2024

HAYWARD FIELD,
a stop on one of
the 2023 IMTC Tours

INTERNATIONAL MASS TIMBER REPORT

INTERNATIONAL MassTimber CONFERENCE


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MassTimber℠

CONFERENCE

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ON THE COVER

HAYWARD FIELD, UNIVERSITY OF OREGON

Mass timber manufacturer Western Archrib teamed up with leaders in the fields of architectural design, structural engineering, and waterborne coatings to ensure that the iconic wooden features at the reimagined Hayward Field at the University of Oregon in Eugene are able to go the distance.

One of the design objectives was to showcase Oregon's history, culture, and industry, so 462 glulam pieces made of Douglas-fir were used to create 77 unusual curves. Each curve contains 6 glulam pieces. The design created an iconic look for the roof canopy and paid homage to the forests of the Pacific Northwest.

Engineering the wood on such a grand scale and developing a coating system to protect it from the elements were the keys to the project's success. The curved pieces were over 100 laminations deep, and the straight pieces were 59 laminations deep. The 6 glulam pieces in each curved frame had to be installed per grid line, and there were no repeat or common pieces. In other words, each piece had only 1 spot in which it could be placed. Prefinishing the glulam with 1 coat of Sansin's KP12-UVW (engineered wood undercoat) and 1 coat of Precision Coat ENS (exterior breathable topcoat) in the Western Archrib shop prior to shipment ensured proper preparation of the wood and adequate product coverage (mil thickness), and protected members in transit and in situ during construction.

HAYWARD FIELD WAS ONE OF THE STOPS ON THE POPULAR MASS TIMBER BUILDING TOURS AT THE 2023 INTERNATIONAL MASS TIMBER CONFERENCE.
For more examples of the tour stop and other activities, check out the 2023 IMTC Highlights featured in this Report.

The project's donors include Phil Knight of Nike, who competed in track and field events at the original Hayward Field while he attended the university. The 12,650-seat stadium was designed by SRG Partnership and constructed by Hoffman Construction. Hayward Field was the setting for the 2020 US Olympic Team Trials, the 2022 World Athletics Championships, and the Wanda Diamond League Final in 2023.

The creation of one of the world's most amazing outdoor stadiums took teamwork from all design partners and suppliers.

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A special thanks goes to 2024 report sponsors Weyerhaeuser and Simpson Strong-Tie, without whose support the report would not be possible.

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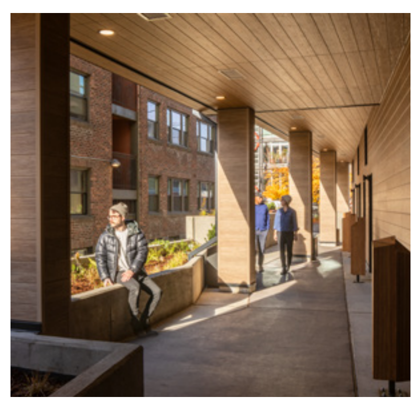
PUBLISHER'S MESSAGE

Despite serious global issues and concerns, 2023 was an exciting year for the development of mass timber. A record number of people attended the International Mass Timber Conference (IMTC), where a variety of new features and activities were introduced. The *2024 International Mass Timber Report*, which you are reading, will be the biggest report yet as we continue our efforts to deliver the most comprehensive and valuable information available on the mass timber industry.

In Chapters 1-10, we are reinforcing our commitment to providing the core information needed to fully understand the value of mass timber by providing detailed information on everything from the forest to the completed buildings, including the latest updates on carbon considerations and international news. In the front of the report, we are continuing our efforts to address specific issues facing the industry. For this issue we have written feature articles on the developing applications of mass timber to single-family home construction and the list of various other environmentally friendly materials that can be included in mass timber construction projects, and updated our Mass Timber Performance Index.

The number of mass timber case studies included in the 2024 report has doubled from 2023. We appreciate all the submissions and are excited that the list of those selected for inclusion represents a wide variety of mass timber buildings and new technologies from around the world. If yours didn't make the cut this year, for we have limited room, we encourage you to consider submitting again for next year.

We are introducing 3 new features this year. First is a brief photo essay of highlights from the record-setting 2023 IMTC. The exhibit hall was amazing, including the first-ever actual live demonstration of mass timber construction put together by WoodWorks. The sold-out Mass Timber Tours are always a highlight, and we have included pictures from a variety of the tour stops. For those of you who attended in 2023, we hope you'll find this a fun way to revisit some of the highlights. If you haven't attended IMTC in the past, you can get a feel for the energy and excitement around the mass



timber movement and the value in attending in the future.

Many of you are probably familiar with the Forest Business Network's newsletter and Craig Rawlings' activities on social media to promote the latest news from the world of forest products and mass timber. The second new feature this year is a compilation of the most popular news releases shared by Craig in 2023 based on social media analytics. Let us know if you find this interesting and informative.

The third new feature this year is the development of a mass timber terminology glossary. Our authors have curated a list of the most common terms used in the report along with short definitions. We envision this being a living document, updated each year as new terminology arises along with input from readers.

Finally, the team at Trifecta, IMTC, and the report are excited about exploring the opportunity to expand the digital presence of the report. You may have already noticed increased content at masstimberreport.com, including making the various features articles available online, as well as selected case studies. You can now also access all of the past issues of the report online or order your own hard copies.

Keep your eyes open as we continue to develop and expand our online presence. As always, we are very interested in your thoughts and recommendations for how to improve the *International Mass Timber Report*. Please give us your feedback at masstimberreport.com.

Best,

David Parcell
Publisher

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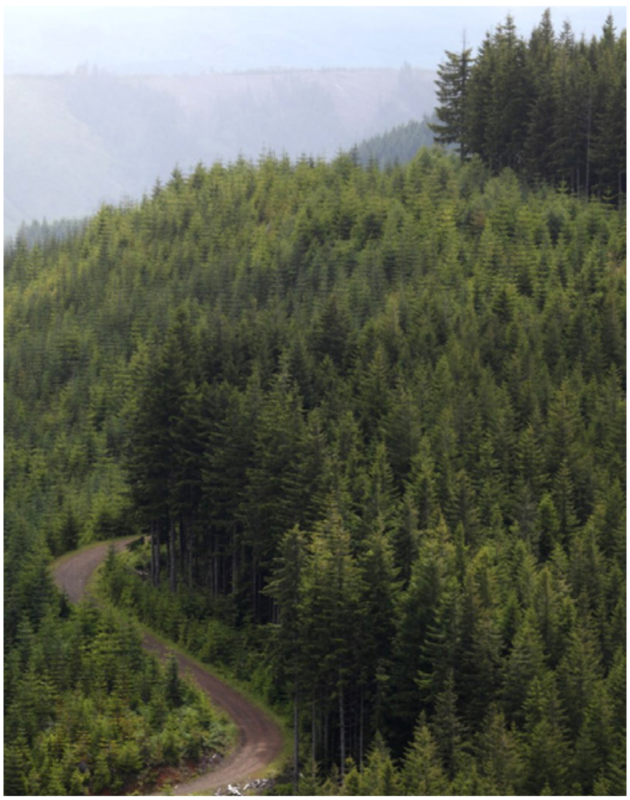

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At Weyerhaeuser, we have been global leaders in sustainable forest management for more than a century, and we believe working forests and the wood products that come from them provide some of the most sustainable, versatile, and cost-effective building materials in the world.

As we look to grow the usage and applications of wood in construction, we believe we can significantly increase the overall availability of quality, affordable housing. By leveraging our deep industry and supply-chain expertise and working with cross-sector partners, we can unlock the ability to build more efficiently and at scale to serve housing needs across all income levels, building types, and geographies.

We can accomplish that by:

- Increasing the overall understanding and acceptance of wood as a renewable, climate-friendly, and less energy-intensive alternative to other building materials such as steel and concrete.
- Updating building codes and supporting increased adoption of new techniques and material innovations.
- Expanding the definition of "home" by lending our resources to key initiatives to develop quality, sustainable, nontraditional home-building efforts.
- Partnering with mass timber producers and the design community to drive innovation and the development of wood-based products to replace steel and concrete.

Together, we will demonstrate that sustainable working forests and wood products can increase the overall quality, availability, and affordability of housing for everyone.


2005 NBA CHAMPIONS
2007 NBA CHAMPIONS
2014 NBA CHAMPIONS


FirstUnited

MASS TIMBER IN SINGLE-FAMILY HOMES

Credit: © Trong Nguyen | Dreamstime.com

BY EMILY DAWSON, AIA, LEED AP
Architect | Owner, Single Widget

Overcoming the paradigm of site-built, light frame housing in the $570B construction sector

I recently spoke to a market analyst who said something that made my jaw drop. Consultant Tim Seims has worked for decades in both the US and Japan introducing new construction products to risk-averse markets. He told me, "No product category has hit mass-market adoption without getting into single-family residential." I could hardly believe my ears, having spent most of my own career in commercial construction. But his declaration validated my growing sense over the past few years investigating manufacturing and mass timber housing—this sector holds important feedback for bringing mass timber into the mainstream. After all, it is a very nice scale to prototype new ideas. If what he says is even partially true, anyone trying to scale a structural timber business would be remiss to ignore the country's largest construction sector.[1]

Getting mass timber into single-family homes has clear advantages to the homeowner over its main competitor, light framing. The resulting structure is higher-quality and has an increased ability to protect the occupants and recover from events like fires and earthquakes. This security equates to real value, especially if we consider lenders' and insurers' mounting concerns about asset resilience in the face of increasingly frequent climate disasters. Other benefits include an environmental carbon and forest management story;

1 According to US Census Bureau data, the modest yet proliferating single-family home represents almost two-thirds of all residential construction, and nearly one-third of all construction dollars (2022).

WHILE THEY VALIDATE THEIR MARKET, GREEN CANOPY NODE PARTNERS WITH A FABRICATION CONTRACTOR TO REDUCE OVERHEAD. THIS ALLOWS THE COMPANY TO FOCUS ON PRODUCT DEVELOPMENT AND SCALE SUSTAINABLY AS THEY BUILD REVENUE.

Source: Green Canopy NODE
Credit: (left) Inside Spokane, (right) J. Craig Sweat

new timber markets that use fiber from forest thinning projects could help sustain the forest management needed to create resilience on the landscape, and in turn, store carbon in durable structural products. But standing squarely in the way of swift adoption are the multiheaded challenges of uneven regulations across jurisdictions, high material costs, and the inertia of ingrained light frame construction methods.

Cost aside for the moment, could higher-quality buildings be enough to tip the scales? Timber Age Systems[2] founder Kyle Hanson shares a concern about the durability of light frame buildings with MOD X[3] founding partner Ivan Rupnik, though they come at the problem from different angles. Hanson says he is dismayed by the overall quality of housing in Durango, Colorado, an opinion he formed after years of working in real estate. He believes that high-quality mass timber homes will be an essential part of creating lasting financial security in his community. From a fabrication standpoint, Rupnik notes that the stability of most softwood lumber produced today does not integrate well with manufacturing assembly lines, which require material precision to run smoothly. Indeed, modular timber manufacturers across Europe, where the baseline construction analogues are sturdier than in the US, wouldn't dream of framing with feisty dimension lumber. They reach for a shelf-stable laminated veneer product like Laminated Veneer Lumber (LVL).[4]

Hanson and Rupnik both point to 1 promising answer to 2 major problems: the nation's housing crisis, and the need to cut emissions in the carbon-intensive construction industry. It could lie in an industrywide shift from site-built to off-site construction.

