Chubb Construction Risk Engineering

Mass Timber Construction

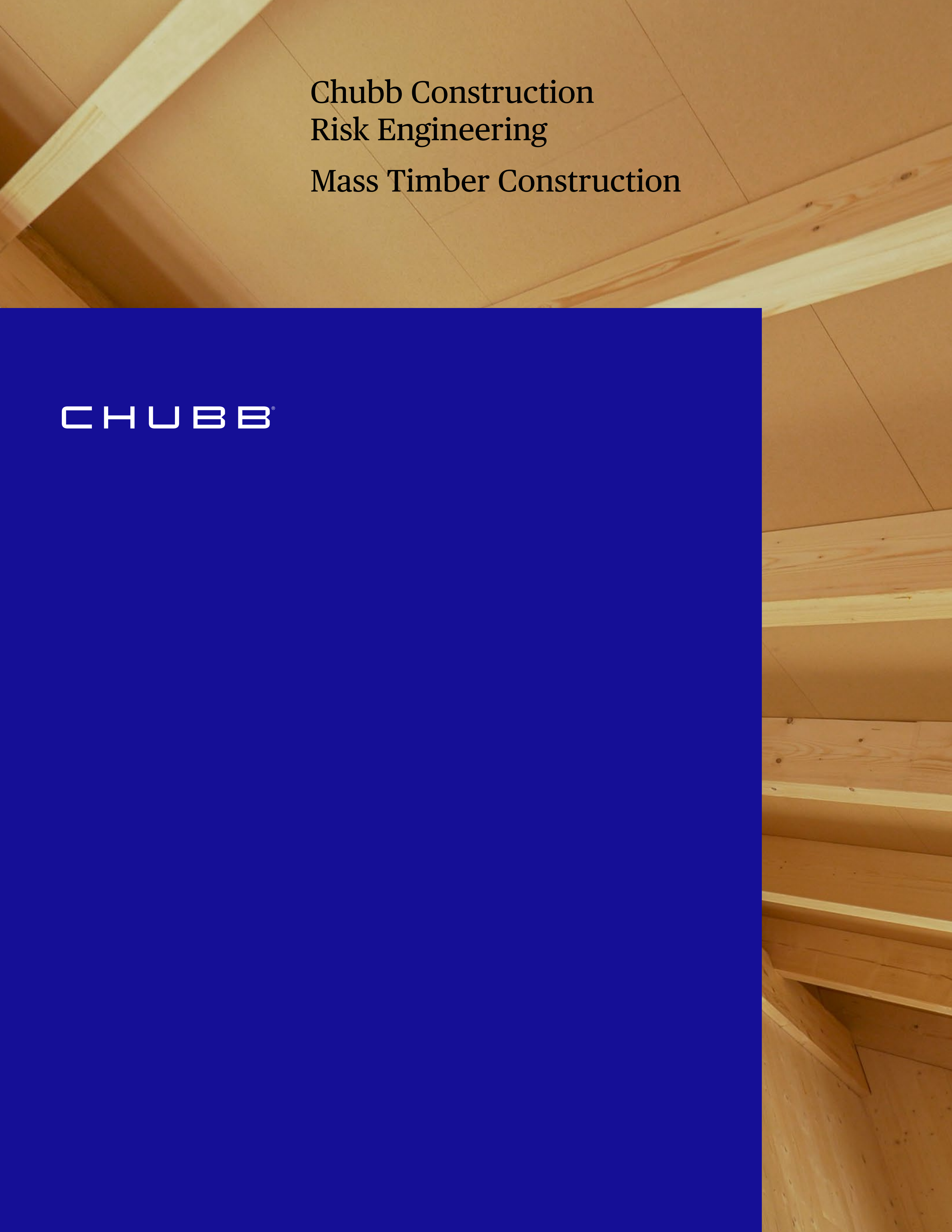


Table of Contents

Detail of modern wooden architecture in glue-laminated timber (Glulam)

As the construction industry continues to focus on building environmentally friendly structures with an emphasis on sustainability, mass timber – a natural and renewable material that is also aesthetically pleasing – is becoming a popular alternative to traditional construction materials such as steel and concrete.

In Europe and Australia, timber has been a popular building material used in the construction of residential, commercial, and educational structures for many years. While mass timber construction has not been as prevalent in the United States, it has garnered increased interest and momentum in recent years. However, despite that growing interest, mass timber is still a fairly underutilized material here, and as such there have not been many U.S. case studies that assess the actual construction feasibility of mass timber for industry professionals. In turn, this could also partially account for reluctance in its expanded use.

