World Conference on
Timber Engineering
Oslo 2023

ECONOMIC COMPARISON OF MASS TIMBER AND CONCRETE CONSTRUCTION IN THE NORDIC REGION

Julie Swartz Andersen[1], Yutaka Goto[2], Michael Englund[3], Henning Johansen[4], Ketil Armann Hansen[5], Alexander Hollberg[6], Daniela Grotenfelt[7]

ABSTRACT: The timber sector has been growing strongly in various regions of the world. Yet, the construction industry is still far from being sustainable. One barrier is the economic concern in planning and construction works of timber constructions. This study aims to provide insights on the cost performance of Cross Laminated Timber (CLT) constructions for stakeholders to make an informed decision. It analysed the production cost of multi-story residential buildings with CLT in comparison to concrete in Norway and Sweden. The production cost data of various construction projects with either CLT or concrete was collected and analysed. Interviews with stakeholders were conducted to complement the interpretation of the cost data. The result showed that each project had its individual conditions in the economic background and requirements by client, and thus it was difficult to formulate a general tendency on the cost performance. The variability of the cost was larger and the average production cost was higher in CLT cases. Yet, there are high incentives of contractors and clients for a more sustainable alternative in general. The incentive is also reinforced by the general experience of contractors that the construction cost is better optimized as the contractor gains more experiences.

KEYWORDS: Construction cost, LCC, mass timber, CLT, Nordic region, residential building, comparison to concrete

1 INTRODUCTION

1.1 Background

The construction sector is the source for approximately 37% of the global greenhouse gas emissions [1]. When considering the application of technologies with greenhouse gas (GHG) emission reduction potentials, one must consider its economic aspect as well in order to practically succeed in reducing the GHG emissions. In the practices of construction projects in the current market, decisions are very often made based on the priority on the economic performance among all viable technical alternatives. This is because construction projects must satisfy numbers of legislative requirements for safety, comfort, energy efficiency, etc., and this incurs already a large cost in general even in the case of solution with the lowest possible cost.

In fact, there is an increasing number of applications of more costly solutions with a higher initial investment in the construction industry. This is especially the case when those technologies directly concern the energy efficiency of the buildings, such as thicker insulation, heat exchanger, better-insulating window, etc. This trend is driven by both environmental and economic views. While the solution may be more environmentally, the saving of energy over a certain period can compensate the higher initial investment. This payback time analysis is key to promote those energy efficiency measure in many cases. However, in the case of embodied carbon emissions of construction materials, there is no tangible payback time for different levels of investment unless some substantial carbon tax rules would be introduced in the market. The current market situation does not economically favour a less carbon intensive material unless it is less costly than other common materials.

In order to reduce the climate impact of the industry, the use of timber is seen to be an efficient alternative to conventional materials [2]. The Nordic construction market has seen a major development of the timber construction sector in the past decades especially in Norway, Sweden and Finland. The major drivers of this significant growth are; (1) there are large areas of productive forest and thus there are sufficient resources for the local market, (2) there are well-experienced wood-processing and timber construction companies since timber construction has been very common for smaller buildings, and (3) there is the growing consciousness of environmental sustainability and timber is seen as a more favourable option for its carbon neutrality, renewability and circularity. This advancement of the timber

[1] Julie Hansted Andersen, Arkitema, Denmark, juhan@arkitema.com
[2] Yutaka Goto, Chalmers University of Technology, Sweden, yutaka@chalmers.se
[3] Michael Englund, Arkitema, Sweden, MIED@arkitema.com
[4] Henning Johansen, COWI, Norway, HJOH@cowi.com
[5] Ketil Armann Hansen, COWI, Norway, KEHE@cowi.com
[6] Alexander Hollberg, Chalmers University of Technology, Sweden, alexander.hollberg@chalmers.se
[7] Daniela Grotenfelt, Arkitema, Sweden, dagro@arkitema.com

https://doi.org/10.52202/069179-0568

construction industry is primarily supported by research and developments in structural and fire safety technologies. Among various technologies, cross laminated timber (CLT) has been a major contributor of the expansion of the technical possibilities especially in structural capacity [3].

Yet, the construction industry is still far from being sustainable in terms of the use of renewable resources among other sustainability concerns. Although there have been innovative solutions for CLT constructions to overcome technical challenges in structure, moisture, fire and acoustics, the economic aspect is still a barrier for the further expansion of the timber industry is the economic uncertainty. There is a common concern that timber structures tend to become more costly in planning and construction works compared to other alternatives such as concrete structures.

1.2 Objective and limitation

This study aimed to analyse construction cost of timber buildings and to discuss the advantages, disadvantages and potential of cost optimization in comparison to concrete alternatives. The objectives of the study were (1) a systemic literature review on the construction cost of timber structures, (2) the quantitative data collection and comparison of production cost of various residential construction projects in CLT and concrete in Norway and Sweden, (3) qualitative data collection on the view of stakeholders on the production cost of CLT/concrete constructions, and (4) analysis of the cost structure in order to highlight the economic advantages and disadvantages of CLT structure.

The investigation was limited to the cost of the design and construction stage (A1-A5 module, according to [4]) until the project is handed over to the occupants. Only the actual construction cost was investigated, and the sales price and other sales- associated factors of the apartments is not included. The rest of the life cycle was disregarded in this study. [5, 6] show that if a timber construction is fully protected against weather, the lifespan of the construction will be the same as for a conventional concrete construction. Thus, it was assumed that the maintenance cost for the load bearing frame was zero in both CLT and concrete cases during a calculation period of 50 years. The operational cost for heating etc., was assumed to be the same between CLT and concrete cases with the same energy performance and appliances installations. The demolition phase was excluded as CLT constructions are still new in the market and there is little practical experience in the demolition of CLT apartments.

