Feasibility of Cross-Laminated-Timber Production In The Netherlands

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Abstract. Cross-Laminated-Timber (CLT) is an environmentally friendly construction material which is suitable to replace concrete and steel in mid- and high-rise buildings. The global usage of CLT is expected to grow annually by 12.6% until 2027. Due to a housing shortage as well as the tightening environmental regulations an increased use of CLT seems likely in The Netherlands. Here we expect the number of wooden residential buildings to rise by around 20% every year until 2030. This could require an annual production of 250.000m^3 to 500.000m^3 of timber.

We conclude that it is feasible to add The Netherlands to the list of CLT producing countries. Setting up a factory including land and the building can cost anywhere from 14 to 40 million euros. On an annual basis such factory can produce between 20.000m^3 and 100.000m^3 of CLT for 400 to 2.000 apartments. To guarantee international price competitiveness a production capacity of at least 50.000m^3 seems to be needed, while a larger highly automated facility of nearly 100.000m^3 would better suit the Dutch context.

Because of the limited availability only a part of the required timber for a factory can realistically be of Dutch origin. Creating new Dutch production forests is not economically viable as the forest industry in the Netherlands is already barely profitable and the acquisition of land too expensive or time consuming. It could be beneficial to locate a factory in the vicinity of a Dutch production forest, however a logistically strategic position for importing timber seems more important.

Keywords: CLT, construction industry, environment, agroforestry, The Netherlands

1 Introduction

1.1 Background

Cross-laminated-timber (CLT) is best suited for mid- and high-rise buildings. Due to its in-plane strength and integrity they are good at making a building resist forces such as those of the wind (Sun, Li & He, 2020). Since it was first produced and utilized in the early 1990s in Austria, CLT has developed into a versatile, strong building material. This versatility is partly thanks to its attributes such as its environmental friendliness compared to mineral-based building materials like concrete and masonry (Chen et al., 2019).

In Europe, the use of mineral-based building materials like concrete and brick slowly replaced the traditional timber constructions used in the early 20th century. This development in the construction sector reached a point in the 1980's where timber as a construction material played only a small role. Since the 2000s, this development has reversed. Timber is quickly retaking a significant position in the market (Brandner et al., 2016).

The recent growth of CLT can be observed by comparing production capacity in the 2000s with 2020. In 2003 worldwide only one CLT producer could be found, producing 4.000m^3 per year (Crawford & Cadorel, 2017). In the year 2020, there are over seventy CLT producers supplying two million m^3 of CLT every year (Muszynski et al., 2020). This recent development is partly thanks to the commercial launch and following widespread use of CLT. The demand for CLT is projected to grow even further (Muszynski et al., 2020).

Cross-laminated-timber constitutes an engineered rectangular timber structure which is best suited for the use in high-rise buildings. CLT is a semi-rigid, plate-like product with an uneven number of layers made of boards placed side-to-side. These boards are placed in a crosswise manner with a 90-degree angle. Adhesives are used during this process. The leading adhesives used are melamine urea formaldehyde (MUF) and polyurethane (PUR). There are other less used options available such as phenol formaldehyde (Brandner, 2013).

The crosswise layering increases the rigidness of the final product. The number of layers chosen is one of the determining factors in the strength of the final CLT product. The cross-wise configuration of CLT distinguishes it from similar glued timber designs like laminated timber (glulam) and laminated veneer lumber (LVL), which have a simpler parallel structure. Another alternative are timber frame construction that use wood without glue layers. The cross-wise method used to make CLT is crucial to its ability to carry in- and out-of-plane loads. Glulam as well as LVL can be cheaper to produce

then CLT. These alternatives are chosen depending on the structural requirements of a building element (Brandner, 2013; Brandner et al., 2016).

The advantages of CLT can be summed up as follows (Brandner, 2013; Pierobon et al., 2019; Quesada et al., 2018):

- **Lightweight**, the strength to weight ratio of wood product is high the cross-wise configuration is amplifying this strength.
- **Ability to be prefabricated**, steps such as milling and sawing can already be done automatically in the factory as opposed to doing it by hand on the building site.
- **Lower environmental impact**, due to the relative low production emissions. If sequestered carbon starts playing a bigger role in regulations environmental benefits of CLT can be improved.
- **Ability to carry loads out of plane,** making CLT especially attractive to build floors with. In particular. floors of high-rise buildings.
- **Good thermal insulation properties** timber generally has quite good insulation properties (Sun, Li & He, 2020).

