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Mass Timber: The New Sustainable Choice for Tall Buildings

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Abstract

Professionals who work in the realm of tall building design and construction are well aware that high-rises are the best solution for accommodating growing urban populations. Until recently, few would have thought to include tall *wood* buildings as part of that solution, but there is growing awareness that tall mass timber structures can help satisfy the need for density while addressing the need—equally urgent—for a more sustainable built environment. This paper examines the trend toward tall wood buildings in the United States, including their history and international influences, market drivers, structural performance, and economic viability, as well as building code changes that allow wood structures up to 18 stories. It highlights examples of mass timber projects, with an emphasis on benefits that impact return on investment.

Keywords: Tall wood, Mass timber, Cross-laminated timber, Wood high-rise

1. Why Tall Timber?

The math is straightforward. Analysts predict a 30% increase in the global population by 2050. More people are choosing to live in cities and fewer in rural areas, and this trend is expected to continue. In 2018, 55% of the world's population lived in urban centers; in 2050, that number is projected to be 68%. In the U.S. alone, cities will have to accommodate an extra 76 million people in that timeframe. (UN DESA, 2018) With limited room for horizontal expansion, they'll have to build up.

The other part of the equation is sustainability and, in particular, the carbon footprint of the built environment. According to Architecture 2030, the embodied carbon of new buildings—which refers to greenhouse gas (GHG) emissions resulting from the manufacture, transportation, and construction of building materials—makes up 11% of global GHG emissions and 28% of all building sector emissions. As buildings become more energy efficient, embodied carbon is also becoming proportionally more important. While operational energy has in the past resulted in far greater emissions than embodied energy, the two are expected to be roughly equivalent within the next 30 years.

What if there was a material that offered the performance and safety of conventional high-rise building materials, but was also renewable and sustainable, sequestered carbon, had less embodied energy, and could positively impact the wellbeing of building occupants. What if buildings made from this material could be constructed more quickly than typical high-rises, and were cost-competitive?

This material does in fact exist; it is the group of products collectively known as mass timber. And while there is no single answer to complex societal issues such as population growth and climate change, tall mass timber buildings offer an important opportunity to help address the need for both urban density and sustainable construction.

Figure 1. Ascent, a 25-story mass timber tower planned for Milwaukee, Wisconsin Credit: Korb + Associates (architect and rendering); Thornton Tomasetti. (structural engineer)

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2. Carbon Footprint and Forest Health

From a carbon perspective, mass timber products offer the same benefits as all wood products, which lower a building's carbon footprint in two ways.

1) Wood continues to store carbon absorbed by the trees while growing, keeping it out of the atmosphere for the lifetime of the building—longer if the wood is reclaimed and re-used. Meanwhile, the regenerating forest continues the cycle of carbon absorption.
2) Wood products typically require less embodied energy to manufacture than other building materials, and most of that comes from renewable biomass (e.g., bark and other residual fiber) instead of fossil fuels. Substituting wood for fossil fuel-intensive materials is a way of avoiding GHG emissions. Life cycle assessment (LCA) studies consistently show that wood outperforms other materials in this area (Sathre and O'Connor, 2010).

In the United States, increasing the use of wood—and mass timber in particular—also has implications for forest health; implications that are in some ways counterintuitive.

As they are in many countries, wildfires in the U.S. are getting worse (USDA, 2018) and overly dense forests are part of the problem. In the western U.S., for example, a paper published by the USDA Forest Service says that severe wildfires "have led to concerns about heavy surface fuel loading and the potential for high-intensity reburning. Ponderosa pine (Pinus ponderosa) forests, often overly dense from a century of fire suppression, are increasingly susceptible to large and severe wildfires especially given warmer and drier climate projections for the future (USDA FS, 2012)."

Underutilized species can potentially be used in mass timber, creating high value end-use markets for low value material. Mass timber products can also be manufactured from relatively small-diameter trees and biomass resources that have traditionally provided low value (such as blue-stain material from forests affected by insects). This creates a market incentive for forest thinning and other landscape restoration efforts, which in turn helps to reduce the risk of fire. This, along with the need to reinvigorate rural U.S. economies, is part of the reason states like Washington, Oregon, and California have developed policies or initiatives to accelerate markets for mass timber.

