Feasibility of Cross Laminated Timber Panels in Construction: A Case Study of Carbon12

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Cross Laminated Timber (CLT) is an extremely strong engineered wood panel intended for roof, floor, or wall applications. Currently there is little research comparing CLT to steel and concrete, materials CLT hopes to replace This research uses a detailed literary analysis on CLT and case study on Carbon12, a recently constructed CLT structure in Portland, Oregon, to compare the cost and schedule requirements of CLT with a cast-in-place concrete slab. The case study consisted of a detailed analysis of Carbon12, interview with Scott Noble, senior project manager for Carbon12, and a detailed schedule and cost analysis. Results showed that for a concrete floor system used on Carbon12, material costs were far less than costs for a CLT floor system and labor costs were far greater than costs for a CLT floor system. For the schedule analysis, results showed that a concrete floor system would add an additional 10 weeks to the construction schedule of Carbon12. These results led to the conclusion that CLT is a feasible building material for dense, urban, mid-rise structures similar to Carbon12. The quick installation time, small crew, and environmental benefits of CLT outweigh the added costs of the material.

Key Words: Cross Laminated Timber, Sustainability, Mid-Rise Structure

Introduction

Since its creation in 1996, Cross Laminated Timber (CLT) has caught the attention of builders around the globe (Brandner, 2016). The new innovative material got many professionals excited, and research on the product quickly began to be conducted. Professionals analyzed CLT characteristics, looking at the product's strength, seismic performance, fire performance, and sustainability. In comparison, little research has been conducted on CLT in direct relation to concrete and steel, the materials it hopes to replace.

The goal of this project is to understand the benefits of constructing a floor system using CLT panels instead of using a more traditional floor system. This will be achieved by comparing the cost of materials, cost of labor, and time to install a CLT panel floor system compared to a one-way cast-in-place concrete slab. In order get to compare these sytems, Carbon12, a multi-story residential structure in Portland, Oregon, was studied. The current hypothesis is that CLT panels will have a larger material cost than a cast-in-place concrete slab, but due to CLT's less labor-intensive process and quick construction time, the two floor systems will be relatively competitive with each other. Through research, quotes from local material suppliers, and an interview with Scott Noble, the senior project manager for Carbon12, the cost and time to construct Carbon12 with the two different flooring systems will be calculated.

Literary Review

CLT Overview

The timber industry took a heavy hit in the early 20th century with the widespread use of concrete. Large concrete structures started to be erected and timber as a construction material was reduced to a market share of only a few percentages and primarily used in timber light-weight constructions (Brandner, 2016). However, over the past decades Europe, and more recently the United States, has seen a revival of timber construction in office buildings, schools, and other building types (Brandner, 2016). This is largely due to the development of a new engineered wood product called Cross Laminated Timber.

Cross Laminated Timber was first used in Austria in the 1990s. This engineered wood product is created by gluing and compressing many layers of solid-sawn lumber together to create one solid extremely strong wood panel intended for roof, floor, or wall applications. CLT panels usually consist of an odd number of layers and are arranged so each layer is set perpendicular to its adjacent layer, as detailed in Figure 1.

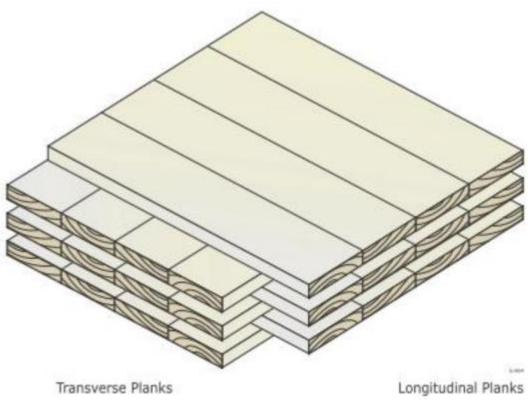

Figure 1- Cross Laminated Timber Design (Scalet, 2015)

Cross Laminated Timber panels are typically constructed with three, five, or seven layers and can be made into panels that are 12’ wide and 60’ long (Kaiser+Path, 2020).