2 Methodology

2.1 Literature study

The aim of the literature study was to investigate the state-of-the-art research of the cost of timber projects. By examining previous studies about the topic, their results can serve as reference for the results of present study's case study analyses and interviews. As a literature study uses second- hand data and case studies deliver first-hand data, the study opens for a wider perspective of results for the study.

2.2 Construction cost of case studies

A case study represents the actual problems and benefits which might occur during the design stage and construction stage of a project. By using case study as first-hand data it enables to examine the data more deeply in a specific context, which is for multi-story residential buildings in the Nordic countries for this study. This specifies the results of the study to actors in the construction industry in the Nordic countries and creates a more detailed insight into the subject of interest for these actors.

However, case study research has its limitations. The results based on a case study are only as good as the data is and the method is as well criticized for generalizing results based on limited number of cases. Yet, case study is useful to explain a process and the result of the studied subject by using both the quantitative and qualitative data for real-life projects. Hence, case study is chosen as the primary method for this study. These case studies are examined during qualitative interviews and quantitative data analyses.

Before choosing the case buildings and collecting data, limitations were set in order to obtain data with sufficient quality and comparability.

The types of case studies were limited to multi-story residential buildings constructed in CLT and conventional concrete and steel in Sweden and Norway. The building should have at least three stories in some parts of the building and a maximum of eight stories. For the timber building the primary loadbearing system should be constructed in CLT. Furthermore, it was prioritized to use case buildings which were built by contractors who have built such types of buildings before. This was for minimizing additional cost as a result of developing new construction methods and larger beginner mistakes. It was identified in previous studies that cost might increase when the contractor is doing a CLT project for the first time [7, 8].

All contractors and building owners who responded to the request for the data collection were asked to provide the construction data in the same cost group structure to ensure comparability. The construction cost data was collected in accordance with the cost structure model in the Norwegian Standard (NS) 3451 "Bygningsdelstabell (Building component table)" [9]. Table 1 shows the structure of the cost items and how the data was delivered. If the contractors or building owners were not able to deliver the cost data according to the standard, they were asked to deliver the total cost sum of the project. It was decided to include these projects with limited level of detail in order to increase the amount of case buildings. However, these projects were excluded from the comparison of each cost group and only used for comparison of the total cost.

https://doi.org/10.52202/069179-0568

Table 1: *Cost group structure according to NS 3451*

Cost elements		Cost
01	Common costs	
02	Building	
03	Plumbing andHVAC installations	
04	El-instrations	
05	IT and automation	
06	Other installations	
Building cost (01-06)		
07	Outdoors	
Contractors cost (01-07)		
08	General cost	
Construction cost (01-08)		

2.3 Stakeholder interview

Qualitative analyses have been performed as interviews of developers and entrepreneurs of the case project and of other stakeholders within the building industry. The interviews can collect insights into behaviours and thoughts which quantitative data cannot. It can as well explain the reason for the data to occur in a specific way. The interviews were performed as semi-structured interviews with the ability to be flexible from the planned questions and to be creative with more questions, which come throughout the interview. The planned questions were provided to the interviewees from Denmark, Sweden and Norway in writing in advance. In some cases, response was collected in writing, which was complemented by an oral interview to ask further questions afterwards. This method was useful for the project since the people interviewed were able to speak of their experiences. Table 2 shows the interviewed stakeholders.

Table 2: *The interviewed stakeholders*

Stakeholder group	Position	Country
Contractor	Technical dorector	Denmark
Municipality	Business Developer	Sweden
Municipal developer	Project Manager	Sweden
Municipal developer	Project staff	Sweden
Contractor	Cost/project/purchase manager	Sweden
Developer	Project manager	Sweden
Contractor	Cost manager	Norway
Contractor	Project and property manager	Norway
Contractor	Project manager	Norway

3 CASE STUDY BUILDINGS

This chapter describes the 9 case buildings (6 projects in Norway and 3 projects in Sweden) for the analyses in the study.

3.1 Bergheim bo- og aktivitetssenter (CLT 1)

Bergheim bo- og aktivitetssenter (CLT 1) is a care home for 96 residents located in Halden in the south of Norway. The gross total area (GTA) of the building is 11,700 m^2, with no underground parking. The building is distributed on three storeys. The upper two storeys were constructed in CLT and the ground floor in concrete. The building is shaped in a horseshoe form with a yard in the middle. The rendering and the completed project are shown in Figure 1. The building was constructed in the period from October 2017 to February 2019 by a turnkey contractor, Solid Entreprenør. The building owner is Halden municipality. The municipality specifically demanded a massive timber building for the care home, and thus the project was planned to be a timber building from the beginning. The supplier of the CLT was Binderholz in Austria.

Figure 1: *Bergheim bo- og aktivitetssenter project (CLT 1) constructed with CLT in Hadlen, Norway*

3.2 Solhøy (CLT 2)

Solhøy (CLT 2) is a care home for 67 residents located in Vestby in the south of Norway. Solhøy has four storeys. The basement is constructed in concrete and steel, and the above three storeys are constructed in CLT. The building has a GTA of 11,536 m^2 including parking basement, with an average apartment size of 33.5 m^2. The construction of the building started the January 2021 and is planned to end in December 2022. The project has a turnkey contractor with a fixed price for the total cost of the building. The contractor is Solid Entreprenør, which is the same company for CLT 1. The building owner is Vestby municipality, who demanded a building constructed in massive timber from the beginning. The supplier for the CLT panel is Splitkon, located in Norway. Figure 2 shows the rendering and the status of the construction in March 2022.