Cross-laminated Timber (CLT) panels

Mass timber represents a relatively new type of construction in North America. Although many mass timber products have been incorporated into buildings for nearly 100 years, the rise of cross laminated timber (CLT) in North America has led to advances in wood construction, allowing buildings as tall as 18 stories to be constructed out of wood. Although mass timber holds great promise as a new market for wood materials, research is needed to open new markets for this type of construction.[1]

Mass timber construction projects in the U.S. have typically consisted of low-rise structures, with projects including hotels, high-end offices, multi-family housing, college dormitories, schools, and museums. Proponents of mass timber systems emphasize their importance in reducing the carbon footprint of buildings.

What is Mass Timber?

Mass timber is a category of framing styles typically characterized by the use of large solid wood panels for wall, floor, beam, and roof construction. Mass timber systems typically comprise 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. This material competes with more traditional building material such as concrete and steel and provides several advantages over those materials, such as improved aesthetics, increased carbon capture, superior resilience to earthquakes, and improved indoor and outdoor environmental performance.[2] There are several types of mass timber building systems available in the marketplace.

Two of the more prevalent systems are Cross-laminated Timber (CLT) and Glue-laminated Timber (Glulam). CLT is typically used for floor, roof, and wall framing, while Glulam is utilized for columns and beams.

- Cross-laminated Timber (CLT) panels are large wood panels made up of several layers of dimensional boards, ranging from approximately 0.625 inches to 2 inches thick. Each layer is laid perpendicular to the previous one before being finger-jointed and glued together with polyurethane, melamine, and phenolic-based adhesives to create one continuous structural panel that can be as large as 10 feet wide by 60 feet long. The panel is known to have exceptional strength dimensional stability and rigidity. CLT has been used as both a stand-alone system and as a product that can be used together with other wood products. CLT panels are typically utilized for structural components such as wall, roof, and floor slabs, but they can also be utilized in hybrid and composite applications.
- Glue-laminated Timber (Glulam) consist of individual layers of wood that are laid parallel to each other, glued together, and end jointed. The grain of all laminations runs parallel with the length of the member, 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. Additional laminations can be added to increase the height of the beam and suit structural load requirements. Typically, Glulam is used for beams and columns however, architects can use Glulam in plank systems for floors and roofing. With the flexibility of Glulam manufacturing, panels can be used to create complex curvatures and geomatic shapes. 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.
- In addition to CLT and Glulam, there is also Nail-laminated Timber (NLT) which is created from individual dimension lumber members (2x4 feet, 2x6 feet, 2x10 feet, etc.) stacked on edge and fastened by nails or screws to create a larger structural component. NLT is not new and has been around for more than 100 years. It is commonly utilized in floors, decks, and roofs. In addition to floors, decks and roofs, NLT has been used for elevator and stair shafts.[2]

Mass timber, specifically CLT, offers several environmental benefits over traditional steel and concrete building construction

Sustainability

According to the 2019 United Nations Global Status Report for Buildings and Construction Sector, "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 manufacturing for building construction, such as steel, cement, and glass.[3]

As a result of its strength and dimensional stability, mass timber offers low carbon alternative to other construction material such as steel, concrete, and masonry. Mass timber, specifically CLT, also offers several environmental benefits over traditional steel and concrete building construction. One study 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.[1] Another study reported that wood-based material consumed 15% less energy compared to concrete over the life cycle of the building. Other reports show that mass timber buildings have 10% lower operational energy demands compared to similar concrete buildings.

Structural Performance of Mass Timber Products

The physical and mechanical properties of wood are two of the most important factors of the structural performance of mass timber materials. Most mass timber panels consist of multiple timber layers in either orthogonal or parallel orientation that act as reinforcement for a mass timber panel. Similar to a concrete slab, the adjacent layers add dimensional stability and allow timber panels to carry the load in both horizontal and vertical directions. Further, mass timber panels have been found to have high shear strength and low deflection. The high strength-to-weight ratio of mass timber panels has also increased the use of wood-based products in a wider range of buildings such as residential, commercial, and educational buildings. Mass timber material allow architectural flexibility during the design process by providing more open spaces without compromising the structural rigidity of a building. Additionally, mass timber panels create an effective lateral load resisting system because of their dimensional stability and rigidity, which leads these materials to perform well against seismic vibration. Mass timber also provides exceptional acoustic performance.[2]