Benefits of CLT

One of the main reasons CLT has become so popular is the many advantages that come with using this product in construction. Many construction materials require a lot of energy and emit carbon dioxide into the air. According to BBC, cement is the source of about 8% of the world’s carbon dioxide emissions (Rodgers, 2018). Cross Laminated Timber produces far less carbon emissions than concrete in production and removes carbon dioxide from the atmosphere. This carbon is stored in the panels and ultimately the overall structure, helping to dramatically reduce the building’s carbon footprint.

Cross Laminated Timber possess benefits in fire protection and insulation as well. When lumber burns, the outside layer begins to “char.” This char will then act as a layer of insulation between the inside core of the panel and the fire. This helps keep the core of the CLT panel structurally intact while the fire progresses. (GreenSpec, 2020). Unlike steel, timber’s structural integrity is not dependent on the temperature of the fire, making charring rates very predictable.

Cost savings are another advantage to building with CLT. Cross Laminated Timber is much lighter compared to concrete which can lead to a much lighter overall structure. This allows smaller and less expensive foundation systems to be used. In addition, CLT panels are prefabricated in a warehouse and often lifted right into place off of the delivery truck. This saves a lot of time in the installation process and allows for projects to be completed faster.

Manufacturing Process

The manufacturing process of CLT is rather simple, it is done by assembling two basic raw materials: lumber and adhesive glue (Scalet, 2015). First, once lumber has been selected, quality checks and visual inspections are carried out making sure there are no major impurities with the lumber. Planing of the board surface will occur to refresh the wood and improve the gluing efficiency. It is important to keep the quality of the lumber consistent. Soon after lumber if cut and arranged to fit the panel size. A typical CLT panel has a size of 13.5m x 3.5m. An adhesive is then applied and a new layer of lumber is added on top. After the desired number of layers are stacked, a minimum of three layers is required, the module is taken to a hydraulic press. The panel is typically pressed for about 10 minutes and then laid out for 10 minutes to let the adhesive fully dry. Openings for doors, windows, and other architectural requirements are cut and then the panel is ready to be packaged and delivered to the jobsite.

CLT Installation

Structures can be erected very quickly when using cross laminated timber panels. This is one of CLT’s main advantages. Unlike concrete, there is no lengthy installation process, requiring formwork installation or curing time. Cross laminated timber panels are often lifted by a crane directly off of the delivery truck and set into place. Connectors allow each panel to be laid in place and then secured together with wood screws or nails. These prefabricated panels have given the designer endless amounts of customization. Today, the only limitation on the use of CLT is the height of the unit one wants to construct (Scalet, 2015).

Methodology

In order to study the feasibility of CLT panels in construction this research included a case study on Carbon12, an eight-story condo building that was constructed using CLT panels. In this analysis, the development and construction of Carbon12 was researched, focusing on the installation of CLT panels and how the installation fit into the entire construction process.

The aim of this case study was to understand the benefits of constructing a floor system using CLT panels instead of a traditional floor system. This will be achieved by comparing the cost of materials, cost of labor, time to install, and carbon emissions for each type of floor system. A CLT floor system was compared to a typical composite cast-in-place concrete slab.

Interview with Scott Noble

Scott Noble has been the Senior Project Manager for Kaiser+Path since 2010 and has had a great amount of experience in mass timber construction. Scott was a project manager for the Radiator, a $6.5 million mass timber structure in Portland, and was the senior project manager for the construction of Carbon12. For this case study, the researcher conducted an interview with Scott Noble, asking about the construction of Carbon12. The objective was to get an insider perspective on Carbon12's construction process and get insight from a professional with experience in the mass timber industry.