1.2 Adoption of wood & CLT products in the Netherlands

The Netherlands has a history in agroforestry. The majority of forests consists of coniferous trees which are a non-native species. Dutch forests are largely developed by human activity as opposed to being grown naturally (Schelhaas et al., 2022). The forest in The Netherlands do produce different kinds of wood that find their way into various industries.

The Dutch association for timber frame constructions (VHSB) indicates that there are about 1.500 wooden residential houses built in The Netherlands in 2020. With 25m^3 of wood per building this requires about 40.000m^3 of timber. The association projects the number of wooden houses built to increase with about 20% per year towards 10.000 in 2030. This would require 250.000m^3 of regular timber or 500.000m^3 of timber when everything would be built in CLT. The market for CLT is expected to grow with an estimated 12.6% per year until 2027 (IMARC Group, 2022).

The familiarity with mineral-based building materials and relatively lower prices when compared to CLT make these the go-to building material for the wider industry (Quesada et al., 2018). When comparing the construction of buildings with masonry and cement, CLT turns out to be about 10-15% more costly at this moment (Centre for the promotion of Imports, 2017). While the Netherlands currently does not have CLT factories there is one being developed by Boerboom. This factory is planned to go operational by 2024 and supply 70.000m^3 of CLT on an annual basis (Redactie Houtwereld, 2022; van Ommen, 2022).

Due to emerging laws and regulations in the Netherlands the environmental impact is priced into constructions. These rules on the environmental performance of buildings,

called Milieuprestatie Gebouwen (MPG), get stricter over time and are very likely to make biobased materials such as CLT the go-to option, especially for high rise buildings (Liao et al., 2017; Pei, Rammer, et al., 2016). The current Dutch MPG calculations for buildings built with CLT and wood have received criticism in the area of sequestered carbon (Keijzer et al., 2020).

Sequestration of carbon is currently not being taken into account in the environmental performance of buildings while they generally last, and thus store carbon, for a long time. Wood products even lend themselves well to circular reuse which extends the time horizon in which carbon is stored even further.

2 Objectives

The current paper focuses on exploring the feasibility of a CLT supply chain in The Netherlands. The following main- and sub-research questions will be answered throughout this paper. Answers to the sub-questions can be found in the Results section while the main questions 1 and 2 are reflected upon in the Conclusions & Discussion chapter.

Research questions:

1. Is it feasible to produce Cross Laminated Timber (CLT) in The Netherlands and what are the conditions to do so?

- What are the required investment and related production volumes of a CLT factory?
- What is the right size for a production facility to make economic sense in The Netherlands?
- How many houses/apartments can be created on an annual basis at a viable CLT production scale?
- What other topics are relevant for CLT production?

2. Is it feasible to supply a CLT factory with Dutch production wood?

- What are the conversion numbers going from the wood content of a hectare of standing trees in The Netherlands towards a CLT product?
- How much forested area is required to sustain the production of a common size CLT production plant?
- How much CLT can be produced with existing wood production in the Dutch Context?
- Can a CLT factory sustainably be run utilizing the existing forests in a province such as Zeeland? What are the alternatives?
- What other topics are relevant when it comes to sustaining CLT factories with Dutch agroforestry?

3 Methods

This paper came about by preliminary research followed by interviews. The preliminary research concentrated on papers and reports on current practices and challenges related to the supply chain of CLT products and the Dutch context. The Province of Zeeland in the Netherlands is the region that has been used for some of the calculations and examples. This province has already been active on the topic of biobased building for a while. They have stimulated building projects such as the Emergis Clinic in order to collectively learn about biobased and circular use of materials. Using a single province as an example is done in order to make the findings more applicable and because of existing relations with organizations in this region that the research group has.

Four semi-structured interviews were held with people with knowledge of different aspects of the CLT supply chain, from forest management, through manufacturing towards realization on the building site. Table 1 contains an overview of the interviewees. With these interviews we have collected first-hand experience from people in several roles, including a director, project management, production engineering, forestry expert & biobased consultancy. For a summary of the interviews in a Questions & Answers format appendix A can be consulted. The interview notes as well as this paper have been reviewed by the interviewees before publication.