Figure 2: *Solhøy project (CLT 2) constructed with CLT in Vestby, Norway*

3.3 St. Olavsvej 18 (CLT 3)

St. Olavsvej 18 (CLT 3) is an apartment building in five storeys including the basement, located in Kristiansand in the south of Norway. The GTA of the building is 1,657 m^2 including 550 m^2 parking basement and 28 apartments of average 45 m^2. The basement is constructed in concrete and the upper storeys are constructed in CLT. The construction started in 2021. Similar to CLT 2 project, this project also has a turnkey contractor, VEF Entreprenør, with a fixed price of the project. Figure 3 shows how the building's rendering and the state under construction.

Figure 3: *St. Olavsvei 18 project (CLT 3) constructed with CLT in Kristiansand, Norway*

3.4 Ski BB1 Magasinparken (Concrete 1)

Ski BB1 Magasinparken (Concrete 1) is an apartment complex, consisting of 7 buildings with 183 apartments in total, and is located in Ski in the south of Norway. The building is owned by Solon Bolig AS Solon Eiendom, and was built by Solid Entreprenør, which as well constructed CLT 1 and 2. The average apartment size is 79 m^2 and the GTA of the project is 24,805 m^2, including 7,800 m^2 parking basement. The number of storeys varies for each building. Three of the buildings have four storeys, three other buildings have five storeys and one building has eight storeys. In addition, each building has a basement. The buildings are constructed in concrete slabs and steel columns. The foundation was made as pile foundation, which often has a higher cost. The project was constructed from March 2019 to September 2020. Figure 4 shows some pictures of the buildings.

Figure 4: *Ski BB1 Magasinparken project (Concrete 1) built with concrete in Ski, Norway*

3.5 Trelasttomta (Concrete 2)

The project Trelasttomta consists of four apartment buildings varying from four to seven storeys and one shared basement underneath all the four buildings. The project is owned by Ekornud Eindom AS and is located in Myrvoll in the southern part of Norway. Architect of the buildings are Nuno Architects and is constructed by Solid entrepreneurs as the turnkey contractor, from January 2019 to December 2020. The total gross area for all four buildings is 9,950 m^2 including 2,250 m^2 parking basement and consists of 72 apartments with an average size of 63.2 m^2. The buildings are mainly constructed in concrete and steel, with concrete slabs and loadbearing system in steel. Figure 5 shows some renderings.

Figure 5: *Trelasttomta (Concrete 2) constructed in concrete in Myrvoll, Norway*

3.6 Fagertun Panorama (Concrete 3)

Fagertun Panorama consists of four apartment buildings with two or three storeys and a basement, which are made in concrete. The GTA of the project is 3,359 m^2 including 1,216 m^2 parking basement with 21 apartments with an average size of 91 m^2. The owner is Dovreveien 3 AS, and buildings are located in Lillesand in the south of Norway. VEF Entreprenør was the turnkey contractors of the project and constructed the building from November 2019 to October 2021. The buildings were constructed as conventional apartment buildings of Norway with steel columns and concrete slabs. Figure 6 shows the project after construction completion.

Figure 6: *Fagertun Panorama (Concrete 3) constructed in concrete in Lillesand, Norway*

3.7 Fagertun Panorama (CLT 4)

Arken consists of three buildings with total of 85 rental apartments and has a GTA of 8,327 m^2 with above ground parking only. The project was built in Växjö in the southern part of Sweden. From the beginning it was required to be constructed as a wooden construction, with environmentally friendly materials and low energy consumption. In fact, the project was planned as a part of the regional Energy Plan with a requirement of yearly energy consumptions of 55 kWh per unit heated floor area. However, this project has lower U-values for the building envelope with thicker insulation compared with buildings built according to the minimum requirement by the Swedish regulation. The buildings consist of apartments with one to five rooms, with an average apartment size of 65,3 m^2. The buildings were constructed with a CLT frame, with slabs, outer walls, load bearing inner walls, joist, balconies, elevator shafts, beams and columns in CLT and glue laminated timber from Martinssons in the north of Sweden. The buildings were constructed by a local contractor in Växjö, Värends Entreprenad. Figure 7 shows the project after the construction completion.

Figure 7: *Arken (CLT 4) constructed in CLT in Växjö, Sweden*

https://doi.org/10.52202/069179-0568

3.8 Björkdungen 5 (CLT 5)

Björkdungen 5, located in Bengtsfors in the south-west of Sweden, is a four-storey apartment building with a dentist office placed on the ground floor of the building. The basement and the ground floor were made from concrete, including the elevator shaft. The load bearing structure in the two storeys above was made from CLT, including half of the facade walls. The other half of the facades was made from Sven Johansson Bygg (SJB bygg) own light weight system in wood. The inner load bearing walls of the smaller top floor was from CLT. The facade walls were made from their own light weight system. The elevator shaft was made from CLT in the three top levels. The CLT was delivered from the mill of Stora Enso in central Sweden

The building is owned by Bengtsforshus AB, which is the municipal housing company in Bengtsfors. The building was built by SJB bygg as the turnkey contractor with a construction time of 15 months, from March 2020 to August 2021. This project was the first CLT building built by SJB Bygg. The GTA of the project is 1,536 m^2 including 375 m^2 for the dentist office, a basement of 166 m^2 and 11 apartments with a size of 55-76 m^2. Figure 8 shows the building Björkdungen 5 under construction and as a finished building.

