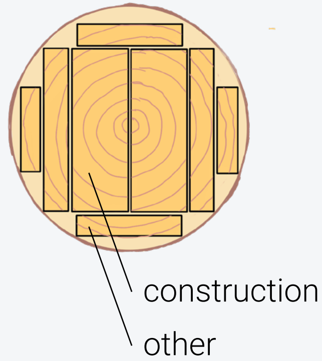


Fig. 13 Sawing pattern

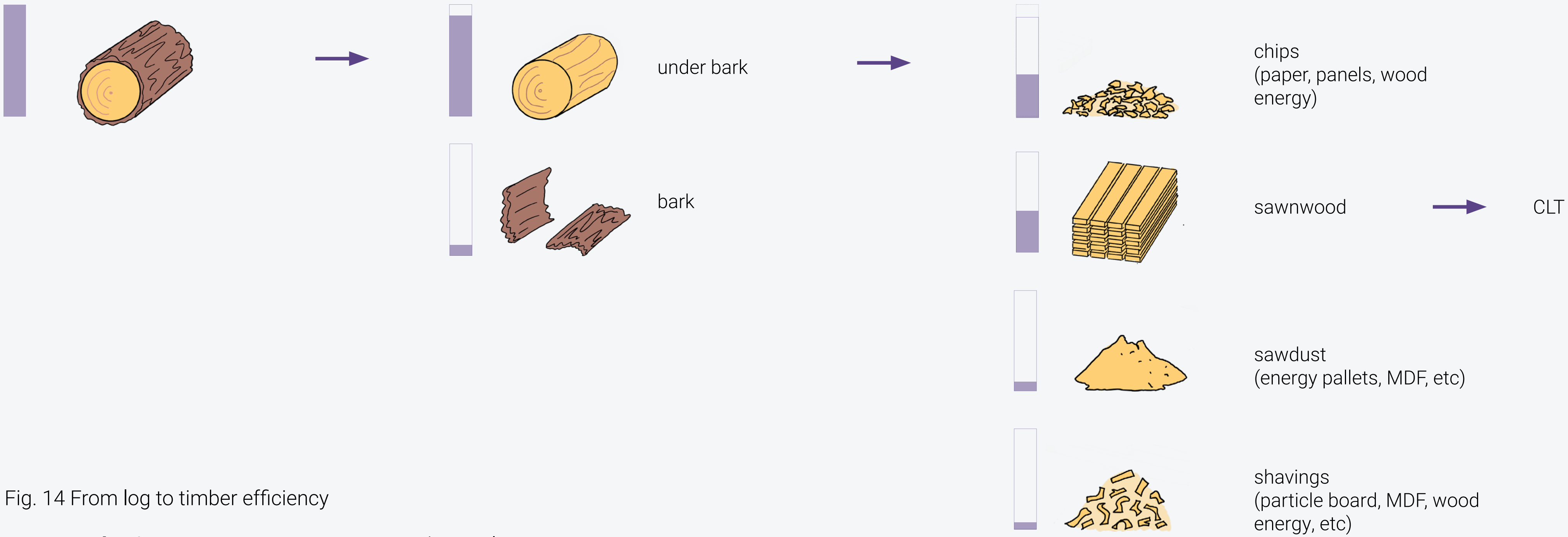


Fig. 14 From log to timber efficiency

PRODUCTION - Efficiency from Timber to CLT

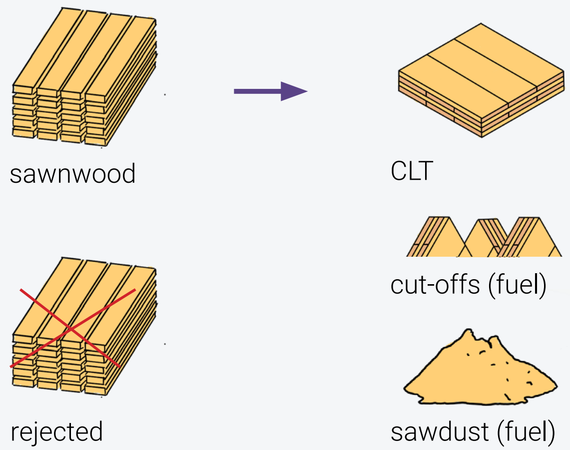


Fig. 15 From timber to CLT

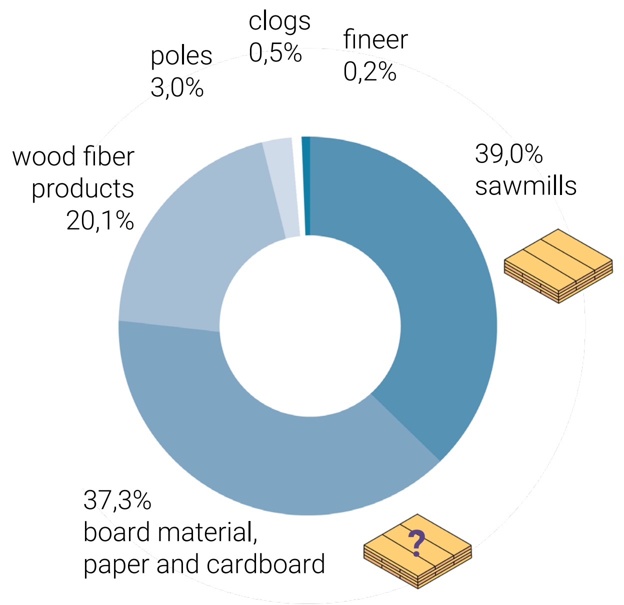


Fig. 16 Application of Dutch wood (Oldenburger et al., 2020a)

The sawnwood is then checked for any deformalities, which will be cut out, see figure 15. The boards are then fingerwelded on the short edges to make boards up to 18m long. Mostly dependent on the size of the production facility. These long boards are then moved through a glue curtain and cross laminated. After being dried under pressure the edges are cut off. Now the CLT panel is prepared for its further application. Openings for doors or windows can be made and a CNC machine is used to cut out space for future pipes and cables to be installed in the home. According to CLT manufacturer Deriks the proces from timber board to CLT leads to about a 5% efficiency loss (Oldenburger et al., 2020a).