Table 1. Interviewees and their details

NAME INTERVIEWEE	ORGANIZATION	ROLE	POSITION IN SUPPLYCHAIN
Artjan van Kooten	**VKP Kapelle**	General Director	Producer & Project Developer
Ingo Möck	**Ledinek**	Managing Director	Timber processing engineering
Izhar van Eenennaam	**Jeras**	Project leader	Construction Project Developer
Fred van der Burgh	**Agrodome**	Biobased consultant & Forestry expert	Advisor/Expert

This paper's content has been presented at the 5th International Conference on Bio-Based Building Materials - ICBBM 2023. As part of the application process to the conference the extended abstract has been peer reviewed and the feedback from the audience has been used to improve this paper.

4 Results

In this chapter you will find the results of desk research and the interviews that were held. Answers will be provided for the research questions that can be found in the Methods section. Firstly, we will dive into the feasibility of a CLT production factory in the Netherlands followed by the feasibility of agroforestry for wood production in the Dutch context. This order has been chosen to allow us to use data from the first chapter in the second one.

4.1 Feasibility of CLT production in The Netherlands

To get a better understanding for the required investment and related production volumes and interviews was held with Ingo Möck. He is the Managing Director of Ledinek. He indicated that a factory can cost anywhere from 14 to 40 million euros to build. About half of this amount is being used for the machines and the other half being the acquisition of necessary land including the building in which the manufacturing line is built. An efficient factory operates for as many hours a day as possible in order to make optimal use of the invested capital (Brandner, 2013; I. Möck, personal communication, June 16, 2022, see Appendix A).

A common output range for a factory is 20.000m^3 to 100.000m^3 of CLT per year. A CLT factory typically requires between three and twenty operators. The investment and number of operators vary with the scale and the level of automation of the factory. (Brandner, 2013; Brandt et al., 2019; I. Möck, personal communication, June 16, 2022, see Appendix A). As labor is expensive in the Netherlands, a CLT factory is more likely to be in the large size, highly automated and forty-million-euro range of factories.

In order to get a sense of the right production scale for a production facility in the Dutch context we looked at a graduation report which studied the demand for CLT in the Province of South-Holland. Assuming 20% of the housing demand being satisfied using CLT, this is estimated to be 120.000m^3. In addition to that, this report states that a production capacity of at least 50.000m^3 is needed to be internationally competitive (Mulder, 2021). This is verified by the data in Figure 1. The CLT price flattens with an increase in production volume. At around 50.000m^3 per year the line flattens. Price advantages due to scale however remain for large-scale production facilities. The figure also tells us that it is important to have a factory work at its full capacity, meaning 24/7 in order to produce at a good price point (Brandt et al., 2019). Since some costs such as labor and the depreciation of land are likely to be higher in The Netherlands a production facility with a maximum capacity of 50.000m^3 or more is recommended.

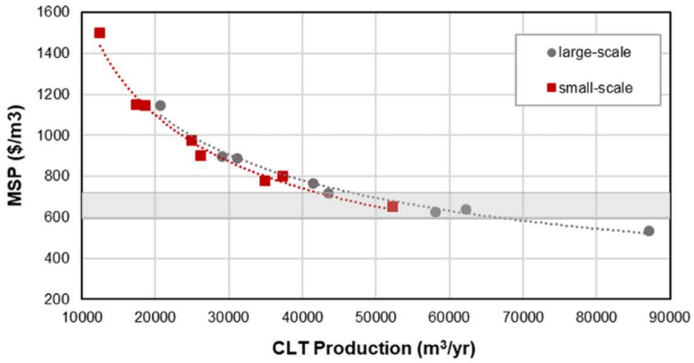

Fig. 1. CLT selling price with varying CLT factory production capacities based on data from 2015. The grey area shows values of CLT prices ($600 to 742/m^3) from literature (Brandt et al., 2019).