Figure 8: *Björkdungen 5 (CLT 5) constructed in CLT in Bengtsfors, Sweden*

3.9 Tingstorget (Concrete 4)

Tingstorget, located in Botkyrka in the south-east of Sweden, consists of 729 apartments distributed in 14 buildings varying from rowhouses in 3 storeys to multi-storey buildings with 6-8 storeys. The GTA of the whole project is 43,007 m^2 including 3,964 m^2 parking basement. Tingstorget has a load-bearing system in concrete, load bearing inner walls, elevator shaft, staircase and joist constructed in steel and massive concrete. The exterior wall is made of concrete sandwich elements. The roofs are constructed with prefabricated timber elements and is covered with steel roofing plates. The contractor team was a combination between a turnkey contractor, Titania, and an executive contractor. The turnkey contractor was responsible for the framework construction and roof, and the executive contractor was responsible for the rest of the work with in- house employees as well as external consultants which might have contributed to a slightly higher cost. The total construction time was 3 years, from August 2016 to 2019. Figure 9 shows the Tingstorget buildings after the construction completion.

Figure 9: *Tingstorget (Concrete 3) constructed in concrete in Botkyrka, Sweden*

4 RESULT

4.1 Literature study

The period for the design and construction stage (project period) has a great impact on the total construction cost of a building, hence it has been examined in different comparative studies of traditional concrete/steel buildings and timber buildings. Table 3 shows the results of project period and cost for five different studies (M.F. Lagurda-Mallo et al. (2016) [10], R.E. Smith et al. (2017) [8], Center for Sustainable Architecture with Wood (2016) [7], Østnor (2018) [11], and Halseth (2019) [12]), comparing concrete/steel and timber buildings.

Table 3: *Comparisons of time and cost of timber building compared to concrete/steel alternative in five different studies.*

Articles	Construction time of timber buildings compared to concrete/steel building [+/- % time]	Project period of timber buildings compared to concrete/steel building [+/- % time]	Cost of timber buildings compared to concrete/steel building [+/- % time]
M.F. Lagurda-Mallo et al. (2016)	-61.1%	N/A	-21.7%
R. E. Smith et al. (2017)	N/A	-20%	-4.2%
Centre for Sustainable Architecture with wood (2016)	+20%	N/A	+4%
Østnor (2018)	-42%	N/A	+60%
Halseth (2019)	-40%	N/A	+13%

The results in Table 3 show a varying result of the project period and cost, but most of the examined studies have a shorter construction time for the timber building. The only study with a longer construction time for the timber building was in [7]. The reason for this study having a longer construction time was that the timber building was constructed as a prefabricated timber frame structure, which was stated to have a longer construction time compared to panel system in concrete. Meanwhile, the other studies, which all showed a shorter construction time in the timber case, compared CLT with concrete. Furthermore, the timber frame construction in [7] was supposed to receive 5 Star grading of the Australian sustainable building certificate, Green Star [13], which was not the case for the compared concrete building. The certification system required more documentation and additional tasks, thus the process extended the construction time additionally.

One of the reasons for higher cost in three of the examined studies was due to the higher material prices for timber compared to concrete [7, 11, 12]. Another reason is that the cases in those studies (with CLT or prefabricated timber frames) were pilot projects, which resulted in more working hours for the design team to create solutions for e.g., acoustic and fire.

The Swedish company, ETC, who develops, finances and built timber buildings, describes how they have developed

https://doi.org/10.52202/069179-0568

construction and design methods and thereby decrease the cost. After building three buildings they have seen that their second building was 9% less expensive in labor costs. The third building was 10% less in labor costs than the second building. They observed this despite of the fact that during this time the labor costs in general had risen substantially [14]. It shows an example of the cost reduction potential in learnings from the experiences for further process optimization.

4.2 Construction cost of case studies

The cost data for the Norwegian and the Swedish case buildings was analysed separately since the market's general economic structure and technical and legislative construction standards are not the same for the two countries.

In order to normalize the influence of the inflation and to show the magnitude of difference in the two markets, the cost data of each project was converted to euro and index regulated to prices of 2021 by the construction cost index regulation for residential buildings [15]. By converting the prices to 2021 euros it enables for comparison between the project and for future similar projects. Furthermore, all prices are presented without VAT (value added tax) and without the cost of land purchase and landscaping.

The results of the analysis of cost data are based on the raw data which was supplied by the contractors and developers. Results are strictly based on those inputs with no subjective correction of those raw data.

4.2.1 Norwegian cases

The cases CLT 1-3 and Concrete 1-3 are Norwegian buildings, and they were analysed and compared to each other in the same analysis. The collected data is divided into the cost group structure according to [9], which is presented in Table 4 and the total construction cost of the Norwegian projects are illustrated in Figure 10. Common cost (Cost element 01 in Table 4) includes dismantling and setup of construction site, cranes, barracks and operation of construction site, insurance, collateral and guarantees. General cost (Cost element 08) includes engineering and the client's administration, project management, constructions management, special consultants (legal, financial, etc). The landscaping cost was excluded in these results since the cost of landscaping is not relevant for the cost of the building in terms of the selection of the construction materials.

