Tall Mass Timber Buildings

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A New/Old Construction Method

Multistory structural wood construction is not a new technology. The Jokhang Monastery in Lhasa was built in the seventh century and is one of the oldest multistory timber framed structures in the world. In Asia several examples exist today of wooden pagodas that date back over a thousand years. In the United States densely populated urban centers through the mid 1800's saw multistory wood frame buildings soar in popularity due to an affordable and plentiful supply of tree stock. As cities grew ever denser, tall wood buildings fell out of favor and were even outlawed due to the inherent fire dangers of wood frame construction. In the Great Chicago fire of 1871 for example, where most of the buildings were constructed of wood framing, over 3 square miles of the city was destroyed by fire.

Nevertheless, today we are seeing a resurgence of taller multistory wood buildings in urban centers thanks to a relatively new method of wood construction, mass timber. Builders and designers are advocating for tall mass timber buildings for a number of reasons; some appreciate the aesthetics, while others are conscientious of the sustainable features of wood. In some instances, cost savings and quicker pace of construction compared to concrete, steel or masonry structures are the driving factors.

A Growing Technology

Still in its infancy, mass timber has enormous potential and is positioned to change the way we build tall buildings. Over the past decade, mass timber has been increasingly utilized in multistory projects across the US. WoodWorks, a not for profit national leader in mass timber design that provides a ranger of support services to architects and engineers interested in designing and building with mass timber technology, tracks the growth of the market. As this this chart shows the volume of mass timber projects built or under construction throughout the US, though fledging, is gaining acceptance.

Mass Timber Projects In Design and Constructed in the US (December 2019)

Graph by permission, WoodWorks.org

Already, mass timber buildings have reached heights of eight stories in the United States, as in the Carbon 12 building in Portland, Oregon by Kaiser Group + Path Architecture, and eighteen stories in Europe, for the Mjostarnet building in Brumunddal, Norway by Voll Arkitekter, something that would have been unheard of just a few years ago.

Technology

Unlike traditional stick frame construction, mass timber refers to a family of wood technology that can take on any number of wood tectonic features. Structural Engineer Tanya Luthi of Entuitive has been focused on mass timber structures since her first mass timber building, the MEC headquarters in Vancouver, which was completed in 2013, puts it like this: "Rather than using individual dimension lumber pieces spaced apart and connected with sheathing, leaving air gaps within the structure, mass timber consists of large cross-sections and panelized products which are solid wood".

One example of a mass timber product is cross laminated timber, (CLT), which refers to a method of binding standard framing members together to create large plates or planks. Think of plywood, but instead of thin sheets of veneer, standard 2x framing members are adhered together to build up large sheets. On the other hand, where CLT panels are typically held together by adhesive, nail laminated timber (NLT) products are held together by nails, which in itself is an older technology found in many low-rise manufacturing and commercial buildings of the industrial revolution. Dowel laminated timber (DLT), are similar to NLT, only timber pegs are used to bind the members together instead of nails. Glued laminated timber (GLT), a much older mass timber product, is typically used for beams and columns as well as floors, roofs and walls, have been around for over seventy-five years. A large benefit of mass timber is that components are often manufactured in a controlled factory setting in order to deliver precise dimensional products that are suited to each specific situation.

In the case of NLT, it doesn't necessarily have to be manufactured in a factory, but can be built on site[i]. NLT panels can be used where only a single directional structural system is required because there is only a single layer of boards nailed together all running in the same direction. CLT products on the other hand are typically manufactured in a controlled environment with precise CNC machining and large presses to bind the members with either glues or timber pegs. Typically, they are made up of 3, 5 or even 7 layers which makes them more ideal for two directional structural systems that can handle shear better than single span NLT. In theory, they can be made in any dimension of either direction, the size typically limited by manufacturing equipment, transportation and handling.