Cost Analysis

This analysis looks at the cost of material, cost of labor, and overall time to erect Carbon12 using CLT panels. The costs and time calculated will then be compared to the cost of materials, cost of labor, and time to construct Carbon12 using a one-way cast in place slab and a metal deck. Floor plans of Carbon12 were acquired, and the total area of each floor was calculated using Bluebeam Revu. For the material cost of CLT quotes were obtained from Structurlam, the CLT suppliers for Carbon12, who is one of the largest suppliers of CLT in North America. Material costs of a one-way cast in place slab were obtained from RSMeans Data. The unit costs ($/SF) of each flooring system were compared, and then, based on the total square-footage of floorspace in Carbon12, the total cost to build each flooring system was compared. In addition, the researcher received unit costs ($/SF) from an interview with Scott Noble, senior project manager of Carbon12. Based on these unit costs, the cost to build Carbon12 using mass timber and a BRB frame was compared to the cost to build Carbon12 using concrete slabs, shear walls, and columns.

When calculating the labor costs for CLT installation, the most recent carpenter rates were used from the Associated General Contractors, Oregon Columbia Chapter. Next, the size of a standard crew to install CLT was obtained from the researcher's interview with Scott Noble. The carpenter's wage rate and crew size were then combined to calculate the total labor costs associated with the installation of CLT panels in Carbon12. For a one-way cast in place concrete slab, labor rates were obtained from RSMeans data for the Portland area.

Schedule Analysis

The time it took to erect Carbon12 using CLT is already known. Literary research was conducted to understand the installation process and calculate the total time to erect the CLT flooring system for Carbon12. Additional literary research was conducted to understand the process to install a cast-in-place slabs. This research was compared with results from the researcher's interview with Scott Noble.

Case Study

Kaiser+Path was responsible for the design, development, and construction of the structure. Carbon12 sits at a height of 85 feet, and after its completion in 2018 became the tallest mass timber building in the United States. Carbon12 resulted in a big step forward for mass timber construction and brought a great deal of attention to CLT construction in the United States. In this case study the researcher will look at the project specifics of Carbon12, conduct an interview with Scott Noble, senior project manager for Kaiser+Path, and create a cost and schedule analysis of Carbon12.

Project Specifics

Carbon12 consists of solid walls clad in custom corrugated metal siding with floor-to-ceiling windows. The building also has glulam beams and columns, and CLT floor panels. Due to seismic activity in Portland the building was unable to incorporate an all wood lateral system. Kaiser+Path decided on a buckling restrained braced frame (BRB). This is a premanufactured bolted connection system integrated into the structural steel core. This system was chosen because it will complement the speed of construction that comes with mass timber. In addition, Kaiser+Path wished to have all wood components exposed, which created many challenges. The team had to figure out how to mitigate sound traveling between condo units and locate where they would run the mechanical and electrical systems throughout the building. To do this, Carbon12 was designed with a layered floor system for acoustic isolation and ran building systems above each unit in soffits.

Interview with Scott Noble

During the interview, Scott Noble and the researcher discussed Carbon12's construction process, specifically the challenges and benefits that came with mass timber and CLT construction. Scott talked about the flooring installation process of Carbon12 and how CLT fit into the process. The process began by closing gaps in the sub-floor system. Areas where CLT notched around steel columns and beams in the BRB frame had to be blocked with expandable foam, sheet metal closure strips, and wood blocking. Next, for extra moisture protection, a layer of plastic sheathing was added to the exposed CLT, wrapped up glulam columns and beams, and then taped at the seams. After this was complete, electricians had the entire floor to run power through the floor system to the exterior walls and ceiling boxes. A layer of insulation board was installed followed by a layer of rigid DensDeck board and then another layer of insulation board. This entire process took roughly one week per floor. Scott then went on to discuss the gypcrete process that followed. For three days, a 1.5" gypcrete topping slab was installed. After the gypcrete had cured drywall installation began. The last floor layer consisted of an acoustic mat between the gypcrete and the hardwood floor. This allowed the wood floor to expand and contract. Scott believed that the use of CLT gave a slight advantage over concrete with this flooring process. The installation of CLT panels was so quick that it allowed the rest of the process and other trades to start work much earlier.