Table 4 and Figure 10 shows that all the Norwegian concrete project has a lower construction cost compared with the CLT building. Thereby this is a clear tendency for the analysed Norwegian project, that it is more costly to construct CLT buildings compared with CLT buildings. However, Table 4 shows that the cost of each project can vary for each cost group. When looking into the cost group, common cost, it shows that the cost for CLT 2 was more than twice higher than for the other projects. Furthermore, the general cost is three times higher for CLT 1 and CLT 2 than for Concrete 1, Concrete 2 and Concrete 3. This might show, together with the literature study (Section 4.1) that there is a tendency that the CLT buildings have higher cost in the design stage than concrete buildings. However, the general cost for CLT 3 is not shown explicitly but is included implicitly among the other cost groups. This is a typical example of the cost calculation practice that even though the cost is divided according to the same standard [9], the calculators of each project can objectively allocate the cost figures to different cost groups. Due to this, the figures of each cost group must only carefully be compared directly and cannot be compared without knowing the background of the numbers.

Table 4: *Results of Norwegian case projects divided into the cost group structure according to NS 3451*

Cost elements		CLT 1	CLT 2	CLT 3	Concrete 1	Concrete 2	Concrete 3
		EUR/m^2(GTA) (2021)					
01	Common costs	251	679	232	309	190	161
02	Building	1302	1561	1573	1232	1105	865
021	Site preparation	16	0	0	0	1	0
021	Ground and foundat	140	219	384	195	129	119
022	Load-bearing systen	20	34	139	15	-	59
023	External walls	167	335	244	186	152	289
024	Internal walls	424	389	277	281	251	61
025	Slabs	223	284	177	300	393	180
026	Roof	103	116	52	38	43	56
027	Fixed furniture	147	144	97	88	73	36
028	Stairs. balconies.	18	24	167	111	52	60
029	Structural relief work - Plumbing	45	16	8	18	11	2
029	Structural relief work - Electrical	0	0	28	-	-	4
03	Plumbing and HVAC installations	350	360	350	226	211	123
04	El-instrations	182	264	141	139	117	52
05	IT and automatior	-	-	-	-	-	-
06	Other installation	18	27	257	17	24	151
Building cost (01-06)		2104	2891	2553	1922	1646	1353
08	General cost	200	163	-	69	65	22
Construction cost (01-08		**2303**	**3054**	**2553**	**1991**	**1711**	**1374**

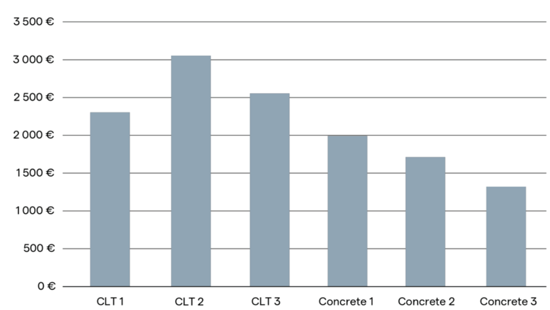

Figure 10: *Total construction cost per GTA for the Norwegian projects*

In the investigation on the cost of CLT buildings compared to concrete buildings, it is necessary to exclude the cost of building parts which are not directly related to building being a CLT or a concrete building. Such building parts are the fixed furniture and installations. The costs of these groups are more dependent on if e.g., the building needs more ventilation according to its particular usage or has many small apartment units (care homes) where each unit has its own bathroom and kitchen. This increases the cost of these groups but is not related to it

https://doi.org/10.52202/069179-0568

being a CLT or concrete building. Therefore, the cost of fixed furniture and other installations are excluded in Figure 11.

The cost of six cases presented in Figure 11 illustrates that the cost of the concrete buildings is still lower than the CLT building. However, the cost difference between all three CLT buildings and the concrete buildings have become lower but cost still varies within the CLT cases and the concrete cases. However, the largest variation was observed for CLT 2. According to the additional questions asked to the contractor of case CLT 2, it was commented that one of the reasons for the case CLT 2 to have a higher cost was that there is a large underground work for the basement constructed in concrete. For this basement, which includes parking areas, technical installation rooms and other functions beneath the whole building, it was required more blasting and other works which were costly. However, this shows that a higher cost of a CLT project do not necessarily need to be a result of the building being constructed in CLT but might be because of other conditions which affects the total cost more.

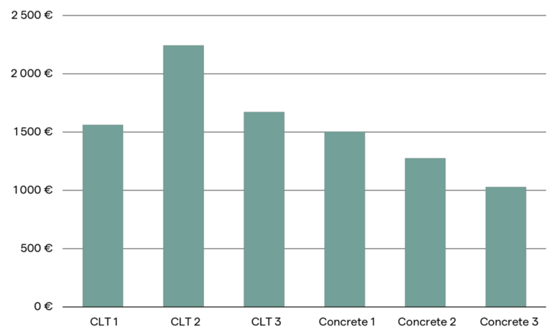

Figure 11: *Cost per GTA for the Norwegian cases, excluding fixed inventory and installations*

Furthermore, it is relevant to investigate the cost of the cases without common cost, and general cost, and thereby only looking at the cost of the materials and labour cost during the construction. This investigation is shown in Figure 12 where the cost of site preparation, ground conditions, load-bearing system, external walls, internal walls, slabs, roofs and stairs and balconies is evaluated separately.

