Highlighting the Unique Challenges and Differences of Building with Mass Timber

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As the construction industry shifts towards sustainability and owners seek to construct buildings that are sustainable - built from natural and renewable materials, and pleasing for their occupants to work in - mass timber is becoming the popular alternative to traditional steel and concrete buildings. An abundance of information is available on mass timber products and their properties and applications, but little information on the process of actually building a mass timber project. This report seeks to extend practical knowledge on building with mass timber. In order to accomplish this, this research will highlight specific differences and challenges related to building with mass timber; create general guidelines and recommendations for contractors tasked with building a mass timber project; and identify new areas of research. Through interviews with two commercial contractors who have built mass timber projects in the California Bay Area, specific challenges have been identified. These challenges include longer project duration; increased preconstruction time and complexity; difficulties getting timely plan approvals; differing design and material procurement methods; necessity of MEP coordination at the beginning of the jobs; unique transportation, storage, and handling requirements; and different installation procedures and requirements.

Key Words: Mass Timber, Cross-Laminated Timber (CLT), Glue-Laminated Timber (glulam), Differences, Building

Introduction

According to Mass Timber (2020), "Mass timber is a category of framing styles typically characterized by the use of large solid wood panels for wall, floor, and roof construction." Mass timber systems are typically made up of various pieces of dimensional lumber that are jointed and glued together to create large, variable sized members designed to be used in different parts of a building's structure. As companies are seeking to create buildings that are cost-effective, sustainable, built of natural and renewable materials, and visually pleasing to their occupants, mass timber building systems are becoming increasingly popular throughout North America. Mass timber is a viable alternative to traditional steel and concrete construction systems (Jackson, Luthi, & Boyle, 2017).

Goals of This Report

The goal of this report is to use information gathered during qualitative interviews with key individuals on two mass timber projects to extend overall practical knowledge of building with mass timber. The objectives that are aligned with this goal are to:

- Highlight at least five specific differences and challenges related to building with mass timber versus traditional concrete and steel buildings;
- Use these identified differences and challenges to create general guidelines for companies to use when beginning a mass timber project; and

- Identify and highlight at least one new area of additional research related to building with mass timber

To gather data for this report, two relevant commercial mass timber projects were identified that are currently in various stages of construction in the California Bay Area. The first is a pair of corporate office buildings currently in the preconstruction phase being built by McCarthy Builders. The project consists of two commercial office buildings, one with two floors and the other with 3 floors, for a combined 270,000 square feet. The buildings' structure will consist of cross-laminated timber (CLT) floor and roof diaphragms with glue-laminated columns and beams. This project is utilizing a design-build approach with McCarthy as the general contractor.

The second mass timber project is being built by Rudolph and Sletten and is currently in the construction phase. This project – a corporate office building, like the McCarthy buildings - when completed will be the largest mass timber building by square feet in the U.S. at approximately 600,000 gross square feet. This building utilizes a hybrid construction method, with CLT floor and roof diaphragms, glue-laminated columns, and steel horizontal beams. The building is a one-story building with two-stories in some areas. Project delivery utilizes a traditional design-bid-build delivery methodology. Rudolph and Sletten is the general contractor.

Background

Types of Mass Timber

There are several types of mass timber building systems, each with unique characteristics and applications for construction, but the two most common and widely used in the U.S. are described below.

Cross-Laminated Timber (CLT) – CLT panels are large wood panels made up of several layers of dimensional boards ranging from approximately 5/8 inch to 2 inches thick. Each layer is laid perpendicular to each other and then finger jointed and glued together to create one continuous panel that can be up to 10 feet wide and 60 feet long. CLT panels are generally used for wall and floor panels, with the main advantage of the cross-laminated orientation being two-way dimensional stability, similar to a concrete slab. This is unlike other forms of mass timber which offer their main strength in one direction. (Karacabeyli, Douglas, 2013).