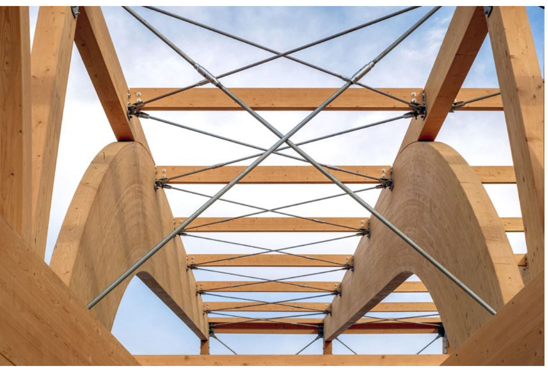
Seismic Safety

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, Glulam, CLT, steel, and concrete – found that a structure composed of a combination of Glulam and CLT products demonstrated exceptional dynamic behavior, resulting in higher dampening coefficients and reduced floor displacements when compared to the other materials.[3]

To assess the seismic performance of mass timber products, a seven-story building in Japan was tested on the world's largest shake table and the building survived 14 consecutive events with zero damage.[2]

Fire Safety

Fire safety is a major factor and consideration when designing and building a project. The current regulatory framework for a building's fire resistance says that the building must be able to remain structurally sound throughout the burnout phase of the fuel load, that is, the phase in which the fuel load inside the building, such as furniture, burns completely. A benefit of mass timber construction is that it has what is called self-protection. This means that 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. Char rate is considered when designing mass timber elements to predict the depth of the charred timber.



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 ignited. However, as the CLT charred, the fire ended up self-extinguishing once the internal temperatures lowered. This promising case study indicates that properly designed CLT buildings can actually self-extinguish during a fire event.[3]

A team of fire experts from the U.S. Bureau of Alcohol, Tabaco, Firearms and Explosives (ATF) working alongside scientists from the U.S. Forest Products Laboratory tested five identically furnished one-bedroom apartments constructed of exposed, partially exposed, and unexposed five-ply CLT. The rigorous series of fire tests demonstrated that mass timber construction performed equivalent to non-combustible construction and provided valuable data that was used in the development of code change proposals by the ICC Ad Hoc Committee on Tall Wood Buildings (TWB) for the 2021 International Building Code.[4]

Moisture Safety

One of the primary concerns with mass timber systems is the potential decay from elevated moisture contents. When wood reaches levels of above 25% moisture content, it becomes susceptible to biodeterioration and decay. While there are a host of environmental and other benefits to building with mass timber, these buildings are different from steel and concrete buildings as the physical and mechanical properties of wood change with its moisture content. Wood-moisture interactions can lead to difficulties in the utilization of wood, including dimensional instability, cracking, microbial attack, and fastener corrosion. Understanding the amount of moisture and range of moisture fluctuations that can be expected in North American mass timber buildings is necessary for more informed design of mass timber buildings. Because CLT can take a long time to dry out if it gets wet, it is important to understand what moisture exposures the CLT experiences on the job site, what the starting moisture content of the CLT panels are when the building is finished, and how quickly the CLT reaches an equilibrium with its environment.[5] The utilization of moisture monitoring sensors installed at the CLT manufacturing facility – as well as sensors placed throughout the job site location – is essential when collecting data valuable in understanding this science. Additionally, sensors must be robust enough to withstand adverse environmental conditions because mass timber is being installed without the building envelope fully finished.

Protecting mass timber components – which can be as simple as wrapping CLT panels during storage and shipping – is effective in protecting them from the rain. Construction project sites utilizing mass timber products must proactively address the weather and take necessary measures in safeguarding the material from the elements.

Although the majority of the studies illustrate that the construction cost of mass timber buildings are more expensive than traditional concrete and steel buildings, several studies found mass timber as a cheaper option overall.[2]

Economic Considerations

Cost plays a significant role in determining the building material and elements that will be utilized to build a particular structure. Although there have not been many mass timber buildings built in the U.S., sufficient cost information has been derived from the projects located in Europe and Australia. As an example, the Murray Grove Building in the United Kingdom experienced a 30% increase in material costs of cross laminated solid timber components compared to the cost of reinforced concrete construction.[2] According to one study, the construction of mass timber building can be up to 4% higher than the cost of using concrete. Another study found that for a six-story building in New Zealand, the predicted construction cost of a timber building is approximately 6% higher than its steel and concrete counterpart.[2] Yet another study looked into construction cost for a mass timber building in the United States and found that for a single-family residential building, the construction cost of using mass timber can be 23% higher than using traditional light framed timber options. Further, construction cost of mass timber building in Canada was found to be 6.43% higher than the same building designed with concrete material.[2] Although the majority of the studies illustrate that the construction cost of mass timber buildings are more expensive than traditional concrete and steel buildings, several studies found mass timber as a cheaper option overall.[2]

Additional cost factors that should be understood include the cost of material transportation, storage, handling, and logistics. For example, as a result of its large size and weight, there are limits to the amount of CLT that can be loaded onto a truck, and that often means that projects utilizing CLT require more trips to the construction site. One must also consider the environmental issues tied to additional trucks on the road. In comparison, trucks can be loaded with significant more sections of metal decking for floor slabs, which reduces transportation and delivery costs.