A Dutch high-rise building in The Netherlands called HAUT consists of 52 apartments and is built with 2.800m^3 of timber. This results in a need of approximately 54m^3 of wood per apartment (Wind, 2022). Another building has been built containing 23 apartments with 1.000m^3 of wood resulting in 43,5m^3 per apartment (Lend Lease, 2013). These apartments were not completely built in CLT but also with other timber products. It still gives a good proxy for the number of houses that can be built with production volumes of 20.000m^3 to 100.000m^3 CLT per year. When these production quantities are divided by 50m^3, which seems to be a good ballpark figure, it results in a total of 400 to 2.000 apartments annually. As discussed before a factory in the Dutch context is most likely to be able to produce nearly 2.000 apartments per year.

4.2 Other relevant topics for a CLT factory

In the desk research we have stumbled upon concerns related to the ability of CLT to resist fire. Testing has shown that the CLT reaches similar fire resistance levels as concrete due to a process called charring (Crielaard et al., 2019; Frangi et al., 2009). We have seen this aspect reappearing in multiple case studies in prior research of the author as well. It seems to be researched multiple times independently (Koster, et al., 2020).

Several relevant topics were flagged by a project manager of a project development organization in an interview. With his organization they have recently been building with CLT products from Austria and thus experienced its use in practice. He indicates that they looked into alternatives to glues in the form of screws and dowels but that this wasn't an option since the CLT was used in a mental care context where visual distractions should be limited. Finishing was mentioned as another aspect where there was differentiation in price and classes of CLT. Downsides of the use of CLT when compared to other (timber) construction materials are the higher price, moisture susceptibility; especially when combined with biobased insulation materials, as well as the

relative difficulty to obtain CLT at short notice (I. van Eennennaam, personal communication, April 19, 2022, see Appendix A).

The use of glue and the decision for the glue type is an important aspect of a CLT factory design. In an interview Ingo Möck, of a wood-processing engineering company called Ledinek (see appendix A) mentioned that they use a glue called PUR in their factories. It allows for fast pressing without the requirement of external heat (extra energy) and is easier to work with for construction workers and producers. In terms of strength characteristics, it is similar to MUF. Shorter curing time helps for a more efficient production process (I. Möck, personal communication, June 16, 2022, see Appendix A).

4.3 Sustaining a CLT factory with wood of a Dutch origin

To explore the feasibility of production forests in the Netherlands the timber production potential of existing forests has been investigated. In this chapter we look at the size of the forest required to supply a CLT factory year-round. For this we take the outputs of 20.000m^3 to 100.000m^3 of CLT per year which has been investigated in the previous chapter. Next to this we look at the sufficiency of the existing lumber market. Next to this we look at other potential feasibility factors standing in the way of the realization of a self-sustaining CLT factory in The Netherlands and The Province of Zeeland specifically.

In order to produce CLT several production steps need to be taken which have losses of wood volume associated with them. Getting trees from their total volume towards sawn lumber has an efficiency of about 37%. A large portion of the tree such as the twigs, as well as crooked or small stems cannot be used (Kerbes & McIntosh, 1969). Going from sawn lumber towards CLT also has losses associated with it. The wood has to be made into the proper size by cutting and finger jointing. With a loss of approximately 15% the efficiency of this step is 85% (Brandt et al., 2019). In order to convert the tree-volume-requirement towards forested area we use a conversion factor of 4,4m^3 of lumber per hectare. This is based on sustainable forestry practices in which only as much as the regrowth rate of the forest is cut (Eugen & Cojinovschi, 2014).

The exact figures for tree growth are very context dependent and determined by aspects such as the forest type, soil quality, management regimes and harvesting method being used (Schelhaas et al., 2022), In this study we therefore take a ballpark estimate in order to be able to relate the potential size of a production forest required for a CLT factory. In the following table (table 2) you can find the estimation of forest requirements for the small and large size factories calculated step by step:

Table 2. Estimations for forest requirements

ANNUAL REQUIREMENTS	SMALL CLT FACTORY	LARGE CLT FACTORY	CONVERSION FACTOR
CLT production volume	20.000 m^3	100.000 m^3	N.a.
Sawn lumber inputs	23.500 m^3	120.000 m^3	+- 85% conversion efficiency
Tree volume	63.500 m^3	320.000 m^3	+- 37% conversion efficiency
Required forested area	14.500 Ha	72.500 Ha	4,4 m^3 annual regrowth per hectare