3. Global Tall Wood Precedents

While tall mass timber buildings are new to the U.S., wood structures between nine and 24 stories have been built successfully in other countries for more than a decade. Around the world, there are dozens of timber buildings over eight stories tall, including the examples shown in Table 1.

In the U.S., tall timber buildings have been constrained by a strong reliance on prescriptive building code limits and less willingness to use performance-based fire protection engineering. That said, mass timber construction has grown significantly; as of January 2020, 250 projects had utilized mass timber and hundreds more were in design. Most of the completed projects were within the size limits of the 2018 International Building Code (IBC), such as T3 Minneapolis, a 6-over-1 office building developed by Hines. A few, such as the eight-story Carbon12 project developed by Kaiser+Path, successfully used an alternative means process to go beyond the prescriptive code limits.

Table 1. Global examples of tall mass timber buildings

Building Name	Location	Stories	Completion Date
Stadhaus at Murray Grove	London, UK	8-over-1	2008
Forté	Melbourne, Australia	8-over-1	2012
Via Cenni	Milan, Italy	9	2013
Treet	Bergen, Norway	14	2015
UBC Brock Commons	Vancouver, Canada	18	2016
Mjøstårnet	Norway	18	2019
HoHo Wien	Vienna, Austria	24	2019

In 2015, with mass timber generating interest across the country, the International Code Council (ICC) established the ICC Ad Hoc Committee on Tall Wood Buildings to explore the building science of tall wood structures and recommend code changes if appropriate. After a lengthy formal process, this resulted in changes to the 2021 IBC that allow timber buildings up to 18 stories.

The 2021 code introduces three new construction types that allow mass timber, Type IV-A, IV-B and IV-C, each with a different maximum allowable height, area, and area per story. (See Figure 2.) Type IV-A allows the greatest height and area, and has the most stringent fire protection requirements (e.g., fire-resistance ratings, noncombustible protection, etc.), followed by Type IV-B and IV-C.

A number of state and city governments have adopted the tall wood code changes prior to publication of the 2021 IBC, including Oregon, Washington, and Denver, Colorado, and others are evaluating early adoption.

In addition to the new code provisions, interest in mass timber has spurred increased manufacturing capacity, creating a more abundant and reliable product supply. The combined effect is a proliferation of taller wood buildings in design across the U.S. Examples include:

- Ascent—a 25-story mass timber project in Milwaukee, Wisconsin (See Figure 1)
- TMBR—a 10-story project in Minneapolis, Minnesota that includes nine stories of residential units over ground level retail (See Figure 3)
- INTRO, Cleveland—a nine-story project in Cleveland, Ohio that includes an event space over 297 apartments

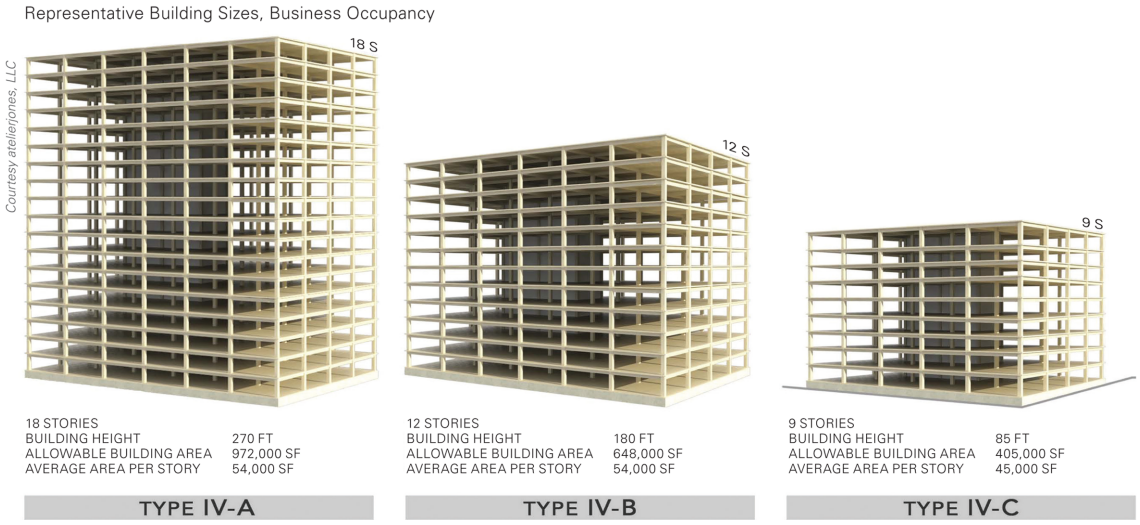

Figure 2. Allowable timber building sizes in the 2021 International Building Code Credit: atelierjones, LLC.