Next, the researcher asked Scott about the coordination and logistics that came with construction. Scott first mentioned that the team had a vacant lot right across the street they were able to use as a laydown area. In addition, Carbon12 is on the corner of two very busy streets, so maintaining pedestrian access was a challenge the team constantly dealt with. The researcher asked if CLT benefited in the overall logistical process, and Scott answered that CLT did not have a significant advantage in comparison to a concrete slab. Scott mentioned that most concrete pours would be happening late at night and would not disturb pedestrian traffic at all.

The researcher and Scott then discussed the CLT delivery process. All mass timber was trucked from Penticton, British Columbia. Scott said that the team never had any problems with deliveries and were never waiting for materials. Each floor required approximately two trailers of CLT. There was space for the trailers in the laydown yard across the street, and the project saw either one or two loads of CLT each day. Once the trailer arrived, a tower crane would lift the CLT panels into place.

The next part of the interview involved the labor and equipment associated with CLT. Scott discussed that for the installation of CLT, only four carpenters were needed. This small crew resulted in less cost, improved safety, and better coordination. Scott mentioned that it wasn't a major factor if subcontractors had a great deal of experience with CLT. The most important thing was that framers had the necessary equipment. The CLT panels were lifted into place using a Potain HDT 80 tower crane. This was a relatively small crane due to the building's small footprint and the weight of the CLT panels. Other equipment used on the project were scissor lifts to erect the steel on the BRB frame, forklifts to move materials, and booms to install exterior siding.

Next, Scott discussed the costs and schedule associated with CLT. Scott mentioned that the mass timber structure using a BRB steel core came out to $42/SF. If concrete shear walls, columns, and slabs were used instead, the project would come out to approximately $39/SF. Scott said that Carbon12 was erected in 9-10 weeks, with top floors being erected in four days. If concrete were used for the slabs, columns, and beams an additional 10 weeks of construction time would be added to the project. Overall, Scott believed that the team did not take advantage of CLT's quick installation process, and that the project could have been erected even faster. Carbon12 was erected faster than the team anticipated, and subcontractors were not able to keep up with this pace.

Lastly, the researcher asked Scott about the biggest challenges the team faced on Carbon12 when it came to CLT. According to Scott, one of the main difficulties was moisture control. Water would leak between a 9" wide plywood spline and stain the CLT panels. Being in Portland, the project faced a great amount of rain and often workers had to push out water and dry the panels with fans. In addition to staining, Scott discussed how moisture can lead to stresses in the wood and cause cracking. The project had to deal with a fair amount of cracking in the CLT panels. Scott then discussed challenges the team faced with the roof. After the CLT panel is installed on the roof, a vapor barrier is placed on top. It is important that this vapor barrier is completely dry when installed. Due to the high levels of rain and snow it was very difficult to keep this vapor barrier dry. The team had to install a temporary tent on top of the roof, resulting in an added $50,000 cost.

Cost Analysis

First, the researcher had to calculate the total quantity of CLT used for Carbon12. Reviewing Carbon12's floor plans the researcher noted that floors 2-8 and the roof contained a CLT panel flooring system. The first floor was constructed using a composite concrete slab. Using Bluebeam Revu, quantity takeoffs were completed for floors 2-8 as well as the roof. The results showed that levels 2-8 had an area of 3,881 square feet per floor and the roof had an area of 4,036 square feet. This resulted in a total CLT area of 31,203 square feet, see Table 1.