The approximately 950.000m^3 of industrial roundwood being produced from Dutch forest has been relatively stable over the last ten years (Teeuwen, et al. 2020). The most popular lumber for the production of CLT is spruce, but other types like fir, douglas and larch are also used. (Centre for the promotion of Imports, 2017). A total of 690.000m^3 of pine, douglas, spruce and larch wood were produced in the Netherlands in 2014. Of the most popular CLT wood, spruce only 76.000m^3 was produced. On average, 46% of the wood is sawn/veneer wood and thus useable for CLT production (Probos, 2014). This results in a total of approximately 317.500m^3 wood being available for the industrial production of CLT of which 35.000m^3 being spruce. A single large factory needs 120,000m^3. It is thus physically possible to supply a factory with Dutch grown wood, however one third is a significant portion of the total and the amount of spruce available is too limited. Therefor it is unlikely for a CLT factory to be fully supplied with Dutch grown wood which is suitable for CLT production.

4.4 Potential for newly created production forests

For reference we look at the possibility for a CLT factory in a province such as Zeeland. The forested area of the Province of Zeeland is 4.100ha (BoschSlabbers Landschapsarchitecten, 2020), which by itself is not enough to sustain a small production facility. It will also be very difficult to harvest wood with the right dimension in the Province of Zeeland due to the strong salty winds and salty groundwater conditions (F. van der Burgh, personal communication, June 19, 2022, see Appendix A).

The next possibility would be to plant forests on existing (farm)land. The available agricultural lands are 118.000ha with 85.000ha being used for crop farming (Provincie Zeeland, 2021). A small factory would require an area of about one sixth of the agricultural land used for crop farming for a province such as Zeeland. A big factory, which is more likely in the Dutch context as discussed in the previous chapter, requires almost all of the crop farming land. With an average of about 2% of agricultural land changing hands each year (Kadaster, 2022) it will be nearly impossible to gather this land in a manageable timeframe. In the following section we will get into the economic consequences of such an effort.

4.5 Other relevant topics for agroforestry in the Netherlands

Managers and owners of production forests in The Netherlands are currently holding back at cutting trees for wood production, as it is unprofitable. This phenomenon is explained in detail in a WUR report on the state of production forests in the Netherlands (Schelhaas et al., 2022). As an example we pick a forest such as Westen-Schouwen in The Province of Zeeland. This is a forest of 300 to 400 hectares with wood that is suitable for CLT. This forest is amongst the top 200 biggest forests in the Netherlands, which counts a total of approximately twenty two thousand forests (Dirkse, et al., 2007). In such a forest it is economically unviable because it would mean underloaded trucks and teams of fellers who cannot work full time shifts.

Lumber production is most efficient when scaled up. For example, in Austria and the Czech Republic, larger groups of fellers work for years on end in the same forest, cutting down forests and completely filling up ships or trucks with timber. In this manner, lumber production is more efficient and profitable (Herbohn & Wall, 2006). The forest expert Fred van der Burgh, who has been interviewed (see appendix A), states that he thinks newly planted Dutch production forests of any sort are economically unfeasible. There is simply too little land with enough scale available.

Another challenge that needs to be considered is the value of land in the Netherlands. Agricultural land is worth around €78.500 per hectare. The highest prices of agricultural land can be found in the Province of Zeeland (€78.500) as well as Flevoland (€134.200) (Kadaster, 2022). The agricultural land value stands in stark contrast with the value of forested land which is worth about €10.000 per hectare (According to forest expert Fred van der Burgh, as mentioned in Appendix A). The consequence of the difference in value is that a significant loss of value is made if agricultural land is converted into forests. A potential buyer can already lose millions or even billions of euros without easy way back since the forested areas cannot easily be converted into agricultural land again (Schelhaas et al., 2022).

5 Conclusions and discussion

This paper came about by desk research as well as four semi-structured interviews with people that have knowledge of different aspects of the CLT supply chain, from forest management, through manufacturing towards realization on the building site. Their views as well as what has been learned in desk research led us to the conclusions of this paper.

When compared to other materials the advantages of CLT are its lightweight, ability to be prefabricated, relative low environmental impact, insulation characteristics and the ability to carry loads out of plane which is especially useful for mid- to high-rise buildings. At the moment of writing there is no CLT factory in the Netherlands while CLT is already being used in the construction industry. There is one Dutch factory

planned to be operational by 2024 with an annual production volume of 70.000m^3 of CLT (Redactie Houtwereld, 2022).