The size of CLT can also become a factor on construction sites in urban environments where the site has limited space to store material. The weight of mass timber systems can also limit the number of pieces that can be stored on site or in the building due to concerns related to overloading or point loading. Further, the size and weight of mass timber systems may require larger cranes to off load and hoist the material, which could also result in additional costs.

Consideration must also be given to 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 if that project utilizes CLT, all of the panels are fabricated offsite to exact specifications and for exact locations in the project beforehand. As a result, 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 the MEP penetrations to be cut at the appropriate locations by the supplier during fabrication.[3]

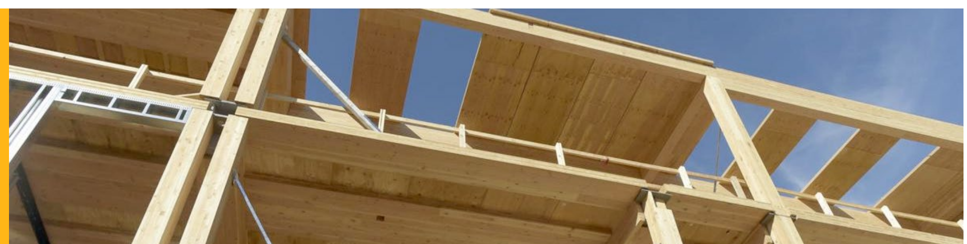
Craft Labor

As a relatively new building system, construction firms may encounter challenges in finding work crews with experience constructing buildings with mass timber products. This can result in productivity concerns as crews have to overcome learning curves during the installation process. Unfamiliarity with a new building system can result in safety-related issues and accidents as well.

Another concern is that failure to properly handle the installation of the mass timber can result in damage to the finished product. As noted, one of the appealing aspects of mass timber is its enhanced aesthetics, and damage can have severe financial implications if the members need to be repaired or replaced.

It is imperative that building contractors hire experienced subcontractors and work crews that are properly trained in the installation of mass timber elements. Failure to do so could result in re-work, accidents, construction defects, and delays in the construction schedule, all of which could have a detrimental impact on the overall success of the project.

Oregon State University Peavy Hall CLT Issue



In December 2016, Oregon State University (OSU) began construction of Peavy Hall, which would be the home of its new forestry school. The building would be constructed with a mass timber construction system consisting of Glulam posts and beams and CLT floors and walls. The three-story building would contain 641 CLT panels, made from 2-foot-by-6-foot boards of local Douglas Fir. The project comprised three zones, Zone 1, Zone 2, and Zone 3. Of the 641 panels, 544 were floor panels and 97 were wall panels. As of March 2018, OSU estimated that 500 panels had been installed. Zone 1 was completed with the installation of 307 floor panels and 34 wall panels. Zone 2 was underway – 188 floor panels and 41 wall panels had been installed – when a failure occurred.

Two layers of a seven-layer CLT floor panel measuring 30 feet by 4 feet came unglued and crashed 14 feet from the third to second floor of the three-story building.[6]

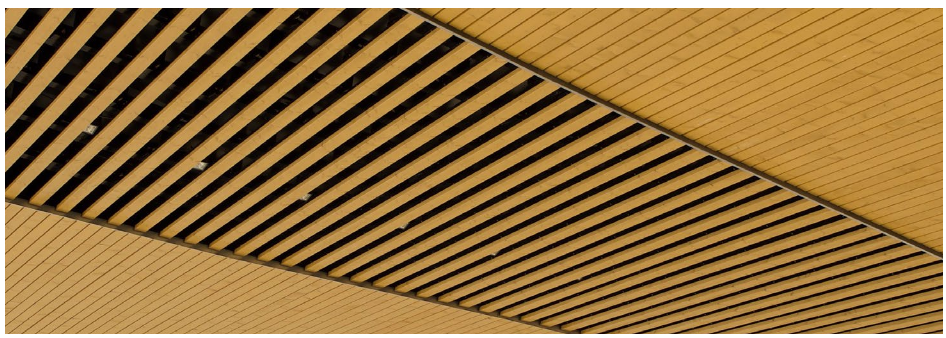
An investigation ensued into the cause of the CLT panel delamination. The entities investigating the delamination generally concur on the cause: a process change at the manufacturer's mill facility created poor bonding between the adhesive and the layers, in some panels. In a period of cold weather, in a mill that was not environmentally controlled, the manufacturer preheated the wood materials and applied structural adhesive between layers, which were then pressed into CLT billets and fabricated into panels. Preheating the wood caused premature curing of the adhesive and resulted in poor bonding of the layers of 2-foot-by-6-foot boards.[6]