Table 1- Carbon12 Floor Areas									
Level	1	2	3	4	5	6	7	8	Roof
Area (SF)	3,820	3,881	3,881	3,881	3,881	3,881	3,881	3,881	4,036
Total CLT Area	31,203 sf								
Total Floor Area	35,023 sf								

To obtain the unit cost for CLT, a quote was provided by a specialist at Structurlam. The specialist gave a unit price of $17/SF for CLT delivered to Carbon12. This price did not include any cost for installation, simply the cost of manufacturing and delivering the material to the jobsite. The unit cost for a one-way cast-in-place concrete slab was obtained from the RSMeans Cost Data. The cost data was for commercial new construction in Portland, Oregon. The bay sizes for Carbon12 are approximately 12’x12’, so in RSMeans Cost Data for a cast in place one-way slab with a 15’ span was chosen. This data included the cost of formwork as well. As shown in Table 2, a one way 6.5” thick cast-in-place concrete slab with a 15’ span, superimposed load of 75 psf, and total load of 156 psf came out to a cost of $6.9/SF.

Table 2- Carbon12 Material Costs

Construction Type	Material Cost	Unit	Total SF	Total Material	% of CLT
CLT	17	$/SF	31,203	$519,520	100%
CIP Slab (One-Way)	6.9	$/SF	31,203	$210,864	41%

The total material cost was calculated to be $519,520 for a CLT panel floor system and $210,864 for a one-way cast-in-place concrete slab floor system. The concrete slab material costs are roughly 41% of CLT material costs.

During the researcher’s interview with Scott Noble, he said that project costs with mass timber and a BRB steel core came out to a unit cost of $42/SF. Scott then mentioned, if Carbon12 were to use a concrete shear wall core with concrete columns, beams, and slabs the unit cost would be $39/SF. These unit costs accounted for labor. See Table 3.

Table 3- Carbon12 Project Costs

Construction Type	Project Cost	Unit	Total SF	Total Cost	% of CLT
Mass Timber w/ BRB Frame	42	$/SF	35,023	$1,470,966	100%
Concrete w/ Shear Walls	39	$/SF	35,023	$1,365,897	93%

If Carbon12 had a concrete shear wall core with concrete columns, beams, and slabs the project cost would be approximately 93% of the cost of Carbon12 with glulam beams, CLT floor panels, and a BRB steel core.

For the labor cost of CLT installation, carpenter rates were used from the Associated General Contractors, Oregon Columbia Chapter. These rates listed a carpenter at an hourly rate of $41.83, and a foreman at an hourly rate of $45.09. Both had a labor burden of $18.30 for a total carpenter hourly cost of $60.13 and foreman hourly cost of $63.39. Through literary research and interview with Scott Noble, the researcher learned that it took a four-person crew to install the CLT panels. Assigning three carpenters and one foreman to this crew created an hourly crew cost of $243.78. Literary research on Carbon12 showed that the CLT panels were erected in 9 weeks. Assigning a four-person crew to 40-hour work weeks for the entire CLT installation process came out to a total of 360 crew hours. As shown in Table 3, this cost was then compared to the labor rate for a one-way cast-in-place slab listed in the RSMeans Data Set. This came to a rate of $10.6/SF.

Table 3- Carbon12 Labor Costs

Construction Type	Labor Cost	Unit	Crew Hours	Total SF	Total Labor Cost	% of CLT
CLT	243.78	$/crew hr.	360	n/a	$87,761	100%
CIP Slab (One-Way)	10.6	$/SF	n/a	31,203	$330,752	377%

The results showed that labor cost for a one-way cast-in-place slab was approximately 377% of the CLT labor costs.

Table 4- Carbon12 Total Costs				
Construction Type	**Total Material**	**Total Labor**	**Total Cost**	**% of CLT**
CLT	$519,520	$87,761	$607,281	100%
CIP Slab (One-Way)	$210,864	$330,752	$541,616	89%

As shown in Table 4, when combining both the material and labor costs for the two flooring systems, a one-way cast in place slab used for Carbon12's flooring system would result in 89% of the cost of Carbon12 erected with CLT floor panels.

Schedule Analysis

For Carbon12, CLT installation process would alternate with the installation of the BRB steel core. Three levels of the BRB steel core was installed, followed by three levels of CLT. The first level of CLT took roughly two weeks to install, but upper floors were completed at a rate of four days per floor. After three floors of CLT were installed there was a break where the next three levels of the BRB steel core was installed. During this period interior walls and stairs were installed on lower floors so they would be safe for other trades to access. It took a total of 9 weeks for all the CLT panels to be installed in Carbon12 during one of the wettest, coldest, snowiest winters in Portland's recent history.