Adding the losses from log to timber and timber to CLT, according to Swedish Wood and Derix, this results in an efficiency of 43% from log to CLT. This is also the number that the municipality of Amsterdam is working with in their Verkenning gemeente Amsterdam. It is clear that when using timber frames in construction one would ommit the efficiency loss of the production process from sawn timber to CLT.

IMPROVING EFFICIENCY

One way to improve the efficiency from trunck to timber is to find quality applications for parts of the tree currently used for low value applications. In the Netherlands roundwood is used for various applications, seen here on the right. The highest quality is used for timber sawn in sawmills. The heartwood from the largest parts of the trunck with the least amount of large disformations. Probos researched wheather the spruce wood usually destined for emballage applications such as board material, paper and cardboard could be used for the production of CLT. In collaboration with the nearest CLT manufacturers just across the boarder in Germany, DERIKS. They found that instead of the usual 5% loss of material from sawn timber to CLT, this increased to 11%. But now almost 37,3% could be put to better use, see figure 16. A promising result (Oldenburger et al., 2020a).

PRODCUTION FACILITY IN THE NETHERLANDS

At this moment there is no CLT production facility in the Netherlands. Most factories, in Germany, Austria, Switzerland or Scandinavia are located close to the forest where the trees are sourced. The large production forests there provide the steady inflow of raw materials needed to keep the factory profitable. The arrival of the first Dutch CLT factory is highly anticipated but not everyone is convinced of its necessity. According to Lambert van den Bosch, at the moment there is not enough dutch timber to feed to factory and timber would have to be imported from neighbouring countries.

PRODUCTION - Additives

In the production of CLT the boards are cross laminated using glue. The glue is either polyurethaan (PUR) or Melamine formaldehyde (MVF). Eventhough less than 1% of the CLT is glue the use of these petroleum-based adhesives does contribute to the release of volatile organic compounds which are harmful to the environment. Furthermore, the use of these adhesives affects the possibilities for matieral reuse, recycling and disposal (Sotayo et al., 2020). According to Puettmann et al. the production and transportation of the glue contribute 3/5 of the total production energy for the CLT (2017). The short edges of the timber boards in the same plane are sometimes not glued, which would mean less glue is used. However, this leads to portruding edges may cause side pieces to fall out in cutouts.

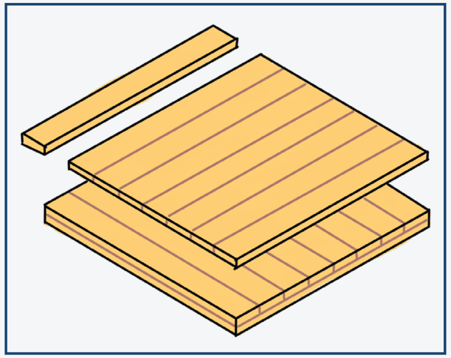
GLUED ALTERNATIVES
Glue laminated timber, paralel laminated boards and laminated veneer lumber (LVL), sheets of veneer laminated, are two different glue based options, see figure 17. In the case of LVL, the strength is greater and the efficiecny is a bit higher so less timber is needed for the same structural performance (Pollmeier, 2022). However, almost five times more glue is needed for LVL (Fraanje, 1998).

DRY ALTERNATIVES
Glueless variations on CLT are nail cross laminated timber, using steel nails or dowel cross laminated timber, using wooden dowels. Here beech wood with a lower moisture content is hamered into the boards which expands due to the higer moisture content of the boards. This way of laminating may also cause portruding edges, which are undesirable or the user and even have to be sanded down for applying finishing material.

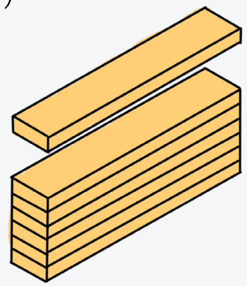
+

Another method is being researched using dovetail connections. Possibly also better for the fireprotection (Emre et al., 2022).

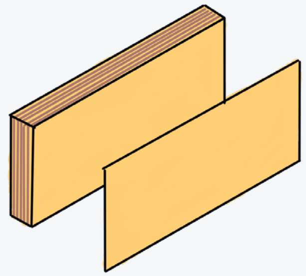
Fig. 17 Laminating methods



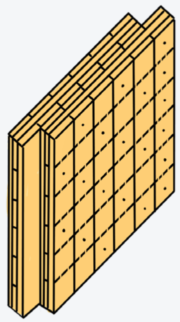
Cross Laminated Timber (CLT)



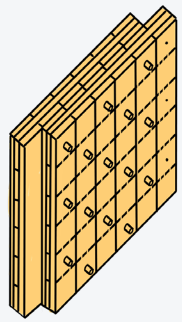
Glue laminated timber (Glulam)



Laminated Veneer Lumber (LVL)

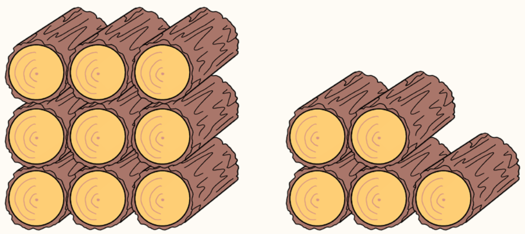


Nail laminated timber (NLT)



Dowel Laminated Timber (DLT)

CONSTRUCTION - Efficiency

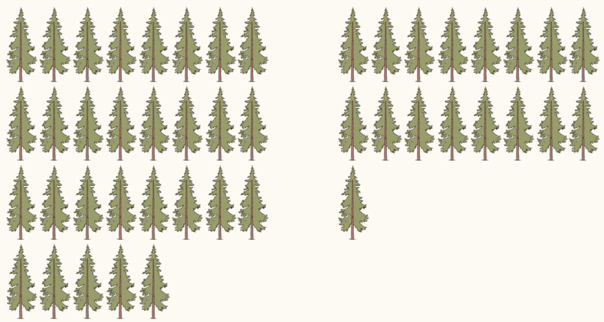


CLT
72m3

timber frame
42m3

Fig. 18 Required roundwood per unit

Fig. 19 Required sprucetrees per unit



CLT

timber frame

When aiming for a local timber supply chain the amount of wood needed is of great importance. Due to the limited amount of land in the Netherlands there is already a fight for space, and at the moment the value of the farmland is much higher than that of a (production)forest, according to Probos.