Currently there are about 1.500 wooden residential houses built. This is expected to raise by 20% per year to 10.000 in 2030. This number of buildings would require an annual production of 250.000m^3 to 500.000m^3 of wood for residentials buildings. Worldwide CLT usage is projected to grow with about 12.6% per year until 2027 (IMARC Group, 2022) . This growth might be higher in the Dutch context. At this stage the prices of CLT for high-rise buildings is about 10% to 15% higher than conventional building methods (Centre for the promotion of Imports, 2017). Production scale could bring down the price of CLT while Dutch regulations such as Milieuprestatie Gebouwen (MPG) are likely to make materials with a low environmental impact such as CLT more attractive.

This brings us to the main question of the paper, is it feasible to produce Cross Laminated Timber (CLT) in The Netherlands and what are the conditions to do so? Based on desk research and interviews we can conclude that it is feasible to set up a factory for the production of CLT in the Dutch context. With a growing demand of wooden buildings as well as CLT in the construction industry and a lack of other major bottlenecks it seems feasible.

A factory can cost anywhere from 14 to 40 million euros. This includes the acquisition of land, the building and the production line. Such factory can produce between 20.000m^3 and 100.000m^3 of CLT per year. Which is enough to build 400 to 2.000 apartments on an annual basis. A production capacity of at least 50.000m^3 seems to be needed to be internationally competitive. With relative high labor and land acquisition costs in the Netherlands, a CLT factory is more likely to move to the large size, highly automated 100.000m^3 of CLT production side of the range.

The feasibility of supplying a CLT factory with Dutch production wood seems less feasible. It is more likely for a CLT factory in The Netherlands to acquire part of their wood from the Dutch market. There is about three times the amount of Dutch grown wood available for supplying a large factory. However, there is not enough spruce which is the preferred material for CLT. Wood is also used in many other places in the construction sector. Therefor it is unlikely for a CLT factory to be fully supplied with suitable Dutch grown wood. It could be beneficial to locate a factory in the vicinity of a Dutch production forest producing suitable timber, however a logistically strategic position that limits transportation costs of imported timber seems more preferable.

Wood production is not very likely to grow substantially in The Netherlands over the coming years. Managers and owners of production forests are holding back at cutting trees as it is unprofitable in many cases. Growing new forests also doesn't seem to be a viable option. The required forest size to supply a CLT factory range from about 15.000 to 75.000 Hectares. We projected that in the context of the Province of Zeeland a large factory, requires almost all of the available crop farming land to be converted to

forests. With an average of about 2% of agricultural land changing hands each year (Kadaster, 2022) it will be nearly impossible to gather this land in a manageable timeframe. Another challenge in doing so is the depreciation of the value of land when converting it to forests. Its value would drop from €78.500 (agricultural land) per hectare to about €10.000 per hectare (forested land).

6 Discussion

For the building industry it could be valuable to appreciate the sequestration of carbon to biobased materials. This sequestration is currently not being taken into account while buildings generally last, and thus store carbon, for a long time.

While the Milieuprestatie Gebouwen (MPG) is one way in which governments can have an influence on the material selection, another way could be policies favoring biobased materials, the government using their own purchasing as well as the use of subsidies. These measures can help people to favor biobased materials such as CLT over mineral building materials. To stimulate the specific use of CLT it can be worthwhile to focus these efforts specifically on mid- and high-rise buildings because that is where CLT can most be found.

The manufacturing process is prone to change in the following decades as new technologies for CLT production as well as applications are developed. In our research we stumbled upon technologies such as reinforced CLT that could gain traction. The benefit of reinforced CLT could be a more limited floor area needed for beams as well as the possibility to build even taller high-rise buildings.

Even though CLT forms an environmentally friendly alternative to building materials such as concrete it is not completely biobased. One of the interviewees was looking for more circular alternatives. CLT performs relatively well when it comes to biobased content, the relative glue-content is limited. Still, it can be relevant if biobased or even biodegradable glues and/or resins for CLT applications are developed. Even tough timber is relatively easy to reuse, the end-of-life scenarios for the material could potentially be improved with alternatives to fossil based glues.