Let's turn our attention back to cost competitiveness. We know that replacing concrete with solid

2 Timber Age Systems is a mass timber housing company based in Durango, Colorado.
3 MOD X is a global strategy advisory group in the prefabricated and volumetric modular off-site construction industry.
4 The advantage of LVL, like many other mass timber products, is its dimensional stability through shifts in humidity and temperature, which are unavoidable during transport, fabrication, and installation.

MARKET RATE OFFERINGS WILL MAKE UP THE MAJORITY OF THE PANELIZED CLT HOMES TIMBER AGE FABRICATES, WITH CONSISTENT DELIVERY OF A SMALLER NUMBER OF LUXURY PRODUCTS.

Source: Timber Age Systems

wood often works for multifamily buildings, but for mass timber to compete with light framing, a major shift in thinking is required. Start-ups across the country are counting on off-site fabrication to find an advantage over light framing's site-based vulnerabilities. The high material cost of mass timber, in many ways, is driving the need for multitrade modular solutions as a way to enter the market by moving the most time-consuming and riskiest parts of construction under cover.

Weather-related schedule delays, unreliable access to labor, safety hazards, sequencing clashes, road closure fees, and delayed inspections are all common reasons on-site construction requires such high contingencies. In a factory setting, scheduled interactions under controlled, ergonomic conditions prevail, ideally creating a construction process that is predictable enough to allow everyone to take contingencies way down. The hurdles new modular companies face when proving their products in established markets are high. For developers to confidently agree to move costs from a site to a factory, they need to see precedents that clearly demonstrate the value; but, at this point, the approach is still relatively uncommon. And of course, it is a much more difficult sale if the product costs even a little bit more overall than the standard approach.

Even in commercial construction, mass timber is a high cost-per-square-foot item. Residential builders working with commercial-grade products have a harder time making it pencil. Trent Debth is an energetic entrepreneur out of Dallas who says his company's[5] most significant pain point is the cost of mass timber panels. His team decided on a kit-of-parts Mass Plywood Panel (MPP) solution that they could fine-tune to a greater degree than working with full panels, which were overbuilt for their designs. Vermont-based Mass Kingdom's Josh Oakley landed on a similar strategy with Cross-Laminated Timber (CLT), noting the advantage to his rural customers of being able to move kit parts on-site by hand.

What if single-family homebuilders had access to panels optimized for lower structural loads, and

5 TimberBLDR.

MASS KINGDOM'S KIT-OF-PARTS SYSTEM CAN BE CONFIGURED IN ENDLESS WAYS AND INSTALLED WITHOUT HEAVY MACHINERY.
Source: Mass Kingdom

tested under lighter requirements? CLT panels made with thinner lamstock would reduce unnecessary fiber and cost. Veneer-based panels are available in increments of 1-inch thicknesses, but they could be configured more finely if the market proves ready.

Some mass timber manufacturers are responding to customers asking for a new kind of product with specialty runs of prototypical thin panels. But it is still a chicken-and-egg situation. To grow a modular mass timber single-family market, builders need a robust array of light-duty offerings focused on noncommercial uses, and manufacturers need compelling reasons to invest in developing these products.

If the only challenge was the bottom line, one could imagine these thinner mass timber products entering the established prefab home ecosystem, validating the market (or not), and we could move on. Unfortunately, whatever the structural material of choice, all modular companies face a daunting regulatory reality. Gary Fleisher has worked in the modular industry for decades and says that the largest challenges have nothing to do with efficiency at the factory level. In his mind, the biggest detriment to modular housing is the vast variation in code adoption across the country.

A modular enterprise is a big-ticket item, and the larger the potential region for sales, the better. State-by-state inconsistencies impede interstate commerce, and local officials wreak even more uncertainty city by city. When inspection requirements change frequently and vary significantly across borders, the investment risk for modular companies mounts. A small change can translate into a huge expense on a production line. Product cost goes up and competitiveness goes down as a result. When code changes and adoption cycles are not triangulated with the broader goals of, say, creating more housing or industry efficiency, they can hold back innovation.

Code creators are interested in industrialization. ICC[6] and HUD[7] are both aware of their roles in clearing barriers, and they have been making regulatory progress to encourage more factory-built construction. But these regulations mean little until they are adopted. That onus rests on state governance; it may take a few years in one jurisdiction and decades in another. Without consistent, collaborative feedback cycles and adoption, innovators are stuck focusing on smaller market regions and constant change management. If code creation and adoption were more strategic and consistent across the country, would we see an increase in industrialized construction? Could regional or national cohorts of modular companies help promote innovation?

The mass timber modular housing start-ups operating today are trying to build for the future in a world still living in the past. Will they succeed? On their side is the uneasy reality that we are living in a time of great change. A nationwide housing crisis is colliding with increasingly destructive climate-related disasters. In our search for solutions to these problems, we find answers in our forests, and, in their endlessly enlightening ways, our forests beseech us back. Wouldn't it be a magnificently balanced case if the buildings we need the most help us serve our landscapes better? To move mass timber single-family housing from niche to norm will require collaboration, and maybe a little risk-taking, from a huge range of industry professionals—from the natural resource to the completed home.

The potential rewards are, well, jaw-dropping. If it works, the gigantic scale of the resulting market would be a boon to expanding mass timber manufacturing. Innovators already working in this sector are confronting these barriers with some successes, but it will take a broadly coordinated effort from many players across the industry to truly lower the hurdles. If the result is a new standard for beautiful, high-quality homes that help our forests, it will certainly be worth the trouble.

6 International Code Council (ICC), *ICC/MBI Standards for Off-Site Construction 1200-2021 (Planning, Design, Fabrication, and Assembly) and 1205-2021 (Inspection and Regulatory Compliance)*.

7 MOD X for US Department of Housing and Urban Development (HUD), *Offsite Construction for Housing: Research Roadmap* (2023.).


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MASS TIMBER PERFORMANCE INDEX

BY ROY ANDERSON
Vice President, The Beck Group
ERICA SPIRITOS
Growing regional mass timber ecosystems

INTRODUCTION

The Mass Timber Performance Index's intent is twofold. First, our aim is to provide an estimate of Cross-Laminated Timber (CLT) market prices in North America. Readers should understand that, although CLT is a lumber- or veneer-based product, CLT's market price is affected by its own set of supply-and-demand dynamics. CLT manufacturers price their product on a whole project basis, given project-specific requirements, rather than focusing on a cost-per-unit-of-production basis. Thus, it is helpful to think of CLT as a custom building component rather than a commodity product.

Second, this index provides an estimate of demand for mass timber across the US and Canada, the corresponding volume of lumber used in mass timber construction, and the associated utilization of existing CLT manufacturing capacity.

CLT PRICE INDEX

Putting a firm number to CLT market prices is a tall task. Accurate market price reporting is challenged by the relatively small number of producers, the lack of publicly available data on market pricing, and perhaps most importantly, the fact that all CLT manufactured in North America is custom-made on a project basis. Accordingly, when reviewing the CLT Product Price Index, please consider the values as indications of likely pricing. Actual market prices will reflect project-specific factors, the size and structure of the manufacturer's business, and how strongly a manufacturer desires to win the work.

In **Figure 1**, we update the CLT price information (the blue line with units that correspond to the left axis) that first appeared in the 2022 edition of the *International Mass Timber Report*. The CLT Product Price Index is meant to serve as a general guide to CLT panel pricing, with values based on a financial model of a prototypical CLT manufacturing plant that includes estimates of the cost of producing CLT, and a profit-and-risk allowance. This year, the model incorporates a more accurate representation of administrative overhead costs, escalation and inflation for all labor and materials beginning in 2016, and 3D modeling and Computer Numerical Control (CNC) fabrication costs to transform billets into custom components. Excluded from the market price estimate is the cost to transport the finished product to customers.

Although the model is a work in progress, this update more closely aligns with market conditions during the 7-year period. Still, it is important to remember that the figure shows modeled CLT panel market prices rather than prices reported from actual transactions between manufacturers and their customers. Also shown in the figure is an estimated lumber market price, which is discussed in greater detail in the next section (the orange line with units that correspond to the right

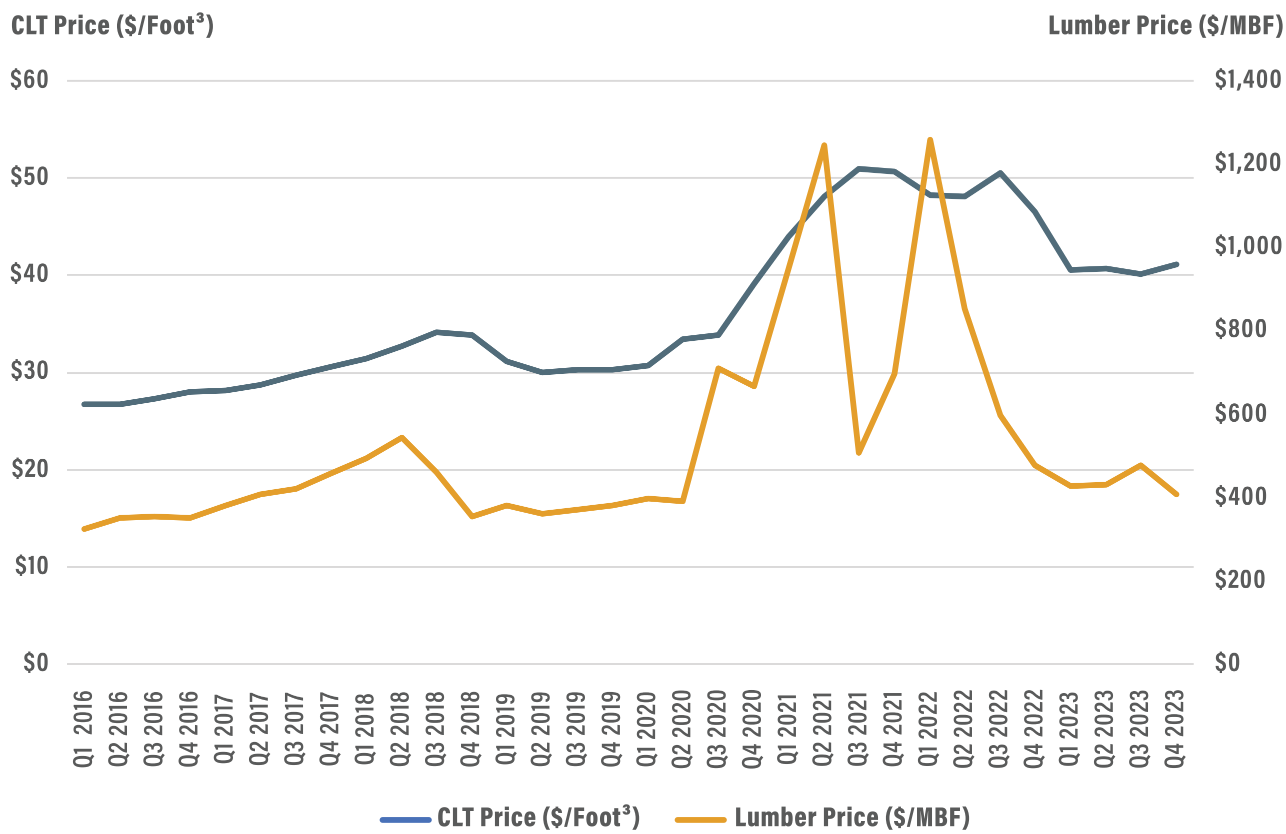


FIGURE 1: CLT PRODUCT PRICE INDEX

axis). Importantly, market research identified a lag in the relationship between CLT price and lumber price, as CLT manufacturers are usually selling off lumber inventory accrued over several months. This lag is reflected in the CLT pricing shown in **Figure 1.**

LUMBER PRICE DISCUSSION

Despite 2023 lumber prices falling more in line with historical norms, lumber cost remains a primary driver for CLT manufacture. According to the financial model used to estimate CLT prices shown in the preceding figure, lumber costs ranged between 40 percent and 60 percent of the total CLT manufacturing cost.