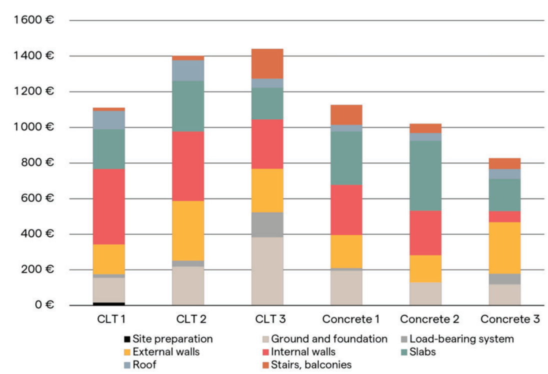

Figure 12: *Cost of the building parts including materials and labour cost of the Norwegian cases*

The results of the cost of the building parts show that the variation within the CLT buildings changed from case CLT 2 having the highest cost to case CLT 3 having a slightly higher cost per GTA. As mentioned earlier, the cost group general cost was not shown explicitly in CLT 3, thus this cost might be included in cost of the building parts shown in Figure 12. Therefore, it cannot be concluded that the building parts are the most expensive for case CLT 3 compared to the other cases.

Through the analysis of the Norwegian cases, it can be concluded that cost varies within the CLT projects and the concrete projects. But there is a tendency that the concrete building has a lower construction cost compared to CLT buildings.

4.2.2 Swedish cases

For the data collection of Swedish case buildings, there was a limited willingness to share cost data from the stakeholders' side. Also, for the ones who contributed with the data, the breakdown of the cost groups was not possible to provide with the level of details as the Norwegian cases. Thus, it was only possible to receive the total cost for three projects, two CLT projects and one concrete project. Table 5 and Figure 13 shows the total cost per GTA for the three Swedish case buildings and the percentage difference from the highest cost per GTA of the three buildings.

Table 5: *Results of total cost per GTA for the Swedish cases*

	CLT 4	CLT 5	Concrete 4
Total cost per GTA (EUR/m^2)	1970	1915	2232
Percentage difference from maximum	-11.7%	-14.2%	0%

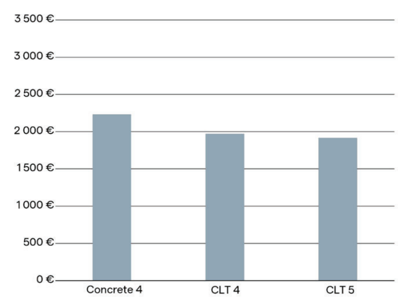

Figure 13: *Total cost per GTA for the Swedish cases*

The results show that the two Swedish CLT case buildings has a respectively 11.7% and 14.2% lower cost than the concrete building. As mentioned above, the results of the Swedish projects are not divided into the same cost group structure. Therefore, it cannot be concluded which cost groups had the highest and lowest cost for each project. However, the contractor of Concrete 4 is different than the projects CLT 4 and CLT 5. Concrete 4 have had a combination of a turnkey contractor and an executive contractor, whereas CLT 4 and CLT 5 only have had a turnkey contractor. This might cause some cost differences. Furthermore, Concrete 4 consists of 14 building whereas CLT 4 consists of three buildings and CLT 5 only consists of one building. It can be assumed that the cost per GTA for the same total floor area becomes higher with increased length of building envelope (more windows, more insulations etc.). Thus, the cost per GTA for Concrete 4 might show somewhat higher number compared to a regular concrete building with just one volume.

Through the questions to the contractor for Concrete 4, Titania, they described that the cost of the final building ran over budget due to complication with the ground and foundations work. This as well might be one of the reasons for the higher cost for case building Concrete 4. Furthermore, Titania stated that if they had a more optimized logistic solution and a lower construction rate, they would probably have been able to save 5-10% of the total cost.

The case building CLT 5, which has the lowest cost per GTA of the Swedish project, can as well be defined as a hybrid building between concrete and CLT. The ground floor and the slab above the ground floor was constructed in concrete. The 1st and 2nd floor are mostly constructed with CLT. The contractor SJB bygg stated that the entire building would have been cheaper if the building was constructed in only concrete and steel or with a timber frame structure. This statement should however be seen in the context that SJB bygg are used to work with concrete and steel and timber frames, but not with CLT. Furthermore, they stated that if they are doing a similar project again the project time would be approx. 10-20% shorter, which should be reflected as a lower cost for the next time.

Moreover, the results illustrated in Figure 13 show that the CLT projects have a low variety for the Swedish project, whereas the earlier mentioned Norwegian projects has a larger cost variation between the CLT projects. Since we know the cost of only two Swedish CLT projects, it cannot be concluded that this shows a general tendency for Swedish projects, and this can be studied further in an additional study where more case studies are available. Even though the cost data of Swedish projects are limited in this study, the results of the Swedish projects still show that CLT buildings do not necessarily have a higher cost than concrete buildings. For a deeper analysis and investigation more project and cost data divided into a cost group structure are needed.

4.3 Stakeholder interview

The results of the interviews from the building industry and the case studies were analyzed in order to recognize tendencies in the costs and methods to construct in CLT and concrete.

4.3.1 Materia cost

The Danish contractor and the one of the Norwegian contractors (see Table 2), who both have constructed concrete building and CLT buildings, stated that it has been more expensive to build CLT buildings compared to concrete buildings up until June 2022 when the project has concluded. They both pointed out that the material cost has been higher in the CLT project, compared to the material cost for a concrete project. The higher material cost has been a result of fewer suppliers and a long transportation. However, the Danish company stated that more suppliers are coming to the Nordic countries and therefore transportation prices have decreased in the last three years. Furthermore, the Norwegian company pointed out that due to the fire regulations in Norway large amounts of fire gypsum boards are needed and it increases the material cost of CLT buildings. In addition, a building of 8 stories constructed in CLT in Norway would need a sprinkler system, which is not the case for a concrete and steel building in Norway. Thereby the material cost for a CLT building may increase further for a building of this height, by adding additional gypsum boards.