CLT

Looking at six CLT appartment reference projects in Europe, mostly made from spruce, the average amount of timber needed per social housing unit of 84m2 is 31m3 of CLT. Seen in figure 18 and table 2 below. Using the material efficiency factor from before, this means about 72m3 roundwood is needed per social housing unit.

architects	project	m3 timber total	m2 total	m3/m2	m3/unit	number of trees/unit	source
Waugh Thistleton Architects	Dalston Works	3851	8500	0,45	**38,1**	14	1
Finch Buildings	M'DAM	2500	5430	0,46	**38,7**	16	2
sps architekten	Hummelkazerne Gratz	1600	6600	0,24	**20,4**	-	3
Lister buildings	Listerbuildings			0,36	**30,2**	76	4
MAATworks	Mijn houten huis	248,0	636	0,39	**32,8**	-	5
Urban Climate Architects	Grote Kreek	690,7	2175	0,32	**26,7**	-	6
	average				**31,1**		

Tabel 2 Amount of CLT in six reference projects

TIMBER FRAME

For every timber frame house a CLT house takes 1.7 times as much timber (Centrum Hout, 2021) For a timber frame unit this would result in 42m3 wood. However it could be even lower as the production of the timber has a higher efficiency as well.

TREES

Eventhough hard numbers are missing regarding how much timber can be used from one tree, A recent social housing project in Monninkendam, M'dam claims to have used a thousand trees for the production of 2500m3 CLT for social housing units (BMB Ontwikkeling, 2022). Using these numbers this would mean a CLT unit would require 29 trees and a timber frame unit 17 trees, see figure 19.

ADDITIONAL ELEMENTS

Dowels, botls and connector plates are used to fasten the CLT elements to eachtother and to other parts of the construction. These metal parts bring with them a high embodied energy, and more material input. The specifics of these connectors are not taken into account in this research.

CONSTRUCTION - Speed and cost

CONSTRUCTION SPEED

Fig. 20 Construction speed CLT vs HSB

CONSTRUCTION COST

Fig. 21 Construction cost CLT vs HSB

LIGHTWEIGHT CONSTRUCTION

Compared to a benchmark of social housing projects of concrete and sand-limestone, timber frame appartments have a reduced building time of -48% and CLT appartments of -17%, figure 20. When the CLT is constructed in modules rather than single elements the construction time for CLT is reduced by -37% compared to the benchmark. (Centrum Hout, 2021, p12) Timber construction specialists Heko Spanten call modular construction the future for timber building. CLT has the advantage that the modules are very rigid and transport proof. This is not always the case with timber frame modules.

A reduced construction time is favorable given the current pressing demand for social housing.
A short building time makes it possible to build on difficult sites in inner cities, were many neighbours cant be disturbed for too long, or near nature reserve areas where the stress on the environment should stay minimal. (Centrum Hout, 2021, p12) In addition, timber frames could possibly be made from fresh wood, eliminating the time needed for the drying of the timber.

The faster the project is built, the sooner the developer can start collecting rent and thus start getting a return on the investment. According to Centrum Hout the costs of timber frame appartments is -21% compared to the benchmark and CLT +14% (2021, p12). See figure 21 on the left.

The MPG score indicates the environmental impact of the building materials. Mandatory to provide for any new construction. This score will become more strict making bio-based materials more popular as the scores lower. Wood is performing well in the MPG score due to environmentally friendly harvesting, easy processing and low weight in application. Wood will score even better when the foloowing flaws in the scoring are adjusted: At the moment CO_2 storage is the wood is not yet accredited and it is assusmed timber will be burned at the end of life while it can be rused or recycled (Centrum Hout, 2021).

The lightweight construction of timber makes it possible to use electric cranes instead of fossil fuels. As fossil fuel prices are ont he rise and renewable electricity will likely drop this will make it cheaper in the future. Also, 50-70% less personnel is needed to install a timber loadbearing structure than a concrete equivalent. (Prins & van Roeden, 2021 p. 65)

CONSTRUCTION - Spatial consequences

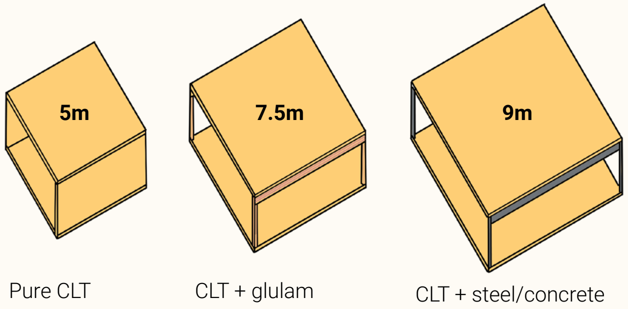


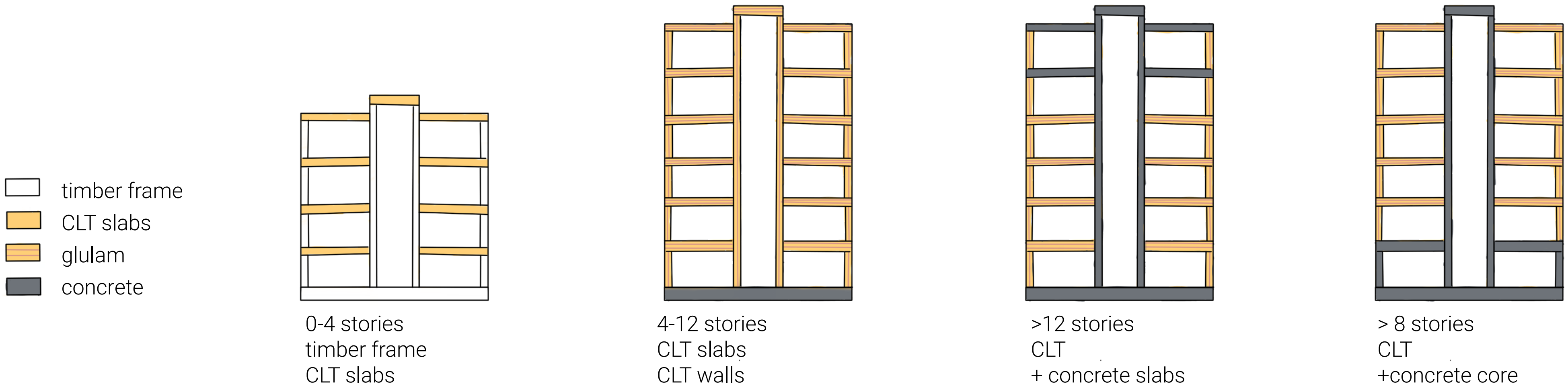
Fig. 22 Span of construciton method

SPAN
Timber as a structural material influences the architectural possibilities. With a constant panel thickness typical spans are pictured on the right in figure 22. For a pure CLT construction, resulting in cellular spaces, a span of 5 meters, typical for domestic rooms is obtained. For a construction of CLT slabs in combination with glulam beams and colums 7.5m can be reached. CLT slabs with a steel or concrete frame can span up to 9 meters (Waugh Thistleton Architects, 2018).