All three projects are scheduled to start construction this year.

4. Mass Timber Products and Performance

Mass timber is a category of framing styles typically characterized by the use of large solid wood panels for wall, floor and roof construction. Products in the mass timber family include cross-laminated timber (CLT), mass timber plywood (MPP), nail-laminated timber (NLT), dowel-laminated timber (DLT), and structural composite lumber (SCL). However, as defined in the IBC, mass timber is an umbrella term that includes heavy timber elements such as glued-laminated timber (glulam) columns and beams, with heavy timber materials and sizes serving as the prerequisite to be considered mass timber.

One thing to bear in mind is that most if not all tall timber buildings are hybrids, whether they include mass timber and products traditionally considered heavy timber, or mass timber and non-wood materials—e.g., concrete cores for lateral stability.

While mass timber products have the same carbon benefits as all wood materials, they have unique performance characteristics—such as strength and dimensional stability—that allow them to meet the structural, fire protection, seismic, and high-wind requirements for tall buildings. Mass timber systems also tend to offer extremely tight tolerances, which contribute to overall energy efficiency when used in building enclosure assemblies.

For buildings up to 12 stories, one of the great attractions to mass timber is that it can be left exposed in structural applications. Exposed heavy timber framing elements have been permitted in U.S. buildings for many years because of the inherent fire-resistance properties associated with their large size. In a fire, large members tend to retain their load-carrying ability longer than members with small cross sections; this is because a char layer forms on the surface while the interior remains undamaged and structurally sound. The predictability of wood's char rate has been well-established for decades and has long been recognized in building codes and standards—which now also recognize the inherent fire resistance of mass timber.

In the 2021 IBC, general allowance for exposed timber are:

- Type IV-A construction (up to 18 stories)—No exposed timber permitted
- Type IV-B construction (up to 12 stories)—Limited exposed timber permitted, as follows:

Ceilings (including integral exposed beams) up to 20% of floor area in dwelling unit or fire area,* or

- Walls (including integral exposed columns) up to 40% of floor area in dwelling unit or fire area,* or
- A combination of each using sum of ratios (actual exposed/allowable exposed wood) not to exceed 1.0
- Type IV-C construction (up to nine stories)—All exposed timber permitted*

*Exceptions: No exposed timber is permitted at shaft walls, within concealed spaces, or on the exterior side of exterior walls.

5. Market Drivers for Tall Wood

Some of the highest profile mass timber buildings to date—internationally and in the U.S.—have been driven by sustainability and, in particular, a desire to reduce the carbon footprint of the built environment. Development and building designers have been vocal about this objective, and their efforts are helping to generate widespread awareness that mass timber and other wood buildings can have a significant impact on carbon reduction.

While mass timber's environmental attributes often pique initial interest, other benefits that directly impact the bottom line make it economically attractive. The combination is proving to be a powerful incentive for some developers to pursue additional mass timber projects once

their first is complete.

5.1. Innovation and Aesthetic Appeal

In the U.S., the mass timber movement was initially led by public sector organizations (e.g., universities and foundations) and a few early adopters in the private sector attracted by the opportunity to create innovative, beautiful buildings. So far, most mass timber buildings completed under market-driven conditions have been creative class office developments, such as the elegantly designed Platte Fifteen in Denver, Colorado. (See Figures 3 and 4.) But the multi-family sector is also starting to see momentum.

The aesthetic value of exposed mass timber provides market distinction and has allowed early adopters to experience superior leasing velocity and attract preferred tenants—such as firms working in creative and technology—related industries. Millennials now comprise almost 50% of the U.S. workforce and they want authentic, healthy office environments that align with their environmentally-conscious ethics. Mass timber buildings are a perfect draw for companies seeking to attract high-caliber employees.