However, the weight of a timber building is lower than a concrete building, thus less material is needed for the foundation. This means that in areas with challenging ground conditions, the cost of the foundation can be reduced because of a lighter building.

The contractors and owners of the CLT cases stated that those case studies were planned as timber constructions from the beginning, and thus there was no solid cost comparison to other alternatives. Yet, as stated in section 4.2.2. according to the contractor, SBJ Bygg, CLT 5 projects would have become less costly if other conventional materials than CLT would have been used.

4.3.2 Time and logistics

Through the interviews with the Swedish municipality, one Norwegian contractor and the Danish contractor, they have all pointed out that construction time of CLT building have potential to be shorter than concrete buildings. The Norwegian company has had experience of shorten the construction time by two months by constructing a CLT building compared to a similar building constructed in cast-in concrete and steel.

It was also pointed out that in order to shorten construction time, then the logistics is important to optimize. For the Norwegian company, it was important that the CLT elements and materials arrived as planned every week, so that all the workers were able to do their job and follow the time schedule.

On the first CLT project that the Danish company carried out, they optimized the cost for deliverance of CLT elements by loading the trucks to the maximum, and thereby decrease the numbers deliveries. However, they found huge logistic challenges by handling all CLT elements before they needed them. It demanded to handle the elements 2, 3 and 4 times and every time with a risk for scratches and marks on the elements. Furthermore, the risk of moisture in the elements as a consequence of unstable Danish weather conditions and no weather protection on the site. From this experience they have learned to demand the CLT elements in the order they needed it for the assembly of the building, and thereby streamline the processes.

In addition, the interviews pointed out that CLT buildings constructed by an architect, engineer and contractor who

https://doi.org/10.52202/069179-0568

experienced a CLT project for the first time, have a higher project cost. The Swedish municipality stated that in the beginning their CLT projects, they had a 20-30% higher project cost than concrete alternatives. As more CLT projects were built in the municipality by various local contractors, the cost difference decreased to 10% between CLT and concrete, where CLT is still higher. During the pandemic period the construction cost was heavily influenced by it.

In addition, the Norwegian contractor stated that the shorter construction time is beneficial for the developer of the project, since the occupancies can move into the apartments earlier and start paying rent, which means that the developer will save interest rate for the earlier incoming money.

In the case of the Swedish municipality, in 2013 they launched the policy that more than 50% of the newly built municipal buildings would be timber construction (including hybrid construction where timber is the primary material) by 2020. Their goal was not only reached but succeeded with an average of 70%. From the city planning viewpoint, the municipality appreciates buildings that are more prefabricated and faster to build as the disruption in the town is shorter. While there are several materials and ways to prefabricate, CLT shows a high advantage for high level of prefabrication.

4.3.3 Weather protection

For the construction work of either a CLT building or a concrete building the weather is an important factor in the construction cost. Concrete must dry before the interior finish work can start, and if the humidity is high, it is more difficult to dry the concrete and might need heating equipment to dry the concrete. Timber constructions is built by an organic material and therefor is important to keep the material dry in order not to be infected by fungus or mold. Therefore, it has been investigated throughout the interviews and in the case studies what have been experienced in relation to weather protections. Through the questions for the case study buildings, it showed that none of the studied cases in Norway and Sweden used a tent to cover the construction for protection against rain. For the case CLT 3 VEF Entreprenør had to dry the construction with heated air, however they only did it for a very limited time. For case Concrete 3, VEF Entreprenør as well used heating to dry the concrete before closing the construction, but in a larger scale compared to case CLT 3.

During the project Maskinparken 3, whose cost data was not a part for this study, its construction company did not use weather protection during the construction. They explained that due to the cold and dry weather in Trondheim they had no need for using a tent or drying, other than natural aeration. According to their experience, when they had snow, they could easily remove it and afterwards let the construction dry. Furthermore, they experienced that if they had snow or rain during a weekend, only a small amount of water had penetrated the construction. The construction was then easy to dry before closing it by gypsum boards and insulation. However, they stated that they had a great awareness of the risk of moisture during the entire construction period.

In addition to the risk of rain, they also had to be aware of the wind. When they had to hoist the large wall and deck elements it was important that the wind was weak. If it was too windy then they were not able to control the large elements with the crane.

In the case of the Danish contractor, they have bad experiences by constructing a CLT building in Denmark without using a tent or other weather protection. They stated that in Denmark they have other weather conditions than Norway, which might occur as a higher risk to build a CLT construction without a tent in Denmark than in Norway.

In the case of the Swedish municipality, two out of ten recent timber buildings were built under a tent, and others were exposed. Meanwhile, they stated that they have experience to save money by using a tent as a result of continuously dry work conditions, which does not incur waste of time by waiting for the construction to dry after accidental wetting.

5 DISCUSSION

5.1 Sensitivity and uncertainties

Throughout the process of data collection, it was clear that the project and results would be limited by the number of cases studies. Many of the companies who were contacted and asked to contribute to the project, did not had time or wanted to participate in the project. The limited number of cases resulted in a limited data base for the project, and therefore creates some uncertainties throughout the project. The uncertainties have been identified and are listed below.