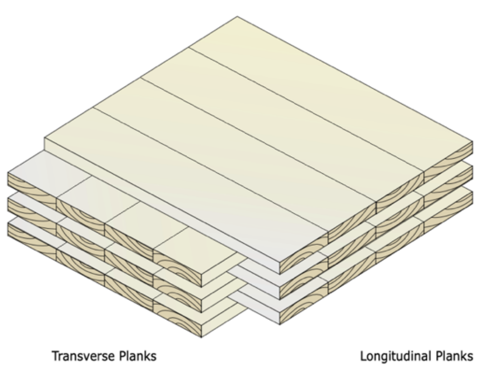

Figure 1: Cross-Laminated Timber (CLT) Panel
Source: CLT Handbook

Glue-Laminated Timber (Glulam) – Glulam timbers are generally beams made up of layers of wood or laminations, glued together and end jointed. The wood is oriented with the grain parallel with the length of the beam with each lamination approximately 1.5 inches thick. Typical member widths are 2.5 to 10.75 inches wide and can be made in almost any length necessary. More laminations can be added to make a taller beam to suit structural load requirements. Glulam timbers can be either straight or curved, depending on the application. According to the APA, a nonprofit trade organization dedicated to researching, testing, and grading manufactured lumber, Glulam provides higher strength pound-for-pound than steel, which allows for longer spans with minimal intermediate supports. (Glulam Product Guide, 2017).

Figure 2: Glue-Laminated (glulam) Beam Cross-Section
Source: APA Glulam Product Guide

Sustainability

According to the United Nations Energy Report, "buildings and construction account for more than 35% of global final energy use and nearly 40% of energy-related CO2 emissions." Eleven percent of these energy-related CO2 emissions are directly from the manufacturing of materials for building construction, such as steel, cement, and glass (UN Environment and International Energy Agency, 2017). Mass timber, specifically Cross-Laminated Timber (CLT), offers several environmental benefits over traditional steel and concrete building construction. Werner, Taverna, Hofer, & Richter (2006) found that the first such benefit is that wood products, "act as a carbon pool during their service life, as they withdraw CO2 from its natural cycle." Werner et al. also found that, "After their service life, they can substitute for fossil fuels if they are incinerated in adequate furnaces." Chen, Pierobon, & Ganguly (2019) found that, "A compelling characteristic of CLT, compared to other wood-based materials, is that it can be manufactured using small-diameter trees that are considered to have low or no commercial value." According to the USDA Forest Service, small-diameter and underutilized (SDU) material, which is defined as "timber left in the forest because it is not economical to remove" is creating major problems for forest management (LeVan-Green & Livingston, 2001). Finding value-added uses for SDU material will have many benefits including reducing risk from insects and disease as well as catastrophic wildfires, providing healthier wildlife habitat, protecting and improving watersheds, and more (LeVan-Green & Livingston, 2001).

A comparative cradle-to-gate life cycle assessment from Canada, whose objective was to "quantify and compare the environmental impacts associated with alternative designs for a typical North

American mid-rise office building" compared two scenarios; a traditional cast-in-place reinforced concrete structure, and a laminated timber design which included cross-laminated timber and glulam (Chen, Pierobon, & Ganguly, 2019). This study found that "it is environmentally advantageous, in all but one impact category, to construct the structural frame and the enclosure system using predominantly laminated timber engineered lumber products, rather than cast-in-place reinforced concrete construction" (Chen, Pierobon, & Ganguly, 2019).

Fire Safety

A major consideration when designing a building of any construction type is fire safety. The current regulatory framework for fire resistance of a building says that a building must be able to remain structurally sound throughout the burnout phase of the fuel load, meaning the phase where the fuel load inside the building such as furniture burns completely (Emberley et al., 2017).

A benefit of mass timber construction is that it has what is called self-protection, in which as the timber burns, the outer faces char and become less flammable, which protects and insulates the interior layers, and allows the timber to remain structurally sound. When designing mass timber elements, a char rate is taken into account to predict the depth of charred timber. An additional "zero-strength" layer is then added which does not contribute to the timber's strength. At this point the timber's capacity is calculated based on the reduced size left after burning to ensure that the structure remains sound during a fire event (Lineham, Thomson, Bartlett, Bisby, & Hadden, 2016).

To test the fire safety of cross-laminated timber (CLT) construction, a large-scale fire test was conducted based on a real proposed apartment building in Brisbane, Australia in which a room was constructed of CLT with the dimensions of a living room for the proposed apartment building. The internal faces were covered with non-combustible material, leaving the ceiling and one wall as exposed CLT. Wood cribs were burned inside the room to simulate a worst-case structure fire and the results were measured. As the wood cribs burned, the CLT was ignited but as the CLT charred, the fire ended up self-extinguishing once internal temperatures lowered. This shows promising data that indicates properly designed CLT buildings can actually self-extinguish during a fire event (Emberley et al., 2017).