Lumber prices are likely to remain at historical norms for the foreseeable future because high interest rates and high inflation have dampened demand for new residential housing, a leading market segment for softwood lumber.

When the housing market strengthens, however, lumber prices are likely to quickly return to higher levels due to log supply shortages in key lumber-producing regions. For example, the government of British Columbia has limited future timber harvests to allow forests in the region to recover from recent wildfires and the mountain pine beetle epidemic. Similarly, in Coastal Oregon and Coastal Washington, both major US lumber-producing regions, new forest management policies have reduced timber harvests on state-owned and privately owned lands. These policies are beneficial to forest ecosystems, but they negatively affect lumber production.

This leaves Eastern Canada and the Southeastern US as the major lumber-producing regions in North America with the ability to increase production to meet increased demand. The Southeastern US has significantly expanded its lumber production capacity over the last 5 to 10 years. However, Southern Yellow Pine (SYP) lumber is not ideal for all traditional residential construction applications. A potential "release valve" on upward lumber price pressure is importing more softwood lumber from Europe. In fact, European softwood lumber imports have been trending upward for several years with over 3 billion board feet imported in 2022 and likely a similar amount in 2023 (final numbers have yet to be published).

In the foreseeable future, lumber prices are likely to remain at the levels observed for much of 2023. An increase in demand, however, associated with stronger US housing starts could quickly cause significant spikes in lumber prices because key producing regions are constrained in their log supply.

OTHER FACTORS AFFECTING CLT PRICE

Although lumber is the primary driver, several other factors also contribute to the CLT market price. Below, we offer a list of these factors to help project teams understand both the impacts of their design decisions and other supply-chain factors outside of their control.

- **Panel thickness:** The ability of a manufacturer to produce a greater number of thinner (3-ply) panels at a time, compared to thicker (5-ply or 7-ply) panels, will often result in different pricing for panels of different thicknesses. This ability is a function of press bed height.
- **Strength grade:** Mechanically rated (E-series) panels will be more expensive than visually grade (D-series) panels, as they are manufactured with stronger and stiffer lumber that is more costly than visually graded lumber.
- **Species:** CLT is manufactured with lumber from a variety of tree species including Douglas-fir; SYP; and spruce, pine, fir (SPF). Each species has its own supply-and-demand dynamics that impact market pricing.
- **Visual classification:** For many manufacturers, architectural or visual-grade CLT will be more expensive to produce given the higher grade of lumber on exposed surfaces, and the added cost of sanding (if in-line sanding is not part of the production process, but rather done manually).
- **Billet utilization (waste):** Billet utilization will fluctuate depending on the geometry of a mass timber building, resulting in waste material as CLT panels are transformed (via CNC machine) from rectangular billets into custom components. Manufacturers will include the cost of unused waste material in their pricing.
- **Project complexity:** CLT manufacturers do not estimate the cost of individual CLT panels. Rather, they estimate the cost of delivering a project. Design assist and 3D modeling (detailing) costs rise as project complexity increases. Thus, buildings with complex designs are more expensive to produce.

STATE OF THE MARKET IN NORTH AMERICA

2023 turned out to be a year of extremes, with company transitions and project delays on one hand, and the delivery of projects on an unprecedented scale on the other.

We witnessed the closing of Structurlam Mass Timber Corporation, a pioneering company that blazed a trail for mass timber construction in North America and set industry standards for every aspect of project delivery from design assistance to production quality. Structurlam was purchased by Mercer International, a global forest products company headquartered in Germany, that in 2021 purchased Katerra's Spokane CLT facility and is now one of the largest manufacturers on the continent with 3 production facilities.

Structurlam's closure did not, however, reflect a slowing of demand for mass timber. Rather, projects of unprecedented scale broke ground in 2023, including the new 2.4 million-square-foot campus at Walmart's headquarters in Bentonville, Arkansas. Meanwhile, in Oakland, California, Mass Plywood Panels (MPP) and columns rose 16 stories tall in the 19-story mixed-use multifamily building at 1510 Webster, setting a record for point-supported (no beam) construction in the United States. According to data provided by WoodWorks and by estimates of the authors, 279 mass timber projects were constructed in the US and Canada in 2023.

MASS TIMBER DEMAND

In 2023, the demand for mass timber continued to grow amid a contraction of the US construction industry caused by inflation, higher interest rates, and labor shortages. According to WoodWorks data, roughly 190 mass timber projects either began construction or were built in 2023 in the US, and approximately 168 projects were in the design stage, indicating that there are plenty of projects at all stages of the development pipeline.

As the demand for mass timber grows, keeping track of completed projects becomes more challenging. For this reason, we ask our readers to review the WoodWorks Wood Innovation Network (WIN) database—the best source of industry information on the demand for mass timber in North America—and ensure that all their mass timber projects are listed.

Notably, the WIN database tells us that the demand for mass timber is not equal across the continent, and that certain states are far outpacing others in the use of mass timber to construct future skylines. This year, California, Georgia, Missouri, and Tennessee led the charge in new mass timber projects in design and construction. Office buildings continue to be the leading market sector, accounting for 45 percent of new mass timber construction in 2023.

WoodWorks's – Wood Products Council provides free project support to the Architecture, Engineering, and Construction (AEC) community on multifamily, institutional, and commercial buildings. Growing the mass timber market is the objective of the organization, and they have been a driver of the market since mass timber began in the US. Feel free to reach out to them for any assistance. Readers can also find the latest data and trends at https://www.woodworks.org/resources/mapping-mass-timber/. They can also see details about most of the projects at https://www.woodworksinnovationnetwork.org/

YEAR	ESTIMATED NUMBER OF MASS TIMBER BUILDINGS CONSTRUCTED	ESTIMATED BOARD FEET OF LUMBER USED IN MASS TIMBER (MBF LUMBER/YEAR)	ESTIMATED MASS TIMBER PRODUCTION, EXCLUDING IMPORTS (CUBIC METERS/YEAR)	ESTIMATED MASS TIMBER MANUFACTURING CAPACITY IN PANELS USED FOR CONSTRUCTION (CUBIC METERS/ YEAR)	ESTIMATED PERCENT OF PRACTICAL BUILDING PANEL MASS TIMBER MANUFACTURING CAPACITY UTILIZED
2019	151	129,000	158,000	355,000	45%
2020	177	148,000	174,000	443,000	39%
2021	183	167,000	205,000	491,000	42%
2022	215	252,000	336,000	602,000	54%
2023	279	308,000	393,000	604,000	65%

TABLE 1: ESTIMATED MASS TIMBER LUMBER USAGE AND PRODUCTION IN THE US AND CANADA (2019 TO 2023)

MBF = 1,000 board feet

LUMBER USAGE

As **Table 1** indicates, it is estimated that 308 million board feet of softwood lumber were consumed in North America's mass timber construction in 2023, an increase of 22 percent from 2022. For context, this total is approximately equal to the annual output of a single, modern North American softwood sawmill.

The increased lumber consumption is driven by the year-over-year growth in the number of mass timber buildings completed in North America; that number grew from 215 in 2022 to 279 in 2023. All other things being equal, the number of buildings completed per year would need to grow to about 900 for annual lumber consumption to reach 1 billion board feet consumed in mass timber construction. As a point of reference, North America has consumed roughly 60 billion board feet of lumber annually for the last several years (2023 was slightly lower).

Several key factors inform the lumber consumption referenced in the preceding paragraph. First, the average building size, which has increased from 35,000 square feet in 2016 to 60,000 square feet in 2023. Second, a mass timber usage factor per square foot of building area was reduced from 0.9 cubic feet per square foot of building in earlier editions of this report to 0.625 in this version of the report. Third, an estimate of the total number of buildings constructed from mass timber that are *not* publicly reported, which was reduced in the current model compared to prior editions.

The latter 2 of the 3 factors described above negatively affect estimated lumber consumption volume. However, the increased average size of mass timber buildings is a large lever impacting lumber consumption in the opposite direction. As a result, despite several new modeling assumptions in this update that reduced estimated lumber use, the total usage estimate for 2023 grew. (Note that the values in the table for prior years have all been updated to reflect the new modeling assumptions.)

Although mass timber accounts for less than 1 percent of total softwood lumber consumption in North America, the manufacturing of glulam (roughly one-third of the total volume of mass timber consumed) demands a stronger, drier, and more square board that's sold by a smaller number of sawmills for a significant premium over the standard KD19 2-by-6 board. For sawmills focused on quality over quantity, glulam manufacturing represents a strong and growing market, and a chance to differentiate themselves from competitors.

MANUFACTURING CAPACITY

In 2023, manufacturing capacity for mass timber components remained consistent with 2022 capacity, with DR Johnson's CLT manufacturing capacity roughly replaced in volume by Boise Cascade's new VersaWorks products, including Veneer Laminated Timber (VLT) panels and Laminated Veneer Lumber (LVL) beams and columns. Although the data used to calculate the capacities shown in **Table 1** is representative only of manufacturers that produce some form of mass timber panel, roughly one-third of mass timber is glulam, and glulam-only producers are not represented in the capacity calculations. In the future, this report hopes to secure more complete information on the glulam manufacturing capacity in the market, as there is a growing concern around the availability of glulam billets, and glulam fabrication continues to be a pinch point impacting manufacturers' ability to deliver mass timber projects. Another factor that affects estimates of structural CLT production capacity is that some panel manufacturers are also producing panels for industrial applications (ground mats for temporary roading). At this time, informed assumptions have been made regarding the relative production of CLT for structural and industrial applications.

When looking at manufacturing capacity on a regional basis, the authors found that plants located in the Western US and Canada accounted for 48 percent of all capacity; manufacturers in the Northeastern US (including Illinois) and Eastern Canada accounted for 27 percent of capacity; and manufacturers in the Southeastern US accounted for 27 percent of all capacity.

CONCLUSION

Despite the challenging financial landscape for projects that hoped to get off the ground in 2023, demand for mass timber continued to rise, with the total number of publicly reported mass timber buildings constructed in the US and Canada greater in 2023 than in the year prior, based on data made available by WoodWorks. The industry is also working hard to stay ahead of the demand; operating manufacturers are expanding their existing facilities, and new mass timber companies are expected to come online in the near future.