Luthi recommends understanding the different products in the mass timber family and selecting the right system for the application at hand. "Products like NLT and glulam are well-suited for structural elements that span only in one direction, such as beams or floors, or in the case of roof slabs that are supported on beams or walls. CLT, with its bi-directional spanning capability, can be used for point-supported floor or roof systems and can also resist in-plane forces, which makes it a good candidate for shear walls."

Tyler Freres of Freres Lumber, a west coast manufacturer of plywood panels, has developed a unique panel he calls Mass Plywood Panel (MPP), a product tested and designed with the help of the Tallwood Design Institute, that consists of sheets of density-grade Douglas Fir veneers glued and pressed together creating large-format platforms, beams and columns ranging from 1" to 24" thick. A patent is pending.

Image Curtesy of Freres Lumber Co, Inc.

Where CLT panels are built up using 1 ½" thick framing lumber, MPP are manufactured using 1/8" thick veneer sheets. Freres says that the orders are rolling in from around the world, which shows the interest in innovative mass timber construction. When it comes to product stability given inherent defects in wood, Freres points out that "MPP is more stable and prone to less defects than CLT because each 1/8" layer of plywood limits the defects, such as knots, to a small area as opposed to CLT where the defect of the wood has a larger cross section". Though this is somewhat of a variation on the theme of more common CLT panels, it shows the interest and creative enthusiasm for engineered wood products. As for sustainable products, Freres goes on to say that "because wood sequesters CO2, it's also the right thing to do".

Sustainability

When sustainability is a criterion for product selection, initial evidence suggests wood is more sustainable and requires less embodied energy to harvest, manufacture and install than either steel, concrete or masonry. There are three key areas where wood excels in being green.

The first is sustainability of forests. Our forests are growing at a faster rate than we are harvesting them for wood consumption. A February 2018 report by the USDA Forest Service study shows that wood and timber demand vary based on domestic US GDP projections which are linked to housing starts[ii]. Because of best practices in forestry, forests now yield a greater supply of wood than demand. According to a July, 2017 report on southeastern forests, prepared by leading wood chain supply experts Forest2Market, healthy forest demand yields better forestry conservation practices that lead to greater wood supply[iii]. As demand for mass timber construction for taller buildings increases, it follows suite that tree harvesting will need to increase to keep pace.

The second is embodied energy, the measure of how much energy is used from the extraction of raw material to final product installation. A primary goal of sustainability is to reduce the amount of embodied energy used in making our world a better place to live. Reducing energy consumption is one way of doing that. Buckminster Fuller called this "the doing of ever more with ever less". Studies have shown that steel and concrete contain more embodied energy than wood beams and require more fossil fuel consumption than glulam beams. According to a report published in the Journal of Sustainable Forestry in 2014 led by Chadwick Daring Oliver, a forestry professor at Yales School of Forestry and Environmental Studies, shows that by substituting wood for steel or concrete in construction worldwide, we could see a savings of global CO2 emissions at around 14% to 31% and fossil fuel savings of 12% to 19%[iv].

The third is carbon sequestering. Wood retains CO2 and only releases it when it decays or burns. Sequestering of CO2 contributes to the reason that wood has lower embodied energy than other materials, and also the means by which the construction industry can achieve a greater goal in reducing CO2 emissions.

Economics of Mass Timber

Another benefit of multi-story mass timber is the potential for reduced construction cost and time. When considering surface area ratio to building volume, the economics of mass timber for high rise buildings can make sense, but only if we see a significant growth in the industry and we see more manufacturers, suppliers and contractors getting on board. Getting the cost of mass timber components in line with more traditional construction methods is a challenge. Mass timber expert Tanya Luthi cautions that cost comparisons are not always predictable. "You need to know your market. It's not just about the cost of timber; concrete and steel prices fluctuate as well, and in smaller cities when one trade gets very busy, you can see a sudden spike in bid prices. Those can be opportunities for mass timber to begin making inroads." In addition, steel and concrete are mature industries with standardized products while mass timber is still in its relative infancy, and manufacturers fabricate slightly different products in terms of sizes, wood species, and structural capabilities. "In the early days of structural steel, producers all had their own catalogues of shapes. Over time, the industry became standardized, and now a W18x40 steel beam for example is the same regardless of which mill rolled it. It's not yet clear whether we will see a significant push towards standardization of mass timber products, so that will be an interesting trend to watch."