FREEDOM WITHIN THE FORM +
Due to the possibility of prefabrication and the strength of the CLT panels it is possible to built geometric volumes. This is however, less efficient and so far only done for private luxury homes.

CONSTRUCTION HEIGHT
Depending on the desired height of the building different combinations of CLT and other construction elements are possible, see figure 23. Up to four stories high, using CLT is only necessary in the floor slabs. Above eight stories, the windload becomes such an important factor that the lightweight CLT would have to be weighed down with a heavier material.

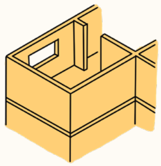
Fig. 23 Construction method per building heigth



CONSTRUCTION - Wall build up

The built up for a mass timber wall is different from a wall with a timber frame. A CLT construction is always insulated on the outside to keep the construction on the warm side, pictured in figure 24. Where for a timber frame construction the insulation material is positioned in between the construction, figure 25. Although it is not common in single family homes, for acoustic insulation and firesafety CLT walls in residential buildings are usually finished with extra board material. According to architect Marco Vermeulen the dimensions of these rediscovered bio-based building materials demand a new architectural expression that is true to the building material and location. Trying to built as light and thin as possible as became the trend after the introduction of steel and glass is not suitable for this bio-based material that demands mass, according to Marco Vermeulen (interview summary available in appendix A).

CLT



Non vapour permeable
Wall thickness +-400mm for R=6
Interior finishing
Determine wiring and plumbing before production
Construction adjustments more difficult
Material consts > construction costs
Glued timber non compostable
CO_2 storage of ca. 105kg/m2

+ Temperature storage massive walls

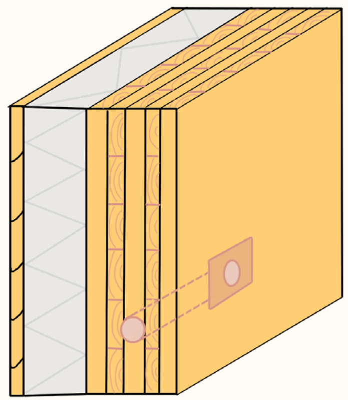
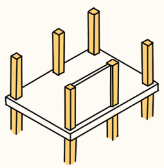


Fig. 24 CLT wall build-up

HSB



Vapour permeable
Wall thickness +-350mm R=6
Interior finishing boards
Construction adjustments easy
Construction costs > material costs
Fully compostable
CO2 storage of ca. 60kg/m2

+ acoustics
+ light construction

(Bruggink, 2022)

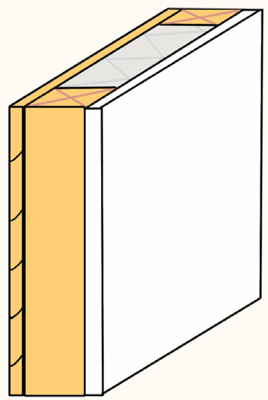


Fig. 25 Timber frame wall build-up

USE

The CLT is manufactured, the construction elements assembled, and the lucky person thats been on the waitlist for years can finally move into their new home. Here they experience the building material through sight, smell and touch. Research shows that a wooden building has a positive effect on the physical and mental healtt of the user. People like to be in an environment that incorporates wood and in addition it has a positive effect on their health, performance and state of mind. Wood also has a positive effect on the indoor climate. Wood regulates the moisture balance by absorbing the excess moisture and releasing it when it is too dry inside. This creates a self-regulating indoor climate (Studio Marco Vermeulen, 2022).

One of the key pillars of regenerative design is to make nature visible and to tune into nature through the senses (Ryn & Cowan, 2007), (Nature connectedness research group, n.d.) Sight, smell and touch, shown in figure 26 below, each influences the connection people have with the engineered wood product (and its additives such as glue). Compared to other typologies, exposed timber is more common in the commercial and educational sectors, and it is less common in mass residential developments. This is brought on by the requirement to include fire and acoustic protection measures, which are most effectively accomplished by lining and encapsulating the timber. In contrast, single-family homes typically have exposed wood in 90% of these case studies (Waugh Thistleton Architects, 2018, p.52). The interviews found that users and builders alike prefer the massive feeling of CLT over timber frame buildings. CLT provides a feeling of security and stability.

In this section the influences of sight, smell and touch on the user experience are looked at closely. Starting with table 3 on the next page that describes these characteristics for different types of tree species.