Fortunately, the failure did not result in any worker injuries nor any structural damage. It did, however, result in project schedule delays and increased project costs. This incident emphasizes the importance of implementing stringent quality assurance/quality control (QA/QC) measures at the manufacturing facility as well as the project site.

Summary

Mass timber construction continues to evolve as a building product here in the United States. As a relatively young construction method, there is a lack of substantial studies into its performance. Further research is necessary for a more comprehensive understanding of this building system, and academia, architects/engineers, manufacturers, and general building contractors must work collaboratively to better understand and improve its capabilities.

The research study conducted by Shafayet Ahmed and Ingrid Arocho from the School of Civil and Construction Engineering at Oregon State University indicated that the construction costs of mass timber buildings is up to 5% more expensive than the other types. However, the study also indicated that mass timber building projects are completed 5% faster than concrete and steel buildings. Further, 45% of the participants indicated that mass timber construction process is safer because of prefabricated nature of timber panels, small crew size, shorter duration, and minimal use of construction equipment such as scaffolding and formwork. However, inexperience, defected products, and fire hazards are identified as some of the negative safety concerns of mass timber construction.



Mass timber is also more sensitive to weather. Different from steel and concrete construction, timber products left exposed and unprotected from the weather for an extended time-period will be susceptible to damage.

Fire safety remains a critical element associated with mass timber construction and further research and studies are required to better understand how mass timber buildings act during a fire. This will be a step toward ensuring that appropriate safety measures are adapted into building codes and architectural/engineering drawings.

As identified in the USDA Research Needs Assessment for the Mass Timber Industry Workshop, research must forge ahead on numerous topics associated with mass timber construction, including – but not limited to – the following:

- Research on CLT shear wall performance and seismic design coefficients
- Develop building codes approved prescriptive designs for CLT diaphragms and shear walls
- Determine how duration and severity of wetting affect mass timber products (dimensional change, surface mold, biological deterioration, corrosion of connections, etc.)
- Develop written specification language that incorporates best practices for moisture management during and after construction

- Perform two-hour fire testing on a wide variety of connections and mass timber configurations
- Research improvements to the American Wood Council 2018 TR-10, Calculating the Fire resistance of Wood members and Assemblies, regarding more efficient testing and design methodology for protection of connections in wood
- Develop nondestructive evaluation techniques to evaluate the structural condition of CLT panels in service
- Evaluate performance of connections and panels as panels shrink and swell because of moisture exposure
- Evaluate the integrity of fasteners and structural connections between mass timber products after moisture cycling
- Conduct whole building life cycle assessments to compare mass timber buildings with those constructed of steel and concrete
- Develop methods for repair and remediation of mass timber products in the field
- Develop intermediate scale qualification tests for adhesives to verify that the adhesive doesn't lead to delamination and fire regrowth
- Evaluate the termite resistance and feasibility of pressure treated Glulam and CLT

References

1. United States Department of Agriculture - Research needs assessment for mass timber industry. Proceedings of the 2nd North American mass timber research needs workshop. September 2019.
2. Mass Timber building material in the U.S. Construction industry: Determining the existing awareness level, construction related challenges, and recommendations to increase its current acceptance level. Shafayet Ahmed, Ingrid Arocho School of Civil and Construction Engineering Oregon State University.
3. Highlighting the Unique Challenges and Differences of Building with Mass Timber. Ryan L. Richmond California Polytechnic State University.
4. Architectural Record August 2020.
5. Moisture monitoring throughout construction and occupancy of mass timber buildings S.L. Zelinka, S. Kordzeil, S.V. Glass, P.C. Tabares-Velasco – 1st International Conference on New Horizons in Green Civil Engineering (NHICE -01), Victoria BC, Canada, April 25-27, 2018 published by the University of Victoria in Victoria, BC.
6. ENR Regluing Oregon State's Showcase for Mass Timber.

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