Figure 3: How Charring Protects Timber in a Fire
Source: Fire Performance, reThinkWood

Seismic Safety

Mass timber has several advantages over traditional heavy construction for seismic factors, including high strength-to-weight ratio and the ability to move without permanently deforming during a seismic event. A study designed to compare the dynamic properties of high-rise building frames constructed from four different structural materials, including conventional wood, glue-laminated timber (glulam), cross-laminated timber (CLT), steel and concrete, found that a structure composed of glulam and CLT products combined together "demonstrate exceptional dynamic behavior, resulting in higher dampening coefficients and reduced floor displacements compared to the other materials" (Kalathas, 2019).

A test program was undertaken at the National Institute for Earth Science and Disaster Prevention in Japan in 2008 by constructing a three-story building out of CLT on a shake table. The building was then subjected to 15 different simulated earthquakes until it reached near-collapse, which was defined as the tension failure of one or more hold downs (Ceccotti, 2008). The program found that even after subjecting the building to 15 "destructive" quakes in a row without any significant repairs, the building was not permanently deformed and was still standing straight and vertical at the end of the testing. This shows that CLT can perform very well during seismic events (Ceccotti, 2008).

Methodology

Background research was conducted in order to gain a better understanding of mass timber, what the different mass timber systems are and how they work. This background research was then used to formulate interview questions. Two commercial contractors were then identified, Rudolph and Sletten, and McCarthy Builders. Both contractors are currently working on mass timber projects in the California bay area. Phone interviews were conducted with key individuals on the two projects. These interviews gathered qualitative data on the companies' experience working on a mass timber project in California. The interview questions were formulated to first gain an overall idea of the two different projects, and then to dive deeper into the unique aspects of working on a mass timber project. The same questions were asked both to Rudolph and Sletten and McCarthy Builders, with slight adaptions and follow up questions based on the responses given by the company representatives. The Carpenters' Union was also contacted to find out if they have a mass timber training program and if so, how it works and what it focuses on.

The interview questions for the two construction companies are focused on five main topics:

- General questions to gain a general overview of the project;
- Design Elements to discuss the design of the project and how using mass timber influenced the design phase and process;
- Coordination to discuss how the companies coordinated mass timber elements with the rest of the project and with other trades and how they dealt with the unique challenges of using mass timber;
- Installation to discuss the actual installation of the mass timber and the unique challenges or solutions needed on a commercial project; and
- Warranty Issues to discuss possible warranty differences and unique issues that may arise due to using mass timber on a large-scale commercial project.

The general interview questions asked to both companies are given below.

1. General Questions
    - o Does your company have a lot of experience building with mass timber?
    - o Are you the General Contractor for this project?
    - o What is the project and its intended use?

- How tall is the building?

2. Design elements
   - Do you know why the owner chose mass timber?
   - Was the project design build or other delivery method?
   - Did using mass timber increase or decrease costs significantly compared to traditional methods?
   - Is it all mass timber, or hybrid, what parts and why?
   - Is the mass timber structural or decorative?
   - What kind of mass timber system was used in the project?
   - Who is the mass timber supplier for the project?
   - Did a third party do the mass timber design or just the architect?
   - Did using mass timber increase lead time?
   - Was mass timber part of the design from the beginning?
   - Did using mass timber change the design of the building significantly?
   - Is the mass timber exposed or covered up?
   - Is the mass timber being prefabbed offsite?
   - Has it been hard to get approval for fire/seismic due to mass timber?
   - Are additional fire sprinklers necessary?
3. Coordination
   - Was it difficult to coordinate shipping and storage of materials before installation?
   - Did using mass timber change the natural building schedule or is it similar?
   - Were there any coordination issues due specifically to the mass timber?
   - Were additional equipment or people necessary for mass timber?
   - How is the mass timber attached to the rest of the building?
   - Are there unique challenges where mass timber integrates with steel or concrete portions of the building?
4. Installation
   - Did your company install the mass timber system or use a subcontractor?
   - What trade did the installation?
   - Does your company have prior experience installing mass timber?
   - Is it hard to find workers with mass timber experience?
   - If self-performed, did your company train employees and how?
   - Is using mass timber faster or slower than traditional construction methods?
   - How are the members connected to each other?
5. Warranty issues
   - Have you had warranty issues in the past with mass timber on jobs?
   - Do you anticipate any warranty issues so far?
   - Who will be responsible for warrantying the mass timber?
   - Is the warranty period different?