Some projects have already seen the cost benefits such as in T3, a seven-story mass timber mixed use office building in Minneapolis, MN built in 2013 by Michael Green Architecture and DLR Group[v],[vi]. Lessons learned from this project showed that the building's weight was significantly less than if it were made of steel and concrete, reducing the size of the foundation which saved time, money and embodied energy. There were also interior costs savings due to the ability to expose the mass timber products without the need to cover them over with finishes, and since the components were supervised by a manufacturing company, on site fabrication was quicker to erect than other traditional construction methods.

T3 Minneapolis, MN

Mass Timber in The Building Codes

Mjostarnet in Brumunddal, Norway, reached a height of 85.4 meters and has been verified as the world's tallest mass timber building by the Council on Tall Buildings and Urban Habitat[vii]. In order to achieve such height in wood, several technological as well as building code challenges had to be addressed. The most critical being at what rate does mass timber burn and what requirements are needed to meet health, safety and welfare of the public as defined in the International Building Codes for example.

Tests demonstrate that wood chars when it burns which helps to reduce its burn rate and behaves in a very predictable way, thus mass timber provides a formidable barrier against fire with predictable burn behavior[viii]. Even in the case of exit stairways and elevator shafts built almost entirely of structural mass timber, as in the case of the 13-story tall residential Origine building in Quebec, by Yvan Blouin Architecte. The elevator and stair shafts were constructed of CLT panels and were proven to meet code standards that maintain integrity required during an emergency[ix].

In December of 2015, the International Code Council, (ICC), formed the Ad Hoc Committee on Tall Wood Buildings (TWB) to study the building science for tall wood buildings and propose revisions for the upcoming 2021 edition of the International Building Code (IBC). The outcome of the study will modify Table 6 of the IBC to expand Type-IV Construction to include three new categories, Type-IV A, Type-IV B & Type-IV C, each progressing in fire rating from non-combustible to combustible, and each progressing from allowed higher-rise to a lower-rise construction. Type-IV HT will remain mostly the same. The International Codes Council has adopted these changes in the upcoming 2021 International Building Code that broaden the use of mass timber by the expanding categories of building construction types, raising heights to 270 feet (80 meters) and by updating other sections to address mass timber.[x] Though many questions still remain, and not all jurisdictions, such as the New York City Building Codes, are quite on board yet.

Table 601 Fire Resistant Rated Construction

BUILDING ELEMENT	***Type I***		***Type II***		***Type III***		***Type IV***				***Type V***	
	A	*B*	*A*	*B*	*A*	*B*	***A***	***B***	***C***	*HT*	*A*	*B*
Primary structural frame	3	2	1	0	1	0	**3**	**2**	**2**	HT	1	0
Bearing walls,												
Exterior	3	2	1	0	2	2	**3**	**2**	**2**	2	1	0
Interior	3	2	1	0	1	0	**3**	**2**	**2**	1/HT	1	0
Nonbearing walls and partitions, Exterior	*See Table 602*											
Nonbearing walls and partitions, Interior	0	0	0	0	0	0	**0**	**0**	**0**	See Section 2304.11.2	0	0
Floor Construction	2	2	1	0	1	0	**2**	**2**	**2**	HT	1	0
Roof Construction	1-1/2	1	1	0	1	0	**1-1/2**	**1**	**1**	HT	1	0

Table available at the ICC TWB web site[xi]

What seems to be a new field in timber application for the construction industry, is really a rethinking, reshaping and advancement of technology that has been around for thousands of years. Today's mass timber movement is a body of science that is based upon concepts and ideas that have been around in various forms for millennia, and only now being expanded upon to employ modern techniques that are driven by innovation and a need for a more sustainable future. Necessity is the mother of invention, and here, we stand on the shoulder of giants in order to address critical needs of an expanding population in a world of diminishing resources.