HOW TO CREATE A CARBON SINK CITY

BY DAVID ATKINS
Sustainabilist, Forester, Ecologist, Writer

Droughts, failed crops, wildfires and smoke pollution, more intense hurricanes, typhoons and floods, and stifling heat domes around the world over the past decade have made the reality of changing climatic conditions personal for everyone on the planet.

The economic consequences and the rate at which costs are rising are staggering. **Table 1** shows that in the 1980s, the number of climate disasters causing more than $1 billion in damage averaged 3.3 per year, and the average total cost was $21.4 billion a year. From 2020 to 2022, the number of events averaged 20 per year at an average cost of $152 billion a year. The total cost for those 3 years was nearly $500 billion.

A study[1] released November 2022 examined the social cost of fossil carbon emissions and conservatively estimated it to be $185/ton. The US EPA included an updated social cost of carbon (SCC)[2] at $190/ton, in the new methane regulations, effective this year. The SCC attempts to quantify the cost to society of fossil carbon emissions. It includes the cost of deaths and illnesses caused by heat, smoke inhalation, and lung and heart diseases; it also includes the costs of natural disasters to the government, to insurance companies, and to businesses as a result of these events and others.

These costs are all externalized from the price of fossil fuels; the companies that are the source of the carbon emissions don't include these costs in a barrel of oil, a ton of coal, or a thousand cubic feet of natural gas. But we are all paying the price through our insurance rates and taxes. If this price was internalized into the cost of every fossil fuel product,

TIME PERIOD	BILLION-DOLLAR DISASTERS	EVENTS/ YEAR	COST	PERCENT OF TOTAL COST	COST/YEAR	DEATHS	DEATHS/ YEAR
1980s (1980-1989)	33	3.3	$213.6B	8.00%	$21.4B	2,994	299
1990s (1990-1999)	57	5.7	$326.8B	12.30%	$32.7B	3,075	308
2000s (2000-2009)	67	6.7	$604.2B	22.70%	$60.4B	3,102	310
2010s (2010-2019)	131	13.1	$967.5B	36.40%	$96.8B	5,227	523
Last 5 Years (2019-2023)	102	20.4	$603.0B	22.70%	$120.6B	1,996	399
Last 3 Years (2021-2023)	66	22	$431.4B	16.20%	$143.8B	1,690	563
Last Year (2023)	28	28	$92.9B	3.50%	$92.9B	492	492
All Years (1980-2023)	376	8.5	$2,661.0B	100.00%	$60.5B	16,350	372

TABLE 1
Source: https://www.ncei.noaa.gov/access/billions/state-summary/US

1 https://www.nature.com/articles/s41586-022-05224-9
2 https://www.nytimes.com/2023/12/02/climate/biden-social-cost-carbon-climate-change.html

it likely would create a powerful market incentive to use products with the lowest carbon footprints because they would become the cheaper alternatives.

Over the years, keynote speakers at the International Mass Timber Conference (IMTC) have painted a vision of urban areas as carbon sinks rather than sources, and the speakers regard mass timber as the cornerstone of accomplishing that. In addition, they have talked about mass timber feeding our biophilic being, how natural materials in our work and home spaces enhance our mental and physical health, our productivity, and our safety. They have also presented the idea of a circular economy where "wastes" from one activity become the feedstock of another. A mass timber building could be designed and assembled in a way that it can be deconstructed, and the elements reused rather than landfilled.

The IMTC has been a source of inspiration for the possible, like urban sinks, and just as important, a source of practical information about how to implement them. Mass timber has come a long way in a decade around the world, and yet it is still early in its growth curve and not without growing pains along the way. Each setback has resulted, however, in learning, adapting, and improving.

The structural elements of a building account for about 80 percent of its embodied energy; therefore, the use of mass timber is the cornerstone of a building as a carbon sink. What other elements need to be incorporated to achieve a carbon-negative city? What are the specific opportunities? Who is responsible? What are the right carrots and sticks to change behavior?

Mass timber is one of many renewable, sustainable products that can store the naturally captured carbon from photosynthesis, as identified in chapters 2 and 9.

Wood Fiber Insulation

Reducing fossil energy consumption is crucial to achieving the 2015 Paris Agreement goal of staying below a 1.5°C global temperature increase. But reducing all energy consumption is important because there are consequences and risks associated with every form of energy production and consumption, whether renewable or not. More news outlets are reporting on threats to the supply of crucial minerals, including some sourced from countries that are not very stable, and some sourced from countries that may want to gain economic or political leverage. New, energy-efficient buildings and the retrofitting of older buildings are vital to the economic and national security of every nation.

Insulation can dramatically reduce our operational energy consumption and greenhouse gas emissions. The type of insulation used, however, has its own energy and carbon considerations.

Wood fiber insulation in the form of loose fill, batting, and rigid board is now made in North America. TimberHP in Madison, Maine, is the first company in the US to produce wood fiber insulation, and it went into production in 2023. That form of insulation has been readily available in Europe for many years. One of the many benefits of its use is that it creates a long-lived carbon storage product from sawdust, slab wood chips, and small trees that need to be thinned out of forests to grow and manufacture sawlogs. The carbon in the insulation is stored for the life of the building along with structural wood components, and its use reduces the building's operating energy. Additional manufacturing plants are in the planning stages in North America.

Borate, a naturally occurring mineral solution, is added to the insulation to help protect it from insects, mold, and rot. It also acts as a fire retardant.

Nanocellulose Concrete

The use of nanocellulose in small quantities can have a large effect on the carbon footprint of concrete. You might have heard that if concrete were a country, it would be the third largest emitter of fossil carbon in the world, behind China and the US.[3]

The US Endowment for Forests and Communities and the US Forest Service's Forest Products Laboratory have developed partnerships that are working to commercialize this material. Nanocellulose concrete has been used in demonstration bridges, sidewalks, curbs, gutters, and parking lots. A 20-acre reservoir was created by a nano-concrete dam in Georgia in 2024.

It is not readily available commercially, however, for a variety of reasons, but primarily because the recipe for concrete varies from location to location. The recipe must be tested and adjusted for it to achieve the desired greenhouse gas (GHG) reductions.

When a 5-gallon bucket of 10 percent solution nanocellulose or a half-gallon of nanocellulose is added to an 8-ton concrete truck, it can reduce GHG emissions by about one-third, according to research done by the Forest Products Laboratory. It has been demonstrated in multiple parts of the US. The addition of nanocellulose is simple, once the local recipe is defined.

Adoption could be quick if the appropriate support mechanisms are established. As with many new products, the challenge is to ramp up the demand to support the development of a full-scale manufacturing plant that can meet the needs of multiple commercial-scale projects. In addition, work to adjust the recipe to fit local and regional concrete formulas is needed. A joint effort by city, state, and federal governments can help concrete companies and developers jump-start the process by requiring it in a portion of all new sidewalks, gutters, streets, highways, and public building foundations.

Mass timber faced these same challenges less than 10 years ago in the US and Canada. Industry and government worked together to raise awareness, fund testing, change codes, and get mass timber to the commercial stage. It is prepped for continued rapid growth.

Biochar: Biological Carbon

People have charcoaled wood and other biomass for millennia. It has been used as an energy source and as a soil enhancement to improve the long-term productivity of fiber and crops.

Technological advances have improved the efficiency of production and almost eliminated smoke pollution. Biochar is carbon that is very stable and, therefore, a powerful carbon capture and storage technology.

Graphene carbon sourced from biochar produces more efficient batteries. Charging is 5 times faster[4] than when current minerals are used. Bio Graphene Solutions (BGS) in Ontario, Canada, has a patent pending on its production process. The company intends to use the carbon to replace bitumen in asphalt, membranes, concrete, and

3 https://biographenesolutions.com
4 https://biographenesolutions.com

other products to reduce their carbon footprints. The drawback is price, so it is only being used in small batteries for electronics. But costs are coming down as production techniques improve, and work to scale up production is underway.

The incorporation of solar panels and batteries in buildings and energy systems can reduce the amount of energy that must be imported to urban areas.

Thermoplastics made of biochar allow a building's plumbing system and its siding to become a carbon sink instead of a source. Made of Air, based in Berlin, is moving these products forward. But the company also needs to scale up production and have the right set of incentives.

Biochar has been found to reduce the carbon footprint of concrete, as does nanocellulose. The potential synergy of using both is being researched.

Opportunities exist to use urban biomass to produce energy for buildings and biochar for local uses.

Billion-Ton Study

As these biobased solutions surface, some people are concerned that the level of demand will incentivize overuse, wiping out forests and grasslands, and depleting our soils. In the US, the question of raw material supply often has been analyzed and reported in what is colloquially known as the Billion-Ton Study by the Departments of Energy and Agriculture.[5]

In the early 2000s, the question was posed as to whether the US had a billion tons of biomass available to develop alternative fuels for airplanes, shipping, large trucks, and other equipment that is hard to electrify. The short answer was yes. This analysis has been updated and expanded several times in the intervening years. The focus of the most recent study is product-agnostic; it provides information about the potential productivity and supply of biomass for any number of uses, including nanocellulose, biochar, energy production, and more.

In the Western US, tens of millions of dollars are being spent to thin millions of tons of trees to reduce wildfire risk and make the forests more resistant and resilient to a variety of disturbances. Most of that material is piled and burned.

The US is a long way from any kind of a shortage of fiber. Rather, the problem is disposal of excess trees by burning, which is adding GHG and black carbon emissions to the atmosphere.

Urban Forests

The vegetative abundance, or lack thereof, in our urban environments can have profound effects on energy use, carbon capture and storage, human well-being (physically, mentally, and emotionally), the cleaning and storing of stormwater runoff, creating wildlife habitat, and reducing crime rates.[6] The latter comes from a study by the National Institutes of Health in 2019.

Designing urban swales full of trees and shrubs can help reduce flooding while also cleaning the water of pollutants from street and sidewalks. Developers can help achieve an urban carbon sink, and urban forests are part of that. Not only do the trees capture and store carbon, but when the trees must be removed, they can be used for a variety of products,

5 https://www.energy.gov/eere/bioenergy/articles/2016-billion-ton-report-volume-2-environmental-sustainability-effects
6 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6950486/

FIGURE 1: THE VERTICAL FOREST DEMONSTRATES GREENSCAPE CONSTRUCTION.
Credit: Ivan Kurmyshov

from furniture and flooring to biochar, energy, mulch, and compost. No technology learning curve comes with this solution; urban foresters, landscape architects, and others know how to design landscapes to reduce energy demand in buildings.

District Energy in St. Paul, Minnesota, uses urban tree and shrub waste as its fuel. Built in the early 1990s, it heats more than 30 million square feet (about the area of Central Park in New York City), cools over 20 million in the summer, and generates 25 megawatts of electricity. It was modeled after systems in Sweden.

Seattle, Washington, and Montpelier, Vermont, also have downtown district energy systems. In Europe, these systems are too common to try and list them. The diversion of green waste from landfills saves money and reduces methane emissions. To create these systems requires an understanding of how these long-term investments help reduce costs we have externalized. Because they are externalized, we ignore them. But we pay for them anyway.

One of the newest creations in this urban greenscape is displayed in **Figure 1**. In Milan, Italy, 2 new buildings[7] incorporated green rooftops, balconies, and more. With the vertical arrangement,

7 https://www.stefanoboeriarchitetti.net/en/project/vertical-forest/

a multiplier effect of vegetative cover far exceeding the footprint of the building was achieved. This level of greenery has a design learning curve, but it has been demonstrated.