If Carbon12 were to use concrete slabs and columns, significant time would have been added to the schedule. The process would be much more complex and would face challenges with Carbon12's small building footprint. All concrete elements would be required to be formed onsite with little prefabrication and then additional crews would need to come in and place reinforcing steel. Concrete pump trucks would be required and would have difficult access with such a small building footprint. After the concrete is poured, there would be a long waiting period while the concrete cures and reaches minimum tensioning strength. Next, forms would have to be removed and re-shoring would take place until design strength is reached. After design strength is reached, the reshores would be removed and the process would repeat on the next floor. According to the researcher's interview with Scott Noble, this process would have added approximately 10 weeks to the construction schedule.

Conclusion

The aim of this research was to compare the use of a CLT panel flooring system with a more traditional cast-in-place concrete slab floor system. By doing this the researcher hoped to understand the major benefits and disadvantages of a CLT floor system and see if CLT can be a feasible construction material. Through the researcher's case study on Carbon12, which consisted of an interview with Scott Noble and cost and schedule analysis on Carbon12, the researcher was able to compare the material cost, labor cost, and construction time of a CLT floor system with a one-way cast-in-place concrete slab. The results showed that cast-in-place concrete had a much lower material cost, only 41% of the cost of CLT. When the researcher analyzed the labor costs, CLT required a four-person crew where cast-in-place concrete would require multiple large crews. In addition, concrete would require an additional 10 weeks of construction time. The speedy construction time and small crew that comes with CLT resulted in a much lower labor cost in comparison to cast-in-place concrete. Cast-in-place concrete had a labor cost that was 377% of the labor cost for CLT installation. These results supported the researcher's hypothesis. Cross laminated timber had a high material cost, but due to the quick construction time and low labor costs the material was able to be competitive with a cast-in-place concrete slab. The total material and labor costs of a cast-in-place concrete slab used on Carbon12 would be 89% of the cost of CLT, but and have a 10-week longer construction schedule. These results support the claim that CLT panels are a feasible material for dense, urban, mid-rise structures similar to Carbon12 and are competitive in cost and schedule to cast-in-place concrete. Cross laminated timber has a higher overall cost but has many benefits over cast-in-place concrete. Cross laminated timber allowed for a much faster and less complex construction process, while delivering a sustainable building that sequesters carbon in the structure and boasts a desirable natural look clients desire. The researcher believes these benefits outweigh the additional cost of the material.

Limitations and Further Research

Although the case study research supported the researcher's hypothesis, there were limitations to the research that could have affected results. Carbon12 was constructed in a tight building footprint, which did not favor cast-in-place concrete. On a larger process with more space for crews and equipment to operate, cast-in-place concrete may not be at as great of a disadvantage. In addition, the construction of Carbon12 took place in the Pacific Northwest, a region close to a many CLT manufacturing plants. Cross Laminated Timber construction in areas where CLT manufacturing plants are scarce, such as the southwest United States, may be more difficult and more costly due to higher manufacturing and delivery costs.

The research from this case study shows that cross laminated timber can be a feasible building material and the role of CLT in the future of construction look promising. Further research needs to be looked into the demand for CLT in the future and how CLT can become a major building material. Cross Laminated Timber boasts so many benefits, but the main drawback to owners is the high cost of the material. Further research must be conducted into ways to reduce material costs and increase demand for the product. As more large general contractors invest in CLT production, will prices begin to fall? In addition, further research must be conducted into the performance of CLT in high-rise commercial offices and apartments. Will CLT's speedy installation process result in even more benefits with high-rise construction, or will the product run into more problems on a larger scale? As the world's population continues to grow and the demand for resources increases, cross laminated timber has the ability to disrupt the traditional building process and create a more sustainable built environment and healthier plant.

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