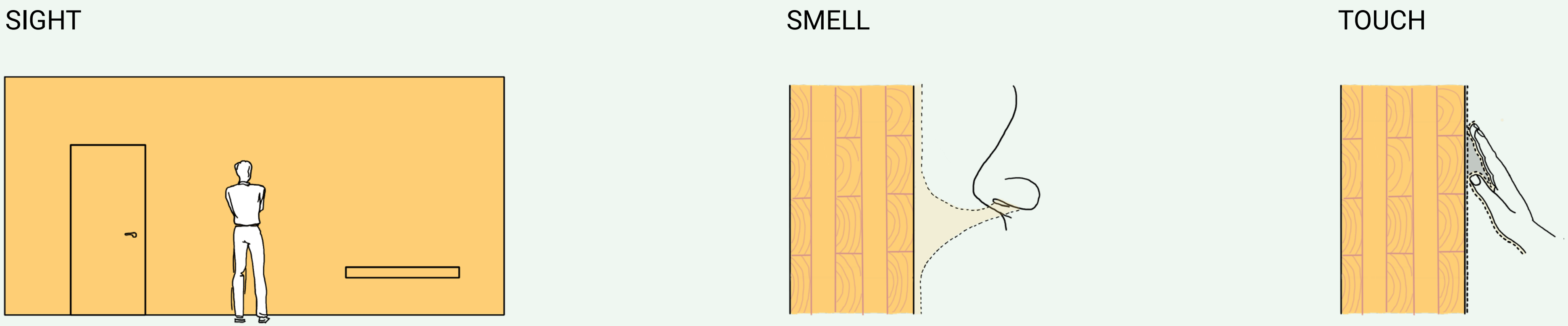


Fig. 26 The sight, smell and touch of CLT

tree species	latin name	sight	smell	touch (effusivity relative to palm)	wood photo
European larch	Larix	Sapwood: dirty white. Heartwood: yellowish brown to reddish brown. discolored over time.	Contains a large amount of resin, pronounced resin smell.	32%	
Douglas fir	Pseudotsuga	Heartwood is light red, to brownish red. Sapwood is light yellow. Yearrings are well defined. 1-2 cm of sapwood.	Relatively resinous.	32%	
European spruce	Picea abies	Almost white to pale yellow-brown. Freshly sawn almost white. Yellow-brown due to exposure to light and air. 5-6cm of sapwood.	Resinous but lacking the distinctive resin smell found in pine.	32%	
Scots Pine	Pinus sylvestris	Fresh heartwood: light brown. Sapwood: white to white-yellow. Clear difference between light-colored earlywood and thinner-colored latewood. Becomes darker over time.	High resin content creates a pleasant resin smell. Disappears over time but when old wood is reworked it smells like new again.	32%	
Silver Fir	Abies Alba	Yellow to greyish white. Bevat veel kwasten en bezit grove jaarringen.	Little resin, no characteristic odor.	32%	
Poplar	Populus	Practically colourless.	Odorless, resinless.	29%	
Birch	Betula	White, silverish, with little difference between heartwood and sapwood	-	42%	
Elm	Ulmus	Relatively high percentage of sapwood, color light yellow. Heartwood color light brown to dull dark brown, sometimes with a greenish sheen.	Said to release unpleasant odor during processing.	-	
Robinia	Robinia Pseudoaccasia	Color of the heartwood is light yellow-green to brown-green, turning golden brown after exposure to light. In sharp contrast with with the 10-20 mm wide gray-yellow sapwood.	-	52%	
European ash	Fraxinus excelsior	Very broad sapwood, contrasting with the brownish heartwood. White to creamy white color. Uniform texture. Light yellow exposed to daylight Nice grain with beautiful markings.	-	39%	
Chestnut	Castanea sativa	Light brown to dark brown. Resembles oak, but slightly lighter, with beautifull grain. Little sapwood.	-	-	
Beech	Fagus sylvatica	Heartwood whitish to light brown. Steamed is pink to light red.	-	41%	
Oak	Quercus patraea	When fresh: yellowish white, later yellowish red. Steamed pink to pale red. In contact with steel blue/black due to the reaction of tannic acids with the metal which will corrode.	Odorless	41%	
	source	(Fraanje, 1999)	(Fraanje, 1999)	(Ibanez et al., 2019)	(Houtdatabase | Houtinfo, z.d.)

USE - Interior sight

Fig. 27 Examples of residential CLT projects

Top f.l.t.r: Murray Grove, Waugh Thistleton before finish; Curtain Place, Waugh Thistleton; the Modern House, Amin Taha; Middle f.l.t.r: Ekoflin Familly home KAW Architecten; Dalston works, Waugh Thistleton (no CLT visible) Woodie, MM Holz; Bottom f.l.t.r: M'dam, Finch Buildings; M'dam, Finch Buildings; Plant je vlag, MAAT works.

USE - Surface marks

Examples of residential CLT projects are shown on the previous page in figure 27, with varying amounts of visible CLT. All of the CLT exposed in homes is of living space quality. For CLT there are three types of visual grades: non-visible quality, visible industrial quality (ISI) and living space quality (WSI). Below the criteria used to assess the surface are shown in figure 28. For visual grade quality they are only allowed to be present in small dimensions and limited number. Pieces of timber with too many marks are cut out or used in the inside layers of the CLT. Pine is much more resinous than spruce and more prone to discoloration. For this reason pine is mostly used on the inside of CLT


Healthy branches/splay knots


Dead knots


Filled knots

Marks from the life of the tree


Pitch pockets


Pith


Blue stain discolouration


Joint width


Glue penetration


Traces of planing

Marks from the production process

Fig. 28 Visual marks CLT (Derix, z.d., p12)

USE - Homogeneness vs unique

In living space quality CLT, discoloration, knots, pits are very miniamlly permitted. Leading to a realively homogenous surface shown in figure 29. In constract to the timber construction of the 16 Eiken schuur of Hilberink Bosch Architecten, figure 30. Here, the uniqueness of the trees used is celebrated by leaving the odd shapes, piths, cracks and discoloration in plain sight (interview summary available in appendix A).

Fig. 29 Spruce CLT visual quality (Novatop, n.d.)

Fig. 30 16 Eiken schuur by HilberinkBosch Architecten (HilberinkBosch Architecten, 2018)

Emphasizing the locality of the wood: Showing the marks left by the iron from WWII grenades and the blue sheen resulting from the reaction of tannin acids from the tree with the iron.

USE - Alienation through processing

In his book *A Place of My Own,* Michael Pollan describes his journey of building his own cabin in his backyard. This process contains as much philosophical as physical labor. He describes the six meter long pieces of douglas fir for the construction that arrive to his house:

> *"A twenty-foot piece of clear Douglas fir is an impressive thing to behold. By virtue of its girth and length it seems more tree than lumber, though you can easily understand why lumber is what we prefer to call it. Lumber is an abstraction - a euphemism, really. Though these logs had been squared up and dressed at the mill, it was impossible not to be conscious of them as trees - and not to feel at least slightly abashed at what had been done to them on my account."* (Pollan, 1998, p. 133)