For investors, early market rate mass timber developments have shown resilience in terms of leasing and occupancy (critical issues for most office buildings), making for lower-volatility cash flows. Perception as to why these buildings lease quickly and stay occupied often centers around the belief that mass timber offers true differentiation from other office building alternatives and is a tangible way to communicate a firm's alignment with Environmental Social Governance (ESG) goals. The United Nation's Sustainable Development Goals (SDGs) are a common framework for measuring ESG. A global UN meeting report showed that building with wood from sustainably managed forests meets all 17 of the SDGs, a compelling example of how building with mass timber aligns with ESG interests.

For example, Clay Creative, a five-story 92,000-sf office building in Portland, Oregon, achieved better-than-market leasing velocity through differentiation and socio-ethical appeal to knowledge-based tenants. The developer, Noel Johnson of Cairn Pacific, said it wasn't just that the building leased quickly, but that it was also quickly occupied as a second-generation sub-lease when the first tenant outgrew the space. As Noel said, "This is a rare and value-creating feature of mass timber."

Developer Mike Heller of Heller Pacific had a similar experience with ICE Block 1, a 110,000-square-foot heavy timber office building in Sacramento, California. According to Mike, the building essentially sold itself because of its unique character—which gave him more leverage to choose the tenants he wanted; it was fully leased in less than six months. Mike said ICE Block 1 was also constructed more quickly than a typical office building made from steel or concrete, which allowed him to convert the construction loan to permanent financing more quickly.

Ben Kaiser of Kaiser+Path, developer of the eight-story Carbon12 condominium project, achieved pricing substantially above its submarket. (See Figures 5 and 6.) This project's 14 units benefit from a small floorplate that lets mechanical/electrical/plumbing (MEP) systems be centralized so most of the timber can be exposed and enjoyed with clean, modern aesthetics. Kaiser+Path is also developing a 70-unit mass timber apartment building known as The Canyons.

5.2. Cost Savings

Cost estimating mass timber systems requires a holistic approach to compare costs and yield savings. This approach considers the potential financial benefits of a shorter construction schedule and reduced installation crew. A direct comparison of the price of a mass timber structure to the price of a steel/concrete structure will not provide an accurate overall project cost comparison.

For example, prefabrication and advanced fastener technology allows faster building erection that enables shorter construction schedules that improve return on investment (ROI). As shown in Figure 7, mass timber buildings can provide schedule savings of up to 25% over comparable steel and concrete buildings. One of the major advantages is that there is no waiting time for concrete to cure and follow-up trades can begin working shortly after the timber panels are erected. There is also cost savings

Figures 3 and 4. Platte Fifteen in Denver, Colorado Credit: Oz Architecture (architect), KL&A Engineers & Builders (structural engineer), JC Buck (photos)

Figures 5 and 6. Carbon12 in Portland, Oregon Credit: Kaiser+Path (developer/architect/contractor), Munzing Structural Engineering (structural engineer), Andrew Pogue. (photos)

where the timber is exposed, since there is no need for additional finishes.

There are also labor cost advantages. Mass timber buildings require smaller crews, which saves money while reducing risk in areas with labor shortages. For example, Lendlease, a large international developer, completed a four-story CLT military hotel at Redstone Arsenal, Alabama 37% faster than a comparable metal stud building, using 43% fewer construction workers (Morrow, 2019).

For more information, *Tall with Timber: A Seattle Mass Timber Tower Case Study* (DLR Group, 2019), offers a direct design and construction cost comparison for a hypothetical