It would be helpful if knowledge of CLT material is more readily available for building parties. Aspects such as fire safety are tested in different projects individually. There might be a role for insurers to play to spread fire safety information and use the latest knowledge on the topic.

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Appendix A

Several semi-structured interviews were held to get more information about the current state of CLT in general and forests in the Netherlands and the Dutch Province of Zeeland in particular. The interviews were a crucial part to get to information that is not available by desk research. In this appendix you find a summary of the interviews in Question & Answer format. These notes have been checked by the interviewees.

The four interviews held were important to the content of this paper. Interviewee inputs were used in the report as sources and can be found beneath. In Table 1 you can find an overview of the interviewees.

Interview 1; Artjan van Kooten
April 11th 2022
VKP Kapelle is an organization searching for ways to produce CLT. They helped us get an understanding of the type of organizations that are making the consideration to start producing CLT in the Dutch context. They provided valuable insights in their considerations.

The interview was held in face-to-face in combination with a site visit. The interviewee was the CEO of VKP: Artjan van Kooten. The questions and answers can be found below in the following table (Table 3).

Table 3. Questions and answers of the interview with Artjan van Kooten

Questions	Answers
What do you mean by reinforced CLT?	A material where part of the material is CLT. There are composites where CLT itself is combined with other materials, but that is not the same as a layer of concrete on top of CLT. The latter is meant with reinforced CLT.
Would you want to start a factory, and how large?	Yes, a small CLT factory to supply CLT for VKP's own projects.
Is Clt used often in your projects?	No, Houtskeletbouw is more affordable and does the job well enough for residential buildings. However, CLT is sometimes used for floor panels and buildings with multiple floors.
Why would you want to produce wood locally?	So the production of CLT is nicely circular and local. It seems a lot of wood is lost to make snippets of timber or other waste materials when it could be used for CLT.

Interview 2: Ingo Möck

June 16th 2022

Ledinek is a timber processing company. They design and install CLT factories and production lines as well. They were a good candidate to interview because of their up-to-date experience with CLT processing and manufacturing lines. We spoke to Ingo Möck over the phone. The notes of the interview can be found in table 4 below.

Table 4. Questions and answers of the interview with Ingo Möck

Questions	Answers
How much does a clt factory cost?	It costs 14-40 million euros to build a manufacturing line along with the building. The more automated such a CLT factory is, the more expensive it is. I cannot say more about the price, and none of the CLT factories will tell you the price since it is highly confidential.
What adhesive is best? Which one do you use in your factories?	In all of our new factories, we use PUR because it allows for faster pressing and easier handling for customers. It has the same strength characteristics as MUF.
Do many CLT factories import wood from the DACH region/Italy/Finland/Sweden?	Yes, almost all of them. The Czech Republic is a popular country as well. I know of CLT factories in France and Japan that have their own forests available for use in their CLT factories.
Is there a market for semi-manufactures?	Not really. Most of the CLT factories produce a finished and tailored end-product with sizing and various finishes from raw wood or sawn lumber. There is a very small market for raw CLT panels.
What are the manufacturing steps for CLT?	You can find them on our website. More specific information is confidential.
How many employees would a CLT factory require and why?	A CLT factory within would require from 3-20 operators. This depends on the level of automation in the factory. Less automation means a cheaper initial investment for the factory but more operational costs. An efficient factory operates for as many hours a day as possible and as much CLT production as possible.

Interview 3: Izhar van Eenennaam

April 19th, 2022

Izhar was interviewed via e-mail. He is a project manager at Jeras, a company responsible for the construction of multiple buildings in the region of Zeeland, including buildings constructed using CLT. He responded with detailed answers to my questions. Table 5 shows the interview which has been translated from Dutch to English.