Identified uncertainties:

- Representativeness of the collected data set
- Cost differences which are derived from different types of buildings (care homes, family apartments, apartment buildings with service facilities)
- Influence of the timing of the project in relation to the general economy and labour market
- Influence of different locations within each country
- Influence of different construction methods
- Influence of the variation of the contractor team
- Influence of the pandemic since 2020

The uncertainty of the representativeness of the data can cause a large sensitivity for the assessment since each project constitute to a large impact of average result. Nevertheless, the results of the cases examined in the project still show that a timber building does not necessarily need to be more expensive. In addition, the interviews and literature studies showed that there are other advantages and disadvantages in the construction methods for timber buildings, which cannot directly be seen in the total cost, such as the construction time.

Not all the case projects are built in the same year. Even though the costs have been index regulated for the price development of the construction industry, the numbers can still be affected by the time the building was built. For instance, there could be advancements in the construction techniques in 2021 compared to those in 2016. Moreover, the prices for different materials develop differently. Thereby, the comparison of projects built during different time periods might cause an uncertainty for such an economic analysis. This must always be considered when project cost is compared.

In our study, the costs were only compared with other project within the same country. This was done in such a way since each country has its own market with different material prices different labour cost, different definitions of floor areas etc. However, there are also different prices within the countries. A project constructed in the northern part of Sweden most likely has a different price in the southern part of Sweden. This is as well an uncertainty in the project.

The global pandemic of corona virus caused a substantial impact on the global economy, and the construction sector have been also heavily affected in many regards such as labour cost, material cost, transportation cost, logistic, real estate price etc. The influence of the pandemic on the construction cost might become more apparent in the near future.

6 CONCLUSIONS

The results found throughout the analysis reflect the cost of cases of CLT buildings and concrete/steel buildings in Sweden and Norway, as well as information from interviews of stakeholders. The results showed tendencies of how the cost have been at the time where the buildings were designed and build. The market develops continuously, especially within more projects with a stronger focus on sustainability. Therefore, it is important not to apply the conclusions of the case studies as an exact forecast for future buildings but must be used as an indicator of the costs and what to be aware of due to cost of timber and concrete buildings in the Nordic countries.

The following are the main findings of the study:

- There is a tendency that the CLT buildings has a higher construction cost compared with the concrete buildings for the Norwegian case buildings.
- The cost of a CLT building does not necessarily need to become higher compared to a concrete building. It depends on the type of project and how it is executed.
- The more experience one has with CLT buildings, from cost calculation to designing and constructing, the more likely the building becomes more cost efficient.
- The material cost is often higher for CLT buildings compared with concrete buildings.
- The prefabrication of CLT modules most often result in a shorter construction time as well as better working conditions in the factory and on site.
- The logistics of a CLT building is different than for a concrete building and most be considered carefully to lower the cost.
- CLT buildings are lighter than concrete ones and in many cases that presents an advantage on foundation costs.
- None of the cases studies used a tent as weather protection, but it is stated that it possible to save money when applying a tent, due to a more continuously workflow.

ACKNOWLEDGEMENT

COWI Foundation is acknowledged for its financing for the project execution. The construction companies and the other stakeholders are greatly acknowledged for their contribution with the data and to the interviews.

REFERENCES

[1] UN Environment Program. 2021 Global Status Report for Buildings and Construction. 2021.
[2] A. Younis, A. Ambrose: Cross-laminated timber for building construction: A life-cycle-assessment overview. Journal of Build. Eng., Vol. 52, 2022.
[3] R. Brandner, G. Flatscher, A. Ringhofer, G. Schickhofer, A. Thiel.: Cross Laminated Timber (CLT): overview and development. European Journal of Wood and Wood Products, vol.74, pp.331–351. 2016.
[4] EN 15978:2011. Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method. 2011.
[5] S. Liang, H. Gu, T. Bilek, R. Bergman: Life-cycle cost analysis of a mass timber building – methodology and hypothetical case study, USDA, 2019.
[6] Waugh Thistleton Architects: 100 Projects UK CLT, Waugh Thistleton Architects, 2018.
[7] D. Bylund: A cost comparison between multi-residential prefabricated timber frame and precast concrete construction, Forest & Wood products Australia, 2016.
[8] R. E Smith, G. Griffin., T. Rice, B. Hagenhofer-Daniell: Mass timber: evaluating construction performance. Architectural engineering and design management, 14:1-2, pp.127-138, 2017.
[9] NS 3451: Bygningsdelstabell. (In Norwegian)
[10] M. Laguarda-Mallo, O. Espinoza: Cross-laminated timber vs. concrete/steel: Cost comparison using a case study. Proceeding of WCTE 2016. Vienna, Austria.
[11] T. Østnor: Massivtre og Plasstøpt betong: en casestudie - forskjeller, erfaringer og forbedringspotensial. NTNU, 2018. (In Norwegian)
[12] P.T. Halseth: Boligbygging i massivtre: Sammenligning av boligblokk i massivtre og betong. NTNU, 2019. (In Norwegian)
[13] https://new.gbca.org.au/green-star/exploring-green-star/ (Accessed on 13.03.2023)
[14] https://etcbygg.se/bygg/ekonomin-for-vara-forsta-hus/ (Accessed on 13.03.2023)
[15] Danmarks statistik, Index of production in construction: https://www.dst.dk/en/Statistik/emner/erhvervsliv/byggeri-og-anlaeg/indeks-for-byggeri-og-anlaeg (Accessed on 13.03.2023)

https://doi.org/10.52202/069179-0568