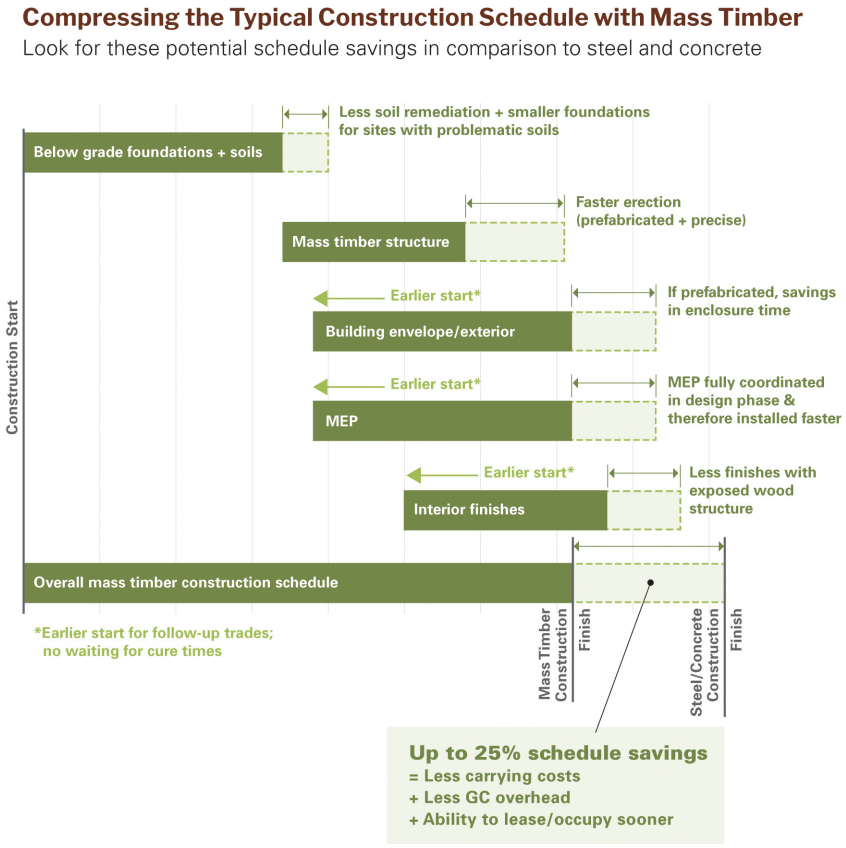

Figure 7. Compressing the typical construction schedule Credit: Mass Timber Cost and Design Optimization Checklists, WoodWorks.

12-story mixed-use building designed in mass timber vs. post-tensioned cast-in-place concrete. The authors conclude, among other things, that "the direct cost of work is higher with a mass timber frame, while the project indirect costs are much lower because of schedule savings achieved with the mass timber frame, with the result of a 0.5 percent savings for the mass timber design in the overall price of the project. The higher direct cost can be viewed as an investment in reduced tenant buildout costs because there will be fewer finishes to put in place in the completed structure. Previous studies of mass timber frames versus post tensioned structures have not accounted for the benefit to the schedule, which is a significant driver to the cost competitiveness."

In the U.S., growing interest has led to more manufacturing capacity, which has increased local product supply and is making mass timber projects increasingly cost competitive. Mass timber is expected to be especially cost–competitive in the six- to 12-story range. Noel Johnson said recently that this has traditionally been considered a "no-build" zone. Projects at this size were generally too tall to take advantage of the lower cost of light wood framing, and steel and concrete become more cost-effective at taller heights.

Mass timber also offers benefits for projects with staging area and weight constraints. Because of the way panels are delivered and erected using just a crane, it is ideally suited to urban infill sites. Meanwhile, wood's relative light weight can reduce foundation costs, and makes it a good solution for sites with poor soils and vertical expansions. Research shows that a quarter of the world's buildings are strong enough to carry additional stories made from wood (Metsä Wood).

For example, the owner of 55 South Bank in Australia wanted to add a 220-key hotel to an existing concrete structure. The design team considered concrete, but could only achieve six additional floors–which didn't come close to the 220-room goal. Instead, the team added 10 mass timber floors, meeting the objective with zero impact to the foundation and structure below.

5.3. Healthy Buildings

Exposed mass timber is more than just beautiful. An increasing number of studies focused on wood's biophilic aspects have linked the use of exposed wood in buildings with improved occupant health and wellbeing.

A recent article, *Putting Nature to Work: Biophilic Design a Boon for Corporate Culture* (Think Wood, 2019), highlights the fact that more companies are seeing the benefits of biophilic design with timber structures. Among the studies mentioned, an Australian survey of 1,000 workers revealed "a close connection between the rate of employee absenteeism, their satisfaction at work, and the presence of wood in their workplace. The more wood surfaces there are, the more people found the workplace pleasant and the more they felt connected with nature."