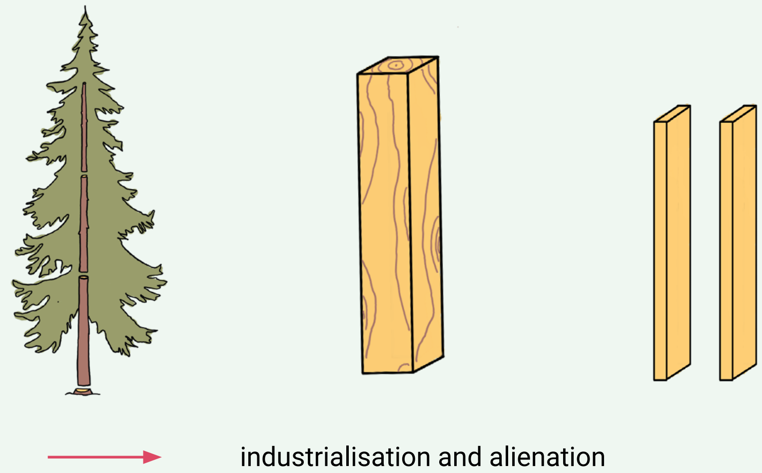


Fig. 31 From tree to timber

He then argues that would the timber have come in standard construction sizes of two by four centimeters, called dimension lumber, he would not have felt so sentimental. The dimension lumber represents yet another 'order of abstraction from the forest' requiring 'a more strenuous exercise of imagination to see the tree in the two by-fours.' (Pollan, 1998, p.134) Pictured in figure 31.

Just as much as the ultimately processed version of meat, shown in figure 32, resembles and respects the pig, CLT, the highly processed product of the timber industry can be said to resemble the tree. We set out to put the natural processes to our own use, but not the other way around. Leading to degenerative practices with little signs of reciprocity, where humans are far removed from other living species.

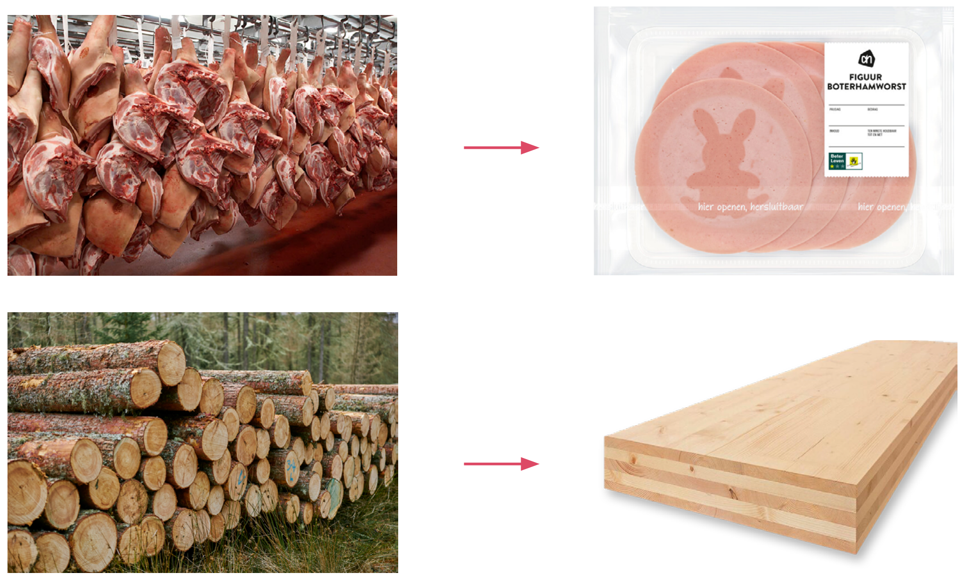


Fig. 32 Alienation through processing

DECONSTRUCTION - Reuse

In the climate agreement and the forest strategy the high-value use of wood is seen as a way to keep CO_2 stored in the timber chain as long as possible and to prevent the CO_2 emmisions of raw materials with a CO_2 intensive production and or with a fossil origin (Oldenburger et al., 2020a). When after years of use the building is no longer up to date, either due increased technical requirements or changed functional requirements the CLT home will be deconstructed. The CLT elements are usually connected using dry connections, such as the connector plates shown in figure 33.

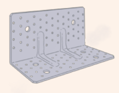


Fig. 33 CLT connector plate

Critescu et al. named the key criteria for succesfull deconstruction and reuse, the ones concerning CLT construction are:

use dry and accesible connections with realistic tolerances for repeated reuse
use lightweight materials
make components size manageable
design for a minimal number of different types of components
use prefabrication and mass production
use and open buildng system
aim for modular design
(2020).

The CLT elements are put together with dry connections which makes it possible to dissassemble them. If the connections are left accessible and if the CLT is not finished with plaster or sheeting for fireprotection or acoustics. With the CNC machine it is easy to customize the CLT panels. CLT panels have the openings for doors and windows and fittings for pipes and electricity already in them, making each panel possible unique. Meaning that after deconstruction, these elements could be used in exactly the same way, or would need to be recut to suit their next application. In terms of reuse, the least processed, or the least unique element is most suitable for reuse, see figure 34.

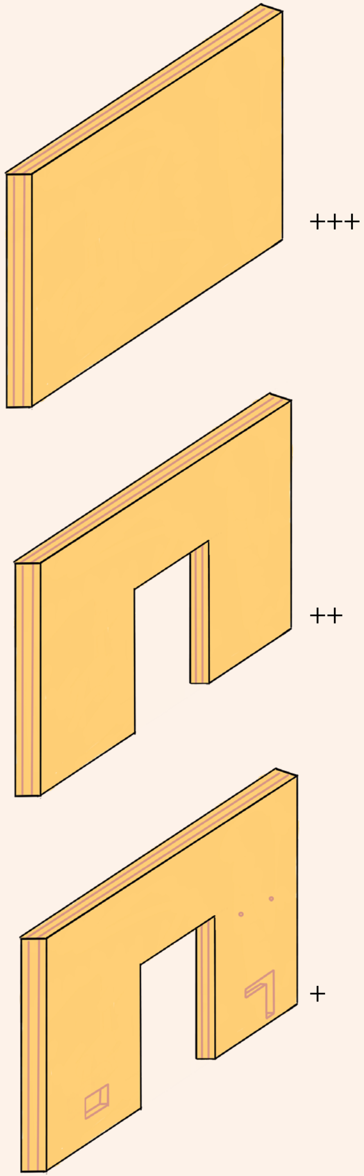


Fig. 34 Reusability of CLT panels

DECONSTRUCTION - Cascading

Resource-cascading is an interesting strategy to reduce the use of virgin resources. Fraanje defines resources cascading as 'the sequential exploitation of the full potential of a resource during its use and is one of the ways to improve efficiency of the raw materials use' (Fraanje, 1997, p.21). This is done through appropriate application, life time extension and quality conservation. (Fraanje) This strategy is also encouraged by Probos, who promote the high-quality use of timber in applications with the longest possible life span and the possibility of reusing the wood after this application for the same or new applications, so that carbon remains stored in the wood chain for as long as possible. Here timber preferably replaces products with a high negative CO_2 impact. The use of wood for energy applications is avoided for as long as possible (Oldenburger et al., 2020a).