Waste Management: Composting

US society spends billions of dollars on waste management,[8] from trash to sewage disposal, and then we spend more to create fertilizers for our gardens, farms, and city parks. What if we closed the loop and turned our waste into valuable products like green methane and soil amendments? Composting, whether through aerobic or anaerobic digesters, can take sewage and transform it into useful products while reducing the need for new or expanded sewage treatment infrastructure. The PAE Living Building Challenge structure[9] toured as part of the 2023 IMTC demonstrated the technology for a single building, but to make this effective at scale and realize the potential savings for infrastructure costs, local, state, and federal governments need to create the incentives and disincentives.

As described above, closing the loop with our urban forest residues to create energy, and potentially biochar, requires recognizing who is paying the costs and what resources we are wasting that could be converted to valuable products. As when the social costs of carbon are disconnected from the sources, somebody else pays for the consequences. A similar thing happens with our waste stream. We make poor investments and miss opportunities to have a by-product rather than waste. Transitioning from a linear approach to a circular one is a challenge—until we create the right set of carrots and sticks to change behavior.

Transportation

Although not part of structures, the streets, sidewalks, and modes of transportation that move people from place to place are another piece of the built environment with a large carbon footprint. Some new developments in addition to nano-concrete include the use of nanocellulose in tire manufacturing to decrease rolling resistance and require less energy to move bicycles, buses, and cars.

Bridges all over the world were originally built with wood and often replaced by steel and concrete in the 20th century. Scandinavian countries have shown the world how wood can return as a primary construction material for bridges. Nordic in Canada is following their lead in North America (see **Figure 2**). The strength to weight ratio advantages of wood allow for greater payloads and have excellent durability and lifespan advantages.

The development of Sustainable Airplane Fuels (SAF)[10] from biomass continues to improve and can help reduce the carbon footprint of flying between urban settings. Several tests around the world in the past 2 years have flown planes using 100 percent SAF.

Who Is Responsible, and How Do We Incentivize Change?

To achieve the vision of cities as carbon sinks, we need to change our behaviors. All of us are responsible as individuals, but that is insufficient; we must also act collectively through our local, national, and international businesses, governments, and especially partnerships between governments and businesses. Overcoming the inertia of patterns and

8 https://www.statista.com/topics/2630/waste-management-in-the-united-states/#topicOverview
9 https://www.pae-engineers.com/about/pae-living-building
10 https://www.energy.gov/eere/articles/lab-sky-five-things-know-about-biofuel-powered-flights

FIGURE 2: MASS TIMBER BRIDGE REDUCES THE USE OF CONCRETE AND STEEL.

Source: Nordic.ca
Credit: ©Stéphane Groleau

habits that are decades old is not easy. We need the appropriate incentives and disincentives to motivate, encourage, and prod the changes desired.

If we are paying for putting fossil carbon into the atmosphere through extreme storm damage, health costs, and more, why not incorporate the cost fossil carbon imposes on society into every product that uses it? Producers of polystyrene insulation products don't pay the cost of their use of fossil carbon greenhouse gas emissions to create their products. Yet society is paying for it through our insurance rates, taxes, health costs, and repairing infrastructure damaged by extreme weather events.

If every user of fossil carbon had to internalize the cost they are imposing on society, the prices of their products would have to reflect that. Products with little or no fossil carbon would have a competitive advantage with their lower prices; consumers would likely buy the products with lower costs and lower carbon emissions content. The use of market-based financial rewards would change our choices, and we likely would shift to low-, no-, or negative-carbon products.

Legislation introduced in the US House of Representatives, the Energy Innovation and Carbon Dividend Act, in September 2023 would achieve these market signals. Canada has implemented such a system. The EU has a price on fossil carbon and is moving to impose a carbon border adjustment on imports from countries that do not have a similar system.

To help kick-start new markets, city, county, state, and federal governments can embrace new concrete and asphalt products by specifying that contracts must use nanocellulose and/or biographene. They can specify renewable, negative-carbon insulation products. Start-ups are riskier than established businesses, but most people are concerned[11] about the changing climate conditions and the costs they are imposing on all of us. What is riskier—doing the same thing with accelerating billion-dollar extreme weather events, or using new tools and products in our urban built environments?

As you might have noticed, all these products can come from forests: urban, agroforestry, natural forests, and production forests. Everything we use is either grown or mined. We need both, but the more we can use renewable, sustainably grown materials, the smaller our carbon footprint will be—and the more resilient, resistant and adapted our forests will be to changing climatic conditions. This is explored more in chapter 9.

Mass timber is a cornerstone product for achieving urban carbon sinks, but we need all these other products as well. The trees we do harvest need to be used for their maximum benefit, from the bark and sawdust to the piles of tree residues in the forest after logging, as well as the sawn lumber that goes into mass timber.

This biophilic, circular economy is a perfect (wooden) bridge across the so-called urban/rural divide. Instead of a divide, we are creating a symbiotic relationship where both areas can thrive by supporting each other. The path to the urban sink is unfolding before us.

11 https://www.pewresearch.org/science/2023/10/25/how-americans-view-future-harms-from-climate-change-in-their-community-and-around-the-u-s/

SPONSOR **SPOTLIGHT**

10-STORY MASS TIMBER BUILDING STANDS TALL AFTER SHAKE TABLE QUAKE

TOP — The tallest mass timber structure ever tested withstood more than 100 seismic tests at UC San Diego.

BOTTOM — The government-funded research team was composed of partners from both the academic and business communities.

Simpson Strong-Tie, the leader in engineered structural connectors and building solutions, completed seismic tests on the tallest full-scale building ever tested in an earthquake simulation shake table. Tests on the 10-story mass timber structure were part of the Natural Hazards Engineering Research Infrastructure (NHERI) TallWood Project, funded by the National Science Foundation and building industry partners to prove the strength and seismic resiliency of mass timber.

Seismic tests simulating both the 1994 magnitude 6.7 Northridge, California, earthquake and the 1999 magnitude 7.7 Jiji earthquake in Taiwan were conducted at the Englekirk Structural Engineering Center at the University of California San Diego (UCSD), home to North America's largest outdoor shake table.

In addition to UCSD, a consortium of universities collaborated on the NHERI TallWood project, including the Colorado School of Mines; the University of Nevada, Reno; Colorado State University; the University of Washington; Washington State University; Oregon State University; and Lehigh University. The project also received support from the US Forest Service and the USDA Forest Products Laboratory.

Innovation was key. The structure features a new rocking wall lateral system designed for resilient performance, meaning minimal building damage from design-level earthquakes and quick repairs after rare earthquakes.

Simpson Strong-Tie developed a new class of beam-to-column and column-to-foundation connections as resilient as the wall structure. Simpson Strong-Tie also donated mass timber fasteners, angled washers, diaphragm spline straps, cold-formed steel connectors, and anchor tie-down systems.

During the tests, an array of sensors measured the impact of seismic forces across a variety of building systems, including the rocking wall lateral system, 4 exterior facade assemblies, a number of interior walls, and a 10-story stair tower.

The full findings are expected to support continued adoption of mass timber as a strong, versatile, low-carbon building material for residential and commercial structures in areas prone to seismic activity.

2023 INTERNATIONAL MASS TIMBER CONFERENCE

Building better and bigger!

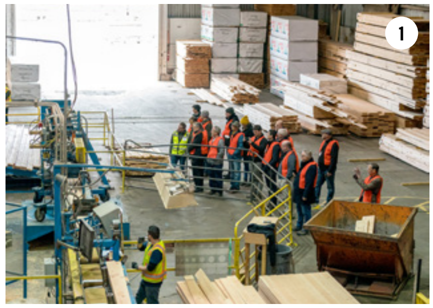
Those of you who attended experienced the incredible energy and enthusiasm generated by the 2023 International Mass Timber Conference.

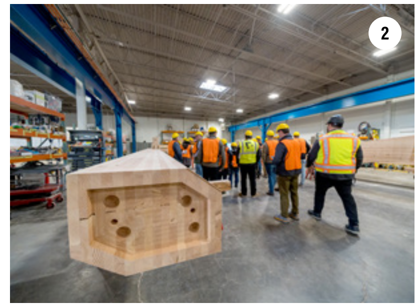
The conference has experienced amazing growth each year since its inception in 2016. In 2023, it set numerous records including these:

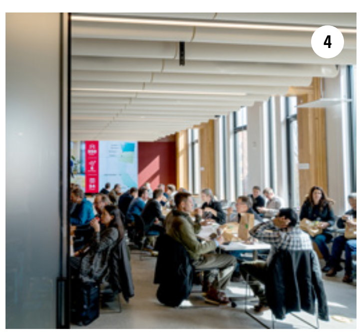
- Over 3,000 attendees, almost 43 percent growth from 2022
- Attendees from 39 countries
- Our largest-ever exhibit hall (occupying 93,000 square feet) and 152 exhibitors
- Sold-out building and facility tours with a record wait list
- Presentations from over 90 industry leaders
- First-ever live mass timber construction demonstration presented by WoodWorks

We captured a variety of images from the 2023 Mass Timber Conference to share as reminder of the vitality of the mass timber movement for conference veterans, first-time attendees, and those who have yet to experience the conference.

BUILDING AND FACILITY TOURS:







1. VISITING ZIP-O-LAMINATORS

2. DISCUSSING A FINISHED/ MACHINED BEAM AT TIMBERLAB

3. THE IMPRESSIVE USE OF MASS TIMBER AT HAYWARD FIELD, UNIVERSITY OF OREGON

4. LUNCH AT THE PAE LIVING BUILDING IN PORTLAND, OREGON

5. THE THESIS BUILDING IN PORTLAND, OREGON

6. LUNCH AT THE FARMERS MARKET IN EUGENE, OREGON

SPEAKERS:

7. MICHAEL GREEN RETURNS TO IMTC AS KEYNOTE SPEAKER FOR THE FIRST TIME SINCE THE INAUGURAL CONFERENCE IN 2016: BUILDINGS OF THE FUTURE: THE NEXT EVOLUTION OF WOOD

8. BILL PARSONS PRESENTS THE WOODWORKS WOOD DESIGN AWARDS

9. ARNIE DIDIER INTRODUCES THE FIRESIDE CHAT PANEL: FOR WHOM/BY WHOM SOCIAL EQUITY AND MASS TIMBER IN THE MAIN BALLROOM

10. ONE OF SIXTEEN EDUCATIONAL PANEL DISCUSSIONS LEAD BY INDUSTRY LEADERS

THE EXHIBIT HALL:

11. THE WOODWORKS MASS TIMBER CONSTRUCTION DEMONSTRATION AREA HOSTED BY WOODWORKS

12. ONE OF THE MANY IMPRESSIVE DISPLAYS IN THE EXHIBIT HALL

13. GETTING BUSINESS DONE ON THE SHOW FLOOR

14. MAKING NEW FRIENDS AT THE RECEPTION

15. AN ATTENDEE SHOWING IMPRESSIVE CONCENTRATION AT THE AX THROWING BOOTH

16. BEN KAISER HOSTING AN ILLUSTRIOUS GROUP OF VISITORS TO THE PATH HOUSE DISPLAY ON THE SHOW FLOOR

17. A SERIOUS-LOOKING CONVERSATION

18. THE RECEPTIONS ALWAYS DRAW A CROWD

2023 MASS TIMBER NEWS HIGHLIGHTS

The mass timber industry is constantly evolving. Many of you are probably already aware of the weekly Wood Product Industry Newsletter produced by Craig Rawlings and the staff of Forest Business Network (FBN). Promotion through LinkedIn and other social media outlets has succeeded at creating significant awareness of the important news releases highlighted in the newsletter. In fact, the various links have generated over 2.25 million impressions in the previous 12 months. We have captured here for your review the most popular news releases of 2023. For more timely access, consider joining Craig's network and/or subscribing to the free FBN Newsletter.