Table 5. Questions and answers of the interview with Izhar van Eenennaam

Questions	Answers
Where from do you order or receive CLT? Where is it produced?	Pfeifer CLT Brettsperrholz, PEFC certificate (Prgramme for the Endorsement of Forest Certification Schemes). On Pfeifer's website, I see that they source timber from four forest locations (Kundl, Unterbernbach, Lauterbach, Uelzen). Pfeifer further has factories in Austria, Germany and the Czech Republic for the various products they supply.
Are there different types of CLT?	Herewith a link to the different types of CLT at Pfeifer (see also tabs 'technische daten', 'standardaufbauten', and 'oberflächenqualitäten': https://www.pfeifergroup.com/de/produkte/holzbau/clt-brettsperrholz/kenndaten/ There may be other types at other suppliers. In terms of wood types, I don't know if there are any alternatives. Another alternative to glued CLT is CLT held together by dowels / wooden screws. Here no / less glue is used. The disadvantage (at least for the Emergis project) is that it looks visually less natural and can also cause a 'busy' appearance. This is not suitable for Emergis clients).
What are the advantages and disadvantages of CLT and working with CLT?	There are differences between the finishing class of the CLT. If you choose a higher finishing class, you can apply it untreated, but it is of course more expensive. For this specific project, the advantages of CLT are as follows: 100% biobased core in the main structure of the building, element consists of one raw material and a minimal amount of glue (about 0.6% of total), this makes the structure less complex. CLT is very strong and stable (also possible for high-rise buildings), in construction for Emergis no extra braces or (wind) bracing are needed and yet the construction remains flexible/modular to move. CLT elements have sufficient thickness and therefore sufficient fire resistance. Due to solid structure > more mass compared to HSB elements and therefore better sound insulation. If the CLT as a material is 'tarnished' as little as possible during construction (read: as little processing as possible, such as cutting, milling, painting, etc.), it can be easily reused at a later stage for other purposes. This benefits the circular life cycle. CLT is particularly convenient to use in prefabricated constructions (it is often made to measure and delivered) and this in turn ensures short construction times and enables easy assembly. Disadvantages: compared to HSB elements/systems, CLT is more expensive and heavier. Compared to concrete, for example, CLT is again more susceptible to problems with moisture. The combination with other biobased (insulation) materials can therefore be extra challenging. The challenge/disadvantage we encountered during the project is that CLT is fairly difficult to obtain, especially when

	material has to be available at short notice. This is not really a disadvantage, but more of a challenge.
Is there such a thing as reinforced CLT?	I think through Pfeifer's site you can read up on different strength classes depending on thickness and possibly different standards.
Is the CLT made using finger joints?	As far as I know, the transport is done by trains or trucks. It is often imported from Austria and Germany.
What adhesive was used in the CLT?	Adhesive conforming to 301 or EN15425 (Polyurethan (PU) Klebstoff (formaldehydfrei) für Keilzinkung und Flächenbeleimung).
What is the cost of one CLT-panel?	This is difficult to deduce back to 1 panel, as it strongly depends on thickness, finish class and required operations (e.g. cut-outs).

Interview 4: Fred van der Burgh

June 19th, 2022

Fred van der Burgh is an expert on forests in the Netherlands as well as consultant on Biobased Materials and Life Cycle Analysis. We interviewed him over the phone. The interview notes can be found in table 6 below.

Table 6. Questions and answers of the interview with Fred van der Burgh

Questions	Answers
Would a forest for CLT be feasible?	In the Netherlands, where forests are positioned on poor soil I don't think so. I don't think any sort of new production forest is economically feasible. There is no more space in the Netherlands for new forests, so you would have to buy agricultural land and convert it, which would cost millions. There is also no place in Zeeland where large-scale forestry can take place, making the process less efficient and thus more expensive. It will also be very difficult to harvest wood with the right dimension, in any case in Zeeland with strong salty winds and salty groundwater conditions. I recommend importing wood for CLT as other CLT factories do. Forested land has also a relatively low value of about €10.000 per hectare.
What are the environmental effects of replacing mineral building materials with CLT, and what does it depend on?	CLT has the potential to capture carbon. It is not true that CLT is completely sustainable as it is hard to recycle, and the adhesives are often not environmentally friendly. Re-use of CLT is another option which could extend the carbon capture. Developments are also made to produce more environmentally friendly adhesives.
How long does CLT last?	I don't know. I know that the first buildings with CLT are not that old. I know of solid wood, which can last for hundreds of years.
How is CLT transported?	As far as I know, the transport is done by trains or trucks. It is often imported from Austria and Germany.
Is there such a thing as "good" and "bad" wood when it comes to sustainability?	Not really, all wood takes up carbon from the atmosphere. Production forests are, however, more effective in this carbon capture as they are cut down as soon as possible so new trees can grow in their place. More CLT means more carbon captured in the wood.