As mass timber becomes more common, inclusive of the multifaceted processes involved, from forestry harvesting to building tectonics, more will be learned as to the real benefits and consequences of tall mass timber buildings. Due to the relatively recent implementation of mass timber construction though, life cycle metrics are still being gathered to understand their techno-economics. There are now many tall mass timber buildings throughout the US and Europe and data as to the durability and performance of these buildings is being gathered. Durability questions of some of the older mass timber buildings in Europe, Austria, Germany and Switzerland in particular where mass timber first started in the mid 1990's, are still open[xii]. A study conducted by the U.S. Forest Service in 2018 looked at moisture penetration of mass timber products and concluded that most tests done were factory controlled, and real-world analysis of whole buildings in use over time are still needed[xiii].

Finally, it often comes down to the public psyche whether or not a product or system becomes a fundamental tool in every professional toolbox or is shelved as yet another hopeful. At a glance, and with just a few clicks of Google word search, it seems likely that the mass timber train is charging full steam ahead. Studying how mass timber has been used in the past, and how it is being developed in architecture and engineering firms may lead to some interesting and as yet unidentified solutions. The bottom line is that mass timber in urban settings has very strong psychological ramifications as cities made of wood have a history of catching fire. It is these obligatory research studies that will create the basis for comprehensive solutions to addressing critical issues in mass timber construction across the country, around the world, and in particular within dense urban environments.

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[i] Treehugger.com "The Old is new again with nail laminated timber"; (https://www.treehugger.com/green-architecture/old-new-again-nail-laminated-timber.html)
[ii] https://www.srs.fs.usda.gov/pubs/ja//2017/ja_2017_prestemon_004.pdf
[iii] https://www.forest2market.com/blog/forest2market-report-shows-increased-demand-for-wood-fiber-leads-to-forest-growth and https://www.forest2market.com/hubfs/2016_Website/Documents/20170726_Forest2Market_Historical_Perspective_US_South.pdf
[iv] https://doi.org/10.1080/10549811.2013.839386 and https://chadwick-dearing-oliver.org/news/2018/11/6/using-more-wood-for-construction-can-slash-global-reliance-on-fossil-fuels
[v] https://www.dezeen.com/2016/12/02/michael-green-architecture-t3-largest-mass-timber-building-usa-minneapolis-minnesota/
[vi] Architecture Magazine, November 2016 issue; "T3 Becomes the First Modern Tall Wood Building in the U.S."
[vii] https://www.ctbuh.org/news/mjostarnet-tallest-timber-building/

[viii] Fire Design of Mass Timber Members: Code Applications, Construction Types and Fire Ratings, McLain, Breneman, Woodworks Wood Product's Council

[ix] The 13-story tall wood residential building, Origine by Yvan Blouin Architecte, is built entirely of solid timber, has bearing and shear walls, stairwells, elevator shaft, floors and roof framing built of cross-laminated timber (CLT), glue-laminated timber (glulam) posts and beams.

[x] The 2021 version of the International Building Code will be coming out shortly and will include chapters specifically addressing CLT and other systems not previously included. The New York City Codes Council is still debating the adoption of any specific language in the city code that allows for tall mass timber construction which is presently not allowed in NYC.

[xi] https://www.iccsafe.org/wp-content/uploads/TWB-Response-to-Concerns-Raised-at-Hearings_8_1_18-_Posted.pdf

[xii] First patented in France in 1985, cross laminated timber was first used in buildings in Germany, Austria and Switzerland in the mid 1990's

[xiii] study conducted at the US Forest Service, Department of Agriculture: https://www.fpl.fs.fed.us/documnts/pdf2018/fpl_2018_wang003.pdf