SIGN UP FOR THE WEEKLY FREE FBN EMAIL NEWSLETTER HERE:

https://www.forestbusinessnetwork.com/newsletter

FOLLOW CRAIG ON LINKEDIN HERE:

https://www.linkedin.com/in/craig-rawlings-0744539/

TOP-PERFORMING LINKEDIN POSTS

Portland's new airport terminal looks like it's from the future—but it's built out of wood

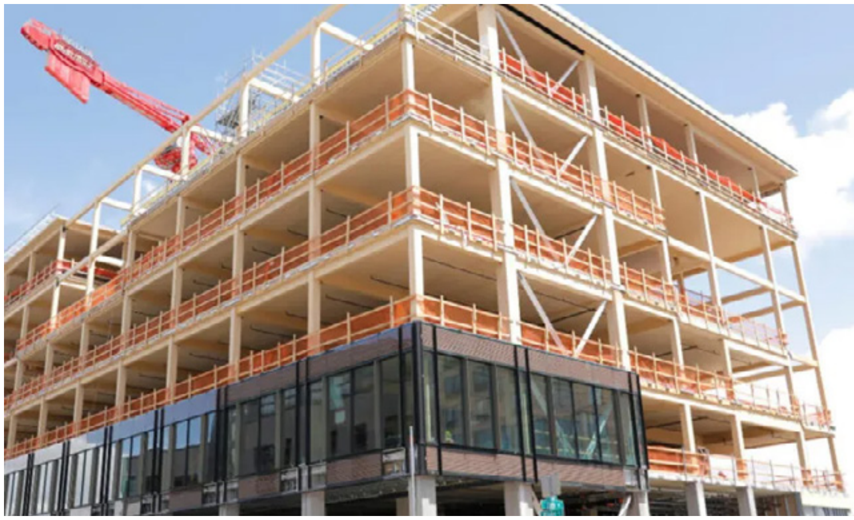
All the wood for the 9-acre roof was sourced from within 300 miles of the airport. It could be a game-changer for #masstimber.

Originally published by Fast Company, 10/26/23.

Fisher & Paykel Picks Builder for Radical $220M Mass Timber HQ

The new campus will be NZ's largest #crosslaminatedtimber project. Fisher & Paykel Appliances has appointed Naylor Love, one of New Zealand's largest builders, to construct its new headquarters in East Tāmaki.

Originally published by Wood Central, 10/10/23.



T3 RiNo
Image courtesy of Ivanhoé Cambridge

Why naturally renewing 'mass timber' is the building block of the future

"Both symbolically and actually, #MassTimber is the building material that our culture needs right now," says Ryan Jones, partner at Lake|Flato Architects. "#MassTimber transforms the structural demands of a building into a warm and tactile environment that also feels organic."

Orginally published by New York Post, 7/8/23.

The largest 'wooden city' in the world is going up in Stockholm

In an old industrial zone in Stockholm filled with former factory buildings and parking lots, developers are planning to build a "wooden city"—the largest #masstimber development in the world, with 30 wood buildings spanning 25 blocks.

Originally published by Fast Company, 6/20/23.

Can building with wood decarbonise construction?

Research shows that if such #masstimber construction (using engineered wood for load-bearing wall, floor, and roof construction) were to become the norm by 2050, annual carbon storage could be as high as 700 million tons of carbon instead of just 10 million tons in a business-as-usual scenario. This would, however, require an optimized use of wood to prevent forest degradation and loss.

Originally published by Energy Monitor, 5/23/23.

Hines JV Tops Out Denver Mass Timber Building

Designed by Pickard Chilton Architects and DLR Group, the project's design is fully recyclable, renewable, and nontoxic. Sourced from Nordic Structures, the #masstimber used for this project is manufactured by Chantiers Chibougamau out of the boreal forest's black spruce.

Originally published by Commercial Property Executive, 4/25/23.

MILWAUKEE'S ASCENT BUILDING, WHICH OPENED IN 2022, IS THE LARGEST MASS-TIMBER APARTMENT COMPLEX IN THE WORLD.
Source: Woodworkingnetwork.com

Building tall with timber 'does not make sense' say experts

"For most buildings, tall timber does not make sense," said Arup fellow Andrew Lawrence. "Timber's natural home is low-rise construction," he told Dezeen. "The reality that #timber is best suited technically to smaller buildings, and that this is where it can have the most impact on reducing embodied carbon, has been lost."

Originally published by dezeen, 3/29/23.

Scientists engineered a wood that gets stronger as it captures CO_2

Scientists at Rice University, Texas, have now developed a special wood that's stronger than its natural counterpart and helps reduce carbon emissions by sequestering carbon dioxide (CO2) from the surrounding air.

Originally published by Interesting Engineering, 2/20/23.

Is Milwaukee becoming the world's mass timber leader?

Milwaukee may soon be home to two of the largest #masstimber buildings in the world after developers of an apartment tower planned for downtown Milwaukee announced that it was doubling in height, and would be among the world's tallest mass-timber buildings when it opens in 2025.

Originally published by Woodworking Industry News, 2/15/23.

Goodbye, concrete and steel? Why timber towers could be the future

The tower, called #T3Collingwood and developed by global real estate company Hines, is one of a handful of recent major #masstimber developments in Australia that could signal the country is catching onto a trend well-established in the United States and Europe.

Originally published by The Age, 12/18/22.

Wood-Based Wind Turbine Towers And Blades Gain Traction

Stora Enso and Voodin Blade signed a partnership agreement to develop wind turbine blades from wood, which will also involve creating a new sustainable supply chain. The two companies are working on producing and installing a 65.6-ft. (20-m) blade for a 0.5-MW turbine near Warburg, Germany, by the end of 2022. Plans are in the works for a 262.5-ft. (80-m) blade down the road. Stora Enso said it is using 100 percent sustainable wood to supply the LVL blades, which will give them a high load-bearing capacity while also leading to a low environmental footprint.

Originally published by ESG Review, 1/4/23.

BC government increases maximum height of mass timber buildings to 18 storeys

"These proposed mass timber building code changes align with our recent work to deliver more homes near transit hubs by allowing taller buildings and more sustainable housing options near transit," said Ravi Kahlon, BC Minister of Housing, in a statement.

"These changes will also help reduce carbon pollution, support the forestry sector, create jobs, build more homes and lead to more vibrant, healthier communities."

Originally published by Daily Hive, 12/11/23.

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CHAPTER 1: INTRODUCTION

ROY ANDERSON
VICE PRESIDENT, THE BECK GROUP

Some of the earliest evidence of wood as a building material dates to 6000 BC, when farmers in Europe constructed Neolithic longhouses, which were made with massive solid wood beams and housed up to 30 people. In some respects, not that much has changed since then. For example, today, wood is a common building material used in many low-rise and light wood-frame buildings where people live and work. A light wood-frame building uses many small and closely spaced wooden members assembled by nailing. Typical light wood-frame construction features 2-by-4s and 2-by-6s as vertically oriented wall supports, wood joists as horizontally oriented floor supports, and rafters as a roof assembly. The application of this light wood-frame construction style is primarily limited to homes, smaller apartment buildings, and low-rise nonresidential structures.

Now, though, the use of wood in building construction is shifting with the game-changing introduction of mass timber to North America. According to Think Wood, a Softwood Lumber Board-funded program that provides resources about mass timber to architects, developers, and contractors, mass timber is inspiring innovation and offering developers a way to differentiate their projects. Think Wood says, “The aesthetic, biophilic, and other benefits of using wood offer market differentiators that can boost a project’s overall value. Wood can contribute to a project’s sales proposition and create warm, beautiful environments that appeal to a new generation of eco-minded employees, residents, and occupants. Some builders and developers have reported higher sales, rental, and/or lease rates for wood buildings compared to similar non-wood structures.”[1]

This report provides readers with a broad, yet deep, understanding of the North American mass timber industry in 2023. This chapter explains why the report was assembled, defines the key types of mass timber products, describes how they are used, and introduces the mass timber supply chain concept.

1.1 WHY A MASS TIMBER REPORT?

This report was developed as a companion piece to the International Mass Timber Conference (IMTC), held annually in Portland, Oregon. As evidenced by dramatic year-over-year growth in attendance, the conference has strengthened the mass timber community by providing a forum for the exchange of ideas and information, and for the development of relationships along the industry’s supply chain.

Mass timber has captured widespread attention in recent years. Architects, engineers, developers, builders, the forest industry, and community leaders are excited about mass timber’s revolutionary potential in building construction. And rightly so. It’s a technology that uses renewable resources, reduces building construction and development costs, increases versatility in building sites, is safe, and yields highly usable structures. It is an exciting time to be in the mass timber industry. The changes and growth are constant, and information on mass timber is being developed at a phenomenal rate. It can be overwhelming, especially when each new piece of information is specific to

1 https://www.thinkwood.com/wood-construction-benefits

just one project or one aspect of the industry. By contrast, this report is intended as a single comprehensive, in-depth source of North American mass timber information, as it stands in 2023.

It is also important to recognize that the mass timber industry is global. The majority of the annual volume of mass timber panels produced globally is manufactured overseas, mostly in Central Europe. As a result, mass timber building projects are often exported to destinations halfway around the globe from the manufacturing plants. Thus, this report includes comments and analyses about the global aspects of the industry.

As the industry continues to evolve, this report will be expanded and updated annually.

1.2 WHAT IS MASS TIMBER?

Mass timber is not just one technology or product. Solid wood (i.e., timber and lumber) has been used as a structural material for millennia. More recently, however, a different class of wood products has emerged. These Engineered Wood Products (EWPs) are a group of construction materials that combine wood's inherent strength with modern engineering. EWPs are manufactured by using adhesives to bind strands, particles, fibers, veneers, or boards of wood to form a composite product. The theory underlying all EWPs is that the process of disassembling wood into smaller pieces and then gluing them back together results in a product that is significantly stronger than a solid wood product of the same dimensions. In a solid piece of wood, strength-limiting defects such as knots, splits, checks, or decay tend to concentrate in a single area. That defective area is where the wood is most likely to fail when subjected to a load. In EWPs, the disassembly and reassembly processes randomize the locations of defects and thereby yield products with predictable strength characteristics. EWPs include structural building materials such as plywood, Oriented Strand Lumber (OSL), Laminated Veneer Lumber (LVL) (see **Figure 1.1**), wooden I-joists, and of particular interest in this report, mass timber products.

Mass Timber Products

Mass timber products are a distinct class of EWPs. The following sections provide descriptions of the different types of mass timber products that have been developed to date.