It was found that each company is currently in different stages of their mass timber project. McCarthy is currently in the preconstruction phase and has not completed a mass timber project in the past. As a consequence, more data was obtained from McCarthy about the design and preconstruction phase and less on the coordination, installation, and warranty areas of the questions. Rudolph and Sletten is currently in the construction phase of their project and has completed a mass timber project in the past. Much more data was obtained from Rudolph and Sletten about multiple stages of the project and they were able to answer all questions.

The responses given by both companies were analyzed for trends or similarities in answers given between the two companies. The question responses were then used to fulfill the project goals of extending practical knowledge of building with mass timber. Responses were first analyzed to highlight specific differences and challenges of working with mass timber, and these differences and challenges were then used to create general guidelines and considerations for companies to use when beginning a mass timber project. At this point, areas of future research were identified.

Analysis

Through interviews, significant preconstruction and construction differences due to using mass timber on a commercial project were identified.

Preconstruction Differences

Several major preconstruction differences appear with mass timber systems. These difference result in the mass timber preconstruction process taking significantly longer than that of a comparable steel and concrete building.

The first difference is that due to the infancy of mass timber building systems, city building officials may be uninformed about mass timber building systems. This can lead to a long process of educating city building officials about mass timber. In the case of the Rudolph and Sletten project, this led to a six to nine-month delay in the project schedule while city building officials became educated about mass timber. If this were a traditional steel and concrete building, the approval process would have moved along quickly without having taken any extra time.

The second major difference is the design process. In a traditional building, the architect and structural engineer can design the building by looking up steel strength values and properties in readily available resources and basing the structural steel sizing off of these values. Using a mass timber building system increases both the number of steps and the number of parties in the design process. Each mass timber supplier has their own proprietary systems and specifications. With a traditional steel building, after the steel has been designed it can be ordered right away and is generally more readily available. With mass timber this process becomes much more complicated as the structural engineer must determine the necessary load requirements for each floor or roof and then coordinate with the selected mass timber supplier to determine the necessary size and specifications of timber products used. After this, shop drawings need to be produced and approved before any wood products can be ordered. For a hybrid project utilizing timber columns and floor diaphragms and steel horizontal beams, it may be necessary to coordinate with a structural engineer, structural steel supplier, and a mass timber supplier before shop drawings can be produced and products ordered. There are no standardized mass timber systems as each manufacturer has their own proprietary systems. Mass timber products must be custom designed and fabricated for each individual job. This greatly increases lead time of getting the timber products onsite.

The third major difference is mechanical, electrical, and plumbing (MEP) coordination. On a traditional steel building, once the structural steel plans are received, the steel can be ordered and installed. MEPS can be coordinated at a later date. On a mass timber project, especially utilizing cross-laminated timber (CLT), all of the panels are fabricated offsite to exact specifications and for exact locations in the project beforehand. Because of this, it is extremely difficult and time consuming to drill, cut, or alter the panels onsite. This means that all of the MEPS must be completely coordinated during the preconstruction phase and before any of the CLT panels can be ordered from the supplier. This allows all of the holes for MEP penetrations to be cut at the appropriate locations in the panels by the supplier during fabrication.

Construction Differences

Mass timber building systems also present several major construction differences. The first major difference is transportation, storage, and handling, especially when using cross-laminated timber (CLT) panels. When transporting metal decking for a traditional steel building, thousands of square feet of metal decking can fit on one truck. This is not the case with CLT panels. The panels are large and heavy, and due to this only about five CLT panels can fit on a single truck. Significantly more trucks are required to transport CLT panels. These large panels consume significantly more storage space too and will quickly take up all free space on the construction site. Depending on the size and congestion of the job site, it may be necessary to store the CLT panels offsite and bring them to the site as needed for installation. This double handling requires additional trucks. This leads to much more complicated logistics as well. Because each panel is meant for a specific location in the building, CLT deliveries must be carefully coordinated with the construction schedule to make sure that the correct panels arrive in the correct order. Once onsite, the panels must be transported and offloaded with a forklift or crane due to their huge size and weight.