Besides technical research needed to advance the cascading of building materials Fraanje argues that the following policy steps need to be taken in order to stimulate the cascading of resources: First, shifting the tax burden from labor to resources in order to encourage a more effective use of raw materials; secondly, allotting more responsibility to producers through regulations for post-consumer waste. Finally, initiating a digital wood bank where the available wood is showcased to prevent prevent unneccesary low quality application (Fraanje, 1997).

If not reused as a whole the CLT element can be cascaded for a new application. As pictured in figure 35, the undamaged parts of the CLT elements can be cut out and reglued to shape a new panel. This patchwork does require more glue and energy and will resemble an MDF board quite soon.

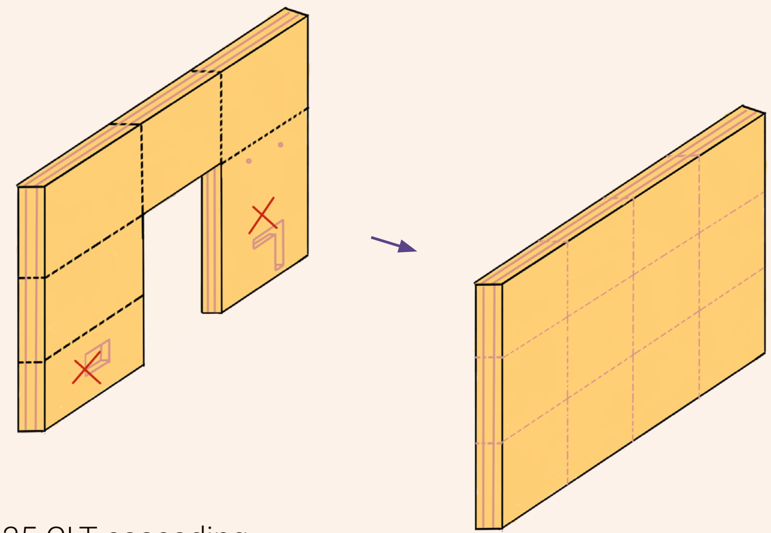


Fig. 35 CLT cascading

+ Alternative cascading for timber frame construction

END OF LIFE

As an architect you never know how long the building you work on will stay relevant. Due to changes in technical or programming wishes and requirements. Therefore, the scenario's at the end of life will have to be taken into account. According to Hafner et al., there are three end of life scenario's for timber constructions; (partial)reuse, incarcination with energy recovery, figure 36, and landfill (2014). CLT can not be composted due to the glue. The final disposal of the glue causes an additional emission of kg CO_2eq at the end of the life (Het Houtblad, 2021).

With the incarcination of the CLT the stored CO_2 is released into the atmosphere. This makes this the least favorable option. There is abundant research going on to make the glues bio-based. This would mean that the CLT could be composted and feed back into the soil where the new young spruce trees are on their way to become CLT in their grown up life.

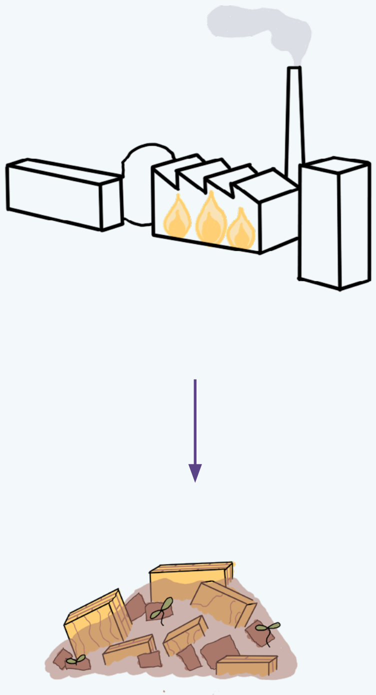


Fig. 36 From pollution to valuable input

DISCUSSION

The goal is not to search for the most efficient and optimized production process, we already have that in the making of cement, and it is depleting our earth. The goal is to make a truly regenerative system. Where the demand for timber promotes the afforestation of forests and the use of timber in housing reminds the user of their role in natural systems, and urges them to take responsibility for their actions. In this discussion the findings presented in the previous part of this report are critically examined, questioned, and used as a basis for recommendations for further research.

INPUT

Fig. 37 Suitable tree species

It was found that many more tree species besides spruce are suitable to be used for CLT construction, pictured in figure 37. Spruce is mostly used, for its properties and, at least so up til now, its dependable yield. Larch is suitable but slightly more expensive and more difficult to process. Pine and fir are more resinous, flammable and susceptible to blue mold. These are well suited to use on the inside layers of the CLT panels. The fast growing poplar could also be used for CLT production, however, more research is needed to test these other species for their structural properties and applications of the end products.

Laminated beech, oak, and birch constructions, all being hardwood species, would require less wood but take significantly longer to grow and require more production energy. In parts of the construction where small dimensions and high strength are needed this would be an appropriate application. A more varied demand of tree species will oppose monocultures and result in more resilient and climate proof production forests. However, the production process would be more labour intensive, less efficient and will result in a more variable yield. The current capitalist building economy is based on seemingly endless supplies of resources; any amount at any time. How the business model of the building sector can shift from conservative to adaptive is up for further multidisciplinary research.

forestry requirements

From the forestry this would require that even though the output will become more variable a certain degree of predictability is needed to allow the building sector to plan ahead and work with what is given. Ideally, the trees meant for high value applications should be selected early on in their life, trimmed at the right time to avoid the formation of knots on the trunk, and cleared from any interfering trees in its proximity to allow for a straight log.

PRODUCTION

The efficiency from log to sawn timber is about 40-60%. Material is lost going from tree to boards and from boards to CLT, because of strength grading but also because of visual grading. If more flaws where permitted in the surface of CLT more parts of the tree could be used.This would also result in the user becoming more aware of the natural life and uniqueness of the tree. The coninuation of testing and validating higher value applications of current by-products is needed.