Cross-Laminated Timber

Cross-Laminated Timber (CLT) is a panelized structural EWP that can be used in all major building components (floors, interior and exterior walls, and roofs). It is also used as a ground mat at construction and mining sites, allowing heavy equipment to operate on unstable soils. CLT is made of 3 or more layers of lumber, with the wood grain of each layer oriented perpendicularly to the adjacent layer (see **Figure 1.2**). The layers are then pressed together with a special adhesive. The lumber is typically preselected, so major defects such as large knots and checks are removed before lay-up. CLT panels used for building construction are commonly 8 feet to 12 feet wide and 3.5 inches to 9.0 inches thick. Panel length is limited only by press size and highway trucking regulations, but common lengths range between 20 feet and 60 feet.

Because the lumber is layered with an alternating grain orientation, the strength, dimensional stability, and fire resistance of CLT panels are significantly greater than for individual boards. CLT

FIGURE 1.1: LAMINATED VENEER LUMBER (LVL)
Source: APA

FIGURE 1.2: CROSS-LAMINATED TIMBER (CLT) PANEL
Source: APA

is produced in dedicated manufacturing plants with machinery for remanufacturing, finger jointing, and surfacing lumber; glue applicators and specialized panel presses; and Computer Numerical Control (CNC) routers that trim panels to size and cut openings for doors, windows, etc.

Most CLT panels are customized for a specific construction project, meaning the exact width, length, thickness (and arrangement of layers), and other properties of each panel are precisely tailored for a designated purpose in a single building. Openings for doors and windows—as well as openings or channels for electrical; plumbing; and heating, ventilation, and air conditioning (HVAC)—are commonly cut from a whole panel by the manufacturer using CNC machines. Prefabricating the panels in this manner minimizes the labor needed at the construction site and dramatically speeds construction. After manufacturing, CLT panels are transported to the construction site, typically by truck. Crews hoist the massive panels into place using cranes, with straps or cables attached to preinstalled pick points, which are removed once the panel is in place. In some cases, CLT panels are prefabricated into entire modular units (rooms and/or building sections) that can be transported by truck and installed using cranes, further reducing jobsite construction requirements.

Nail-Laminated Timber

Nail-Laminated Timber (NLT) is a century-old construction method that recently returned to favor and has been updated with new design guides and construction methods. Like CLT, NLT is a massive wood composite panel. In an NLT pan-

FIGURE 1.3: NAIL-LAMINATED TIMBER (NLT) PANEL
Source: StructureCraft

el, however, the wood grain orientation does not alternate. Instead, numerous pieces of lumber are stacked face to face, with the wide faces adjoining. Rather than using adhesive to bond the layers (as in CLT and glue-laminated timber, or glulam), the lumber is held together with nails (see **Figure 1.3**). Because it does not require the specialized presses used in CLT manufacturing, NLT can be assembled at a temporary workshop close to the construction site or at the building site.

NLT panels are most commonly used in horizontal applications (i.e., floors and roof decks). As a result, fewer precision-machined openings, such as those required for doors and windows, are needed. One drawback is that the metal nails used in NLT can dull or damage woodworking tools such as saws, drills, and routers if the NLT panels are machined. NLT panels can be produced in any thickness common to softwood dimension lumber (e.g., 2-by-4 to 2-by-12). The width and length of the panels are limited only by the application's dimensions. NLT is recognized by the International Building Code (IBC) as being code-compliant for buildings with varying heights, areas, and occupancies.

Dowel-Laminated Timber

Dowel-Laminated Timber (DLT) is like NLT, but wooden dowels hold the boards together instead of nails (see **Figure 1.4**). In a process called friction fitting, hardwood dowels are dried to a very low moisture content and placed in holes drilled perpendicularly into softwood boards stacked on edge and side by side. (The wood grain in a DLT panel is parallel.) The hardwood dowels then expand as they gain moisture from the surrounding softwood boards, which are less dry. The result is a tight-fitting connection that holds the boards together. The panel sizes are like CLT and NLT (8 feet to 12 feet wide and up to 60 feet long), but the thickness depends on the width of the softwood boards being used. DLT is most common in floor and roof applications, but StructureCraft, the lone North American manufacturer of DLT, says its panels can also be used in vertical applications.

DLT is the only all-wood mass timber product. With no metal fasteners, DLT panels can be processed with CNC machinery without damaging the cutting tools. That's why DLT is often selected when certain profiles are needed in a panel (e.g., a design to enhance acoustics). The all-wood approach also allows building designers to select a material with no chemical adhesives.

Unlike NLT, which is commonly manufactured at the jobsite, DLT is typically fabricated in a plant, allowing the panels to be manufactured at precise dimensions and to include aesthetically pleasing patterns, integrated acoustic materials, electrical conduits, and other service interfaces.

Dowel-Bonded CLT

Dowel-bonded CLT is a massive, prefabricated, cross-laminated panel with layers of rough-sawn

FIGURE: 1.4 DOWEL-LAMINATED TIMBER (DLT) PANEL
Source: StructureCraft

boards that are bonded with hardwood dowels. This is the newest of the CLT products and should not be confused with DLT, described above. The low moisture content and tight fitting of the dowels at the time of assembly ensures a durable, close-fitting connection once the dowels swell after gaining moisture in ambient conditions. The panels are assembled in highly automated lines. Only 2 commercially successful systems are known to date: one developed by Thoma Holz in Austria and another developed by Swiss industrial hardware manufacturer TechnoWood AG. By mid-2019, TechnoWood AG had installed 8 highly automated lines in Europe. Unlike other CLT products, some layers of the dowel-bonded CLT are arranged at 45 degrees or 60 degrees to the surface layer direction.

Nail-Bonded Solid Wood Wall or Massiv-Holz-Mauer

Massiv-Holz-Mauer (MHM) is a massive prefabricated cross-laminated panel with layers made of rough-sawn boards bonded with nails. This product should not be confused with NLT produced in North America. The nail-bonded MHM (which literally means “mass wood wall”) technology might have predated the development of adhesive-bonded CLT, but the real breakthrough came with a solid wooden wall system patented in Germany in 2005. MHM is fabricated on small-scale, turnkey, 3-step Hundegger production lines. Panels may consist of 9, 11, 13, or 15 layers (each about 16.5 millimeters, or $^{10}/_{16}$ inch). The intended use of this product is as load-bearing and division walls for low-rise buildings with moderate exposure to moisture (below 20 percent) and low to moderate exposure to corrosion.

Mass Plywood Panel

A Mass Plywood Panel (MPP) is another innovative mass timber product that’s produced at a single plant: Freres Lumber Co. Inc., located in Oregon. MPPs are veneer-based, rather than lumber-based, and are constructed by gluing together

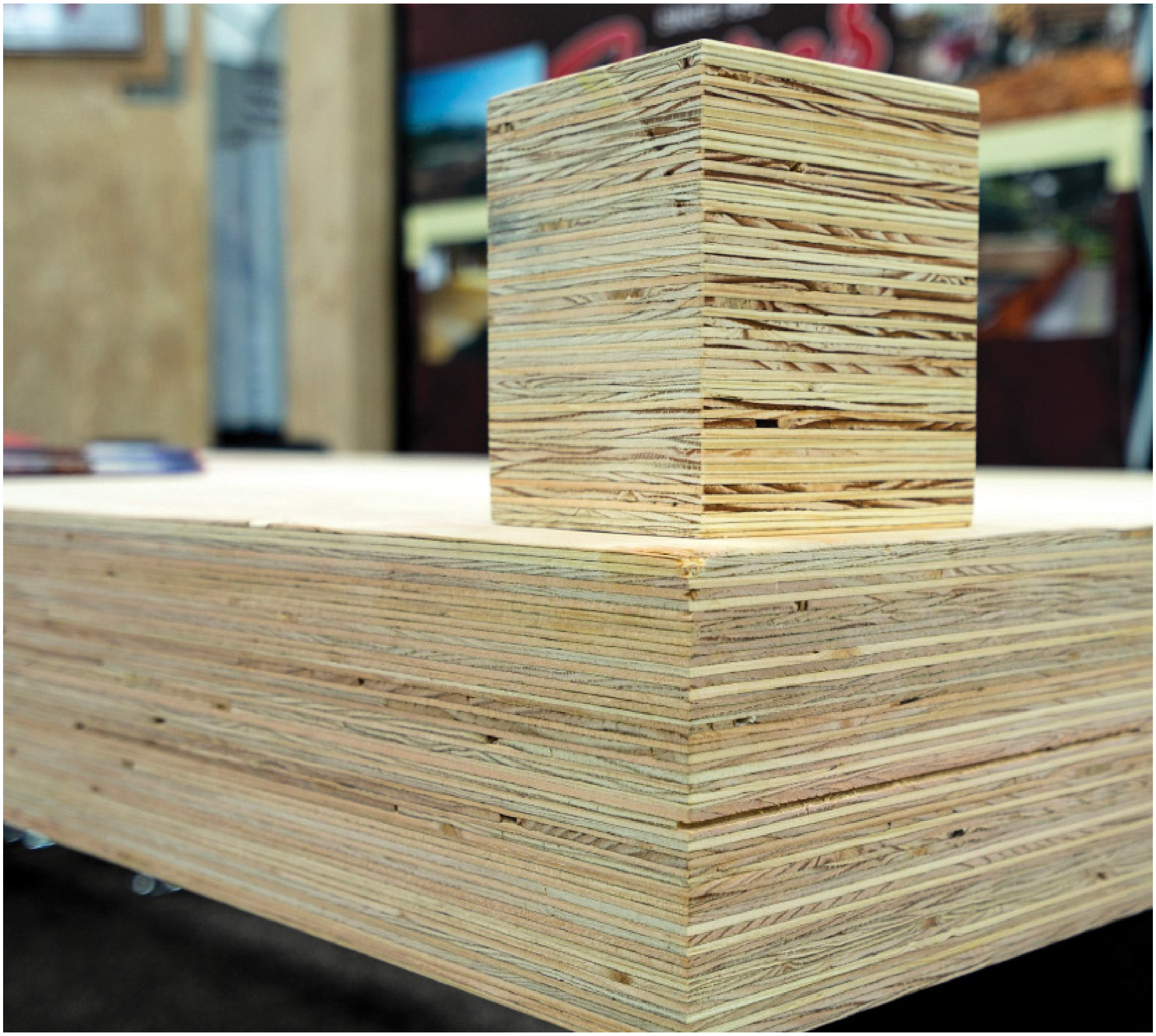

FIGURE 1.5: MASS PLYWOOD PANEL (MPP)

Source: Oregon Department of Forestry

many layers of wood veneer in various combinations of grain orientation (see **Figure 1.5**). The uses of MPPs are like those of other mass timber panels, though the manufacturer says veneer-based panels can form thinner panels and/or longer, unsupported spans than are possible with lumber-based panels, and they still achieve the desired strength properties.

Glulam

Glulam is another form of mass timber, an engineered wood composite made from multiple layers of lumber. The grain is oriented in a parallel direction in all layers, and the layers are bonded with adhesive to form a structural element with large dimensions (see **Figure 1.6**). Glulam, a well-established product that has been used in residential and nonresidential construction for

FIGURE 1.6: GLULAM TIMBERS
Source: APA

many years, is typically used as either a beam in a horizontal application, or as a column in a vertical application because of its high strength-to-weight ratio. Glulam use is on the rise because it is commonly used to support mass timber panels. Other less common uses are as members of massive truss systems or as large-scale utility poles.