The second major construction difference is the installation of the mass timber products. The carpenter crews tasked with installing the mass timber may not have installed mass timber before, and they may need to be trained. Because the Rudolph and Sletten project was a hybrid design with wood columns, CLT floors and roofs, and steel beams, a hybrid crew of half structural steel workers and half carpenters was put together and trained onsite on a mockup of the building system. Due to not having prior experience working with these systems, there was somewhat of a learning curve at the beginning of the job. The lack of prior training was overcome relatively quickly once installation began. After speaking with a Carpenters' Union master instructor, it was found that the union offers training for installing traditional heavy timber framing, not for installing mass timber products.

An additional installation difference is that extreme care must be used when moving, installing, and working with mass timber products because the timber is also the finished surface of the building. Rough framing carpenters may be unaccustomed with finish work. It is important to inform all workers in the beginning that they are handling finished products and extreme care must be taken to protect the finishes during installation. Mass timber is unlike structural steel, which will generally be covered up in the finished building. Structural steel can be hit or scraped while installing it. Mass timber products are more fragile; take longer to install; require slower crane movements and more precise guidance of the panels or columns during installation to avoid damaging their finished surfaces.

Discussion & Conclusion

More information was received about the preconstruction phase of mass timber projects because one company was currently in this phase and the other had recently gone through this phase. Rudolph and Sletten provided useful information about the construction phase because their project was currently in the construction phase. Although it was too early in the process for post-construction warranty claims, neither company anticipated any special warranty period changes or issues due specifically to mass timber.

The biggest takeaway of the interviews was that mass timber commercial construction in the US is in its infancy. A mass timber project will likely take longer and involve more steps than a traditionally constructed steel and concrete building. It may be worth educating city building officials on mass timber building systems. Education could reduce the potential for substantial delays in construction schedules and it could speed up the approval process. It might also be beneficial to offer a third-party consulting firm to help educate city building officials about mass timber prior to the start of projects.

Increased preconstruction time and complexity could be mitigated with an integrated project delivery or a design-build methodology. This would allow for easier coordination between all parties from the very beginning of the project. Extensive mechanical, electrical, and plumbing (MEP) coordination is necessary to finalize all penetration locations through the mass timber before the mass timber can be ordered from the suppliers. Design assist could be combined with integrated project delivery or design-build to bring the MEP subs on early in the job.

Mass timber is more sensitive to weather conditions. Unlike concrete and steel construction, timber products will be damaged if left unprotected in the weather for very long. It helps to schedule the mass timber erection process during a drier part of the year or to cover up the mass timber as soon as possible after installation.

The two contractors who are installing mass timber explained that neither general guidelines nor specific training of crews tasked with installing mass timber are currently available . Rudolph and Sletten ended up training their crew onsite through a mockup. Through an interview with a Carpenters' Union master instructor, it was learned that they do offer heavy timber framing courses, but these are not relevant to modern mass timber installations and products. It may be beneficial for the Carpenters' Union to offer mass timber training courses as mass timber installation uniquely differs from traditional carpentry work. It is also important to educate and inform crews that additional care is required when working on and around finished building products, even during the erection stage.

Further research is still needed in mass timber products. In the US it is still a new product that introduced new, uncommon construction methods. There is a shortage of research into the installation methods of mass timber. General guidelines and standards need be produced and published. Guidelines and standards could guide contractors who are working on mass timber projects. Streamlining of the preconstruction and construction processes could reduce overall project duration. City building officials may not be experienced with mass timber products and design. Research on how to educate city building officials in the most streamlined way of getting a mass timber project approved would be useful for contractors who are starting a mass timber project. Finally, research on possibly standardizing mass timber products between manufacturers would be useful. Standardized general specifications and properties could be referenced by anyone on the project without relying on the specific manufacturer chosen for the project, or before a specific manufacturer has been chosen for the mass timber products. This would greatly simplify the design and approval process of a mass timber project.

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