At the moment there is no CLT production facility in the Netherlands. In Germany the forests are much larger resulting in a more dependable input and lower costs for production. There is no need for a Dutch facility except for highly specialised products, last-minute orders or exceptional dimenions that are difficult to transport. At least for now, the CLT could be manufactured in exisitng factories, resulting in a gradient of locality for the construction materials, pictured in figure 38. The bulk of the materials is grown and produced within a small radius, the more specialised the product needed in smaller quanities can be produced further away.

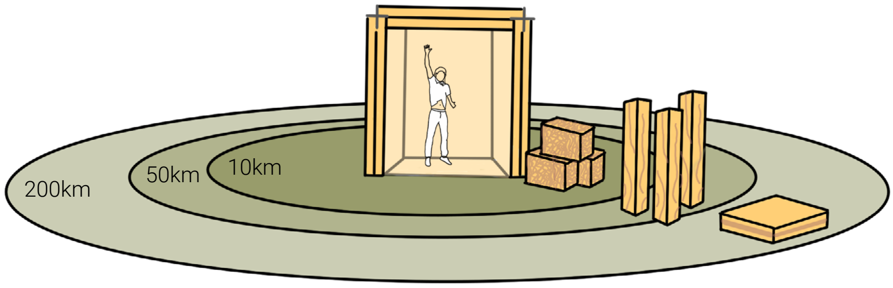


Fig. 38 Gradient of locality

CONSTRUCTION

Modular building is said to be the future; it is cheaper and faster than the concrete benchmark. Housing corporations could form their own material bank by using standard dimensions or modules. The span width obtained by using CLT is suitable for standard housing construction with an average span of 5 up to 7 meters. In social housing exentric shapes are avoided due to higher costs. However, there is an opportunity to search for a new architectural expression through the use of plant based building materials. Most social housing projects are low to midrise buildings. Here, it is sufficient to use CLT only in floor slabs and the structural core. The rest could be made of timber frames, saving material and energy. An open building system is desired to combine CLT, timber frame and even faster growing plantbased materials for insulation. This should be made to match the gradient of locality mentioned above.

USE

Because of the glue the CLT wall is not 100% vapour permeable. Eventhough the glue is not noticeable in smell, or in health related concerns so far, more research has to be done on the volatile organic compounds present. Insufficient literature was available at the time of writing this report on the maintenance of CLT. According to Sutton et al. CLT is said to have the same maintenance requirements as timber frame construction, but no further explanation or specification was found (2011). According to Younis & Dodoo the aspect of maintenance is not yet fully understood inspite of the growing number of life cycle assessment studies on mass timber constructions (2022).

DECONSTRUCTION

The ever changing demand of housing trends and housing corporations being known to be risc averse leads to a preference for demolition and new built. Additional research is needed on how to convince the financial and managerial side of the housing corporations to shift rom maximised profit for stakeholders now, towards durable investments in high quality housing in the future.

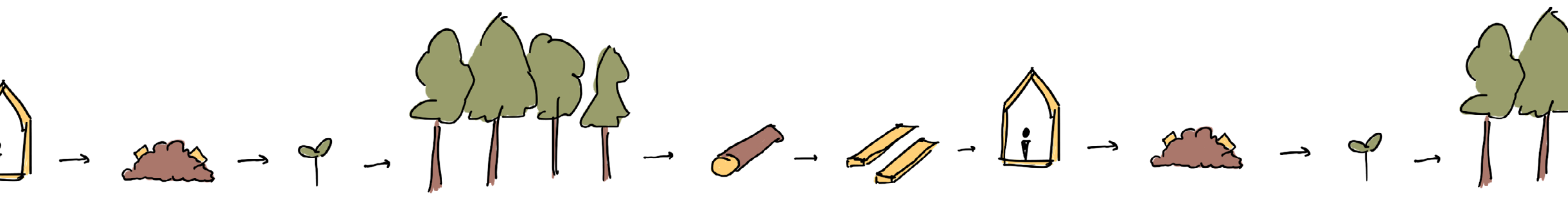
REFLECTION

In retrospect the topic and the research question of this research were extremely broad. Looking at an entire chain spanning decades inevatibily touches upon many more questions, conflicts, and wonderings than are possible to address within the time given. Additionally to the research topic, the research angle was also broad, spanning from technical, to ecological, to financial, to spatial to societal aspects of user experience. This report became a first inventory for a critical analysis of a production system and mindset towards this production system all at once. Taking this report as a starting point for further research, each chapter of the findings could be a full graduation research of its own. However, if given more time, the most important aspects to examine are the relationships between the different parameters. Only when we look at this interaction, how parameters influence, reinforce and also contradict each other, can we see the timber chain as the living system that it truly is. Finally, urging the architectural designer to make an informed decision on how to play their part in the natural systems they are inevitably a part of.

CONCLUSION

The starting point for this report was the problem that human beings currently see themselves as outside of the natural systems, leading to destruction and degeneration, and that careful reconsideration of the entire timber system is needed in order to make building with timber not just another way to exploit natural resources. This meant assessing the impacts throughout the entire service life of a spruce tree in a CLT construction. From tree, through the production, construction, use, and finally disposal of the material. Here, there is a focus on how CLT can help use realise we are part of a natural system of living beings. Through a literature study and interviews with forest and building experts and architects the research question of this report will be answered; *How can CLT construction contribute to the regenerative design of social housing in the Netherlands?*

To summarize the findings, many more tree species that suit the Dutch climate can be used in the production for CLT to opposse monocultural forests. Their growth rates ranging from 25-100 years and with a wide variety of properties such as workability and rot resistance. Almost twice as much timber is needed for a CLT construction compared to timber frame construciton. Low-rise appartments or houses are common in social housing and structurally do not require CLT elements except for a few stability cores. Most energy is needed for the drying and laminating of the timber and great savings can be made if fresh timber could be used in timber frame construction instead of CLT. Futhermore, CLT is highly processed and a far derivative of the original living tree. This alineation from the builidng material weakens the relationship with the natural world. In visual grade CLT all the marks of the life of the tree or the production process are removed. In solid timber frame the tree is more easily recognized. In conclusion; if produced correctly, and used only where necessary, CLT can be a part of a regenerative timber system, in support of timber frame structures for social housing in the Netherlands.



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