ULI published a study last year supporting the business case for healthy buildings. As noted on their website, "*The Business Case for Healthy Buildings: Insights for Early Adopters* reviews the evidence and profiles some early-adopter projects that have been shown–quantitatively and qualitatively–to have a positive impact on people's lives and companies' finances through healthy building design, construction, and management."

Another report, *Building the Business Case: Heath, Wellbeing and Productivity in Green Offices* (World Green Building Council, 2016), highlights a survey of 200 Canadian building owners. Thirty percent of respondents said investment in healthier buildings had a positive impact on the building's value, 46% said they were easier to lease, and 28% said they commanded premium rents.

These studies and others support the idea that exposing natural wood materials in buildings has an impact on ROI. More tenants are seeking healthy indoor environments, and wood gives a tangible response to this conceptual desire.

6. Market Acceleration: Opportunities, Challenges and Next Steps

As an organization that provides technical support and education to project teams designing and constructing commercial and multi-family wood buildings in the U.S., WoodWorks has a unique insight on the mass timber trend. In 2015, the organization assisted on a handful of projects where the architect, engineer or developer had an interest in using mass or heavy timber. Our support grew to 158 projects in 2017, 219 projects in 2018, and 266 last year. We area currently supporting more than 75 projects that exceed the building size limits of the 2018 IBC for mass timber.

We also track mass timber buildings, whether or not they utilize WoodWorks resources. As of January 2020, 714 multi-family, commercial, or institutional projects using modern mass timber materials for all or part of their structure had been built or were in design in all 50 states. This total includes mass timber and post-and-beam structures built since 2013.

There is no question that building designers and developers are interested in the new generation of innovative wood products–for the many reasons described in this paper–or that building code changes and government policies are facilitating more of these structures. But mass timber buildings are unlike other building types, and education is a necessary precursor to true market acceleration.

For example, the design of a successful mass timber building requires early coordination between the design team and key specialty subcontractors, early identification of suppliers to optimize materials, panel sizes and grids, and more. WoodWorks' national education program includes many opportunities for architects, structural engineers and others to familiarize themselves with the nuances that

are crucial to successful projects.

Since mass timber systems are relatively new to the U.S., estimating costs can also be a challenge. General contractors are understandably skeptical about advantages such as schedule savings unless they're among the few who have built a project. A few years ago, WoodWorks began running into examples of bids that priced mass timber out of the running, but closer examination showed that the bids didn't accurately reflect the realities of mass timber construction. WoodWorks is addressing the issue on multiple fronts:

- *Mass Timber Cost and Design Optimization Checklists* (WoodWorks, 2019)—Guides coordination between design and builder teams in optimizing design and estimating costs on mass timber projects. The checklists can help reduce risk for developers pursuing innovative mass timber.
- *Construction Management Training*—Increasing the pool of knowledgeable contractors, this education series is focused on supply chain, risk management, project team selection/management, and logistical planning.
- *Mass Timber Installer Training*—Installer training is being offered collaboratively with the Chicago Regional Council of Carpenters (CRCC) Apprentice & Training Program, the Northwest Carpenters Institute of Washington, and a major general contractor. Additional partnerships will be announced in 2020.

This spring will also see the launch of the WoodWorks Innovation Network (WIN). WIN is an online community that connects developers with design and construction teams, encourages collaboration, and provides networking and business-building opportunities. Features include a searchable directory of experienced mass timber professionals, project listings, and a private forum for information sharing and professional growth.

WIN scales what WoodWorks already does to the virtual world. It connects people who may want to work together on projects, helps teams identify material options, and creates a network of experts and experienced peers in multiple disciplines who can help resolve technical issues. While the initial focus is mass timber, WIN will be expanded to include other areas such as modular, hybrid, and traditional wood-frame construction.

7. Conclusion

Building designers who prioritize sustainability objectives have long recognized the value in wood's renewability and light carbon footprint. However, innovative mass timber products, which are strong enough to be used structurally in high-rise buildings, create an opportunity to help accommodate the need for urban housing in a way that also addresses pressing environmental issues. None of this would be feasible if tall timber buildings did not make good business sense. As more projects are completed, more business case data is becoming available to demonstrate mass timber's many cost-related attributes and ultimate competitiveness with other building types.

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