Most glulam is made from standard-dimension lumber (e.g., 2-by-4s to 2-by-12s). Thus, typical widths range from about 2.5 inches to 10.75 inches. The potential thicknesses and lengths of glulam, however, are much larger. Glulam depths range from 6 inches to 108 inches, and lengths can surpass 100 feet.

Glulam beams are typically much stronger than an equivalent-size solid-sawn beam and can be manufactured in customizable sizes and shapes, including cambered, curved, or arched structures. If glulam is to be used in applications where both structural support and appearance are considerations, it is available in 4 appearance grades: framing, industrial, architectural, and premium.

Post and Beam

Post and beam is a construction method that uses large timbers in both vertical and horizontal applications to create the building framework (see **Figure 1.7**). It allows for large, open spaces within the building and flexible wall structures. Construction using large-dimension (6 inches thick and larger) lumber has been popular in high-end homes for years, but it is now enjoying increased popularity in a variety of larger nonresidential and multifamily residential buildings (office buildings, schools, and warehouses). In these larger buildings, structural loads are typically higher than for single-family residences, so larger-dimension posts and beams and/or engineered wood composites such as glulam are of use. In many cases, post and beam frames make up the structural elements of a building frame, while nonstructural walls are commonly constructed with light wood framing.

In structures where mass timber panels are used for the floor, wooden posts and beams are often used for the supporting vertical structural elements.

Heavy Timber Decking or Jointed Timbers

Heavy timber decking is used in horizontal applications (floors and roofs) where the full engineered properties of panelized products such as CLT are not required. Heavy timber decking consists of a single layer of timbers (usually 3-by-6s or 4-by-6s) joined edgewise with tongue-and-groove profiles on each piece that lock them together (see **Figure 1.8**). The pieces may be solid-sawn or glulam. Timber decking is more frequently used in regions where construction labor is less expensive, giving this labor-intensive application a cost advantage over other mass timber panels.

TOP — FIGURE 1.7: POST AND BEAM

BOTTOM — FIGURE 1.8: HEAVY TIMBER DECKING

Source: Southern Wood Specialties

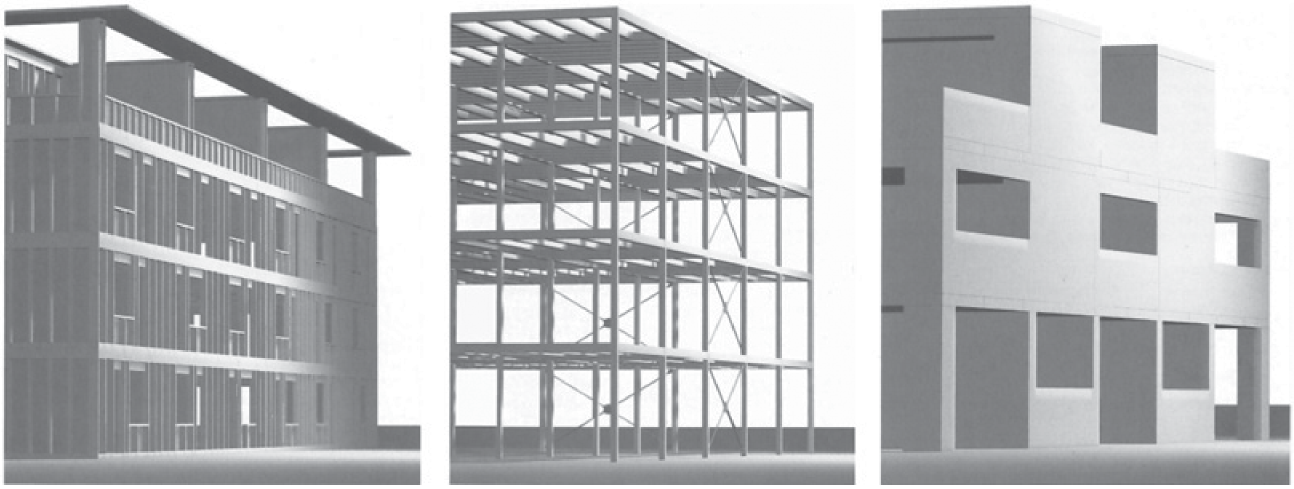

FIGURE 1.9: WOOD-BASE BUILDING CONSTRUCTION SYSTEMS
Source: Fast and Epp

Mass Timber Hollow Core Panels and Mass Timber Ribbed Panel Assemblies

Mass timber hollow core panels use thinner (3-ply) CLT panels for the top and bottom layers, which are connected with internal glulam ribs. The hollow spaces are filled with insulation materials. Mass timber ribbed panel assemblies are another relatively new mass timber product, combining CLT decks with integrated glulam ribs connected by screws, glue, or a combination of both on the bottom. Both products are typically used as horizontal elements (e.g., high-capacity floors with extended spans).

1.3 HOW IS MASS TIMBER USED?

Figure 1.9 illustrates how mass timber construction differs from more traditional wood construction.

Light wood-frame construction (building on the left) is the most familiar construction system. At a given site, a building is constructed using light wood materials. For example, studs form vertical wall members; joists are the horizontal floor supports; rafters provide roof supports; and plywood or Oriented Strand Board (OSB) panels sheathe the walls, floors, and roof. This style is most commonly used in single-family homes and multifamily low-rise housing.

Post and beam construction (center building) involves the use of large, heavy timbers in either sawn or roundwood form. The timbers used as horizontal beams in this style of construction transfer structural loads to other timbers aligned vertically. Diagonal braces between the horizontal and vertical elements provide even more rigidity to the structure. This style allows for an open design because all load-bearing members are fixed points instead of an entire wall.

Mass timber panel construction (building on the right) involves the use of large, solid wood panels for the roof, floor, and walls. Mass timber allows for the construction of wooden buildings that are much taller than light wood-frame construction.

There are many forms of mass timber panels, including CLT, NLT, DLT, and MPP. The term "mass timber," as used in this report, refers to all of the preceding forms.

1.4 DEFINING THE MASS TIMBER SUPPLY CHAIN

A mass timber supply chain is developing in North America, and examining the components of that supply chain offers a way to organize and think about this industry. It is important to note that most mass timber products are not standardized commodities. Rather, the fabrication of mass timber products is perhaps best thought of as a step in an integrated process of producing a building—with the building being the actual final product. Accordingly, the supply and value chains of the mass timber panel industry represent an integrated combination of what is typical for manufacturers of structural EWPs and for the design-engineering-construction sector.

The supply chain starts with the forest resource and flows all the way through to the occupants of a mass timber building (see **Figure 1.10**). In this report, we assess the state of each link in the supply chain, and we address issues such as sustainability, economics, and technology. In short, this report analyzes how people and policies impact mass timber, and what that might mean for its development.

1.5 MEASUREMENTS AND CONVERSION FACTORS

Wood products—including logs, lumber, and mass timber products—can be measured and labeled in a variety of ways, some of which can

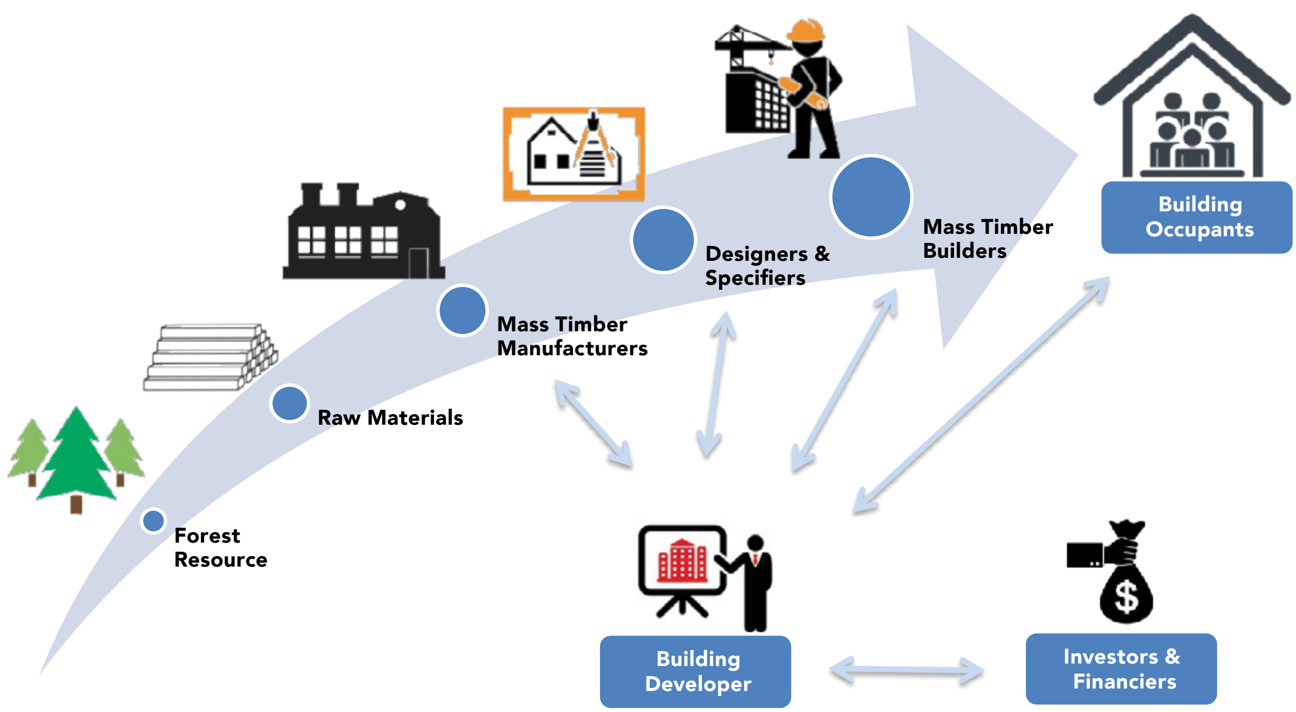

FIGURE 1.10 MASS TIMBER SUPPLY CHAIN

be confusing to those not familiar with common industry practices. This section discusses the terminology, measurement, and conversion conventions used in this report.

Log Measurement

When trees are still standing in the forest, their volume is sometimes reported on a cubic-foot basis, which is the convention used in this report. Cubic feet can be converted to cubic meters using the standard conversion of 35.315 cubic feet per cubic meter. In contrast, after trees are harvested and manufactured into logs, a variety of measurement units is used when logs are bought and sold, especially in the United States. For example, some transactions are in cubic feet, which are often lumped into units of 100, known as cunits. Others use various log scales that predict the volume of lumber in board feet[2] that can be manufactured from a log. Still others use a weight basis for measuring the amount of logs bought and sold. Many of the measurement systems are highly regional. The variety of measurement systems and conversions between them is complex, and further analysis of these systems is beyond the scope of this report.

Lumber Measurement

In mass timber, 2 main types of solid-sawn lumber (not engineered wood or wood/glue composite) are relevant. The first is dimension lumber (most commonly 2 inches thick and 4 inches to 12 inches wide). When used in mass timber panels, multiple pieces of dimension lumber are fastened or glued together to create one larger mass of wood. Mass timber is typically bought and sold in cubic feet (or cubic meters). Dimension lumber is bought and sold in board feet. Thus, a cubic foot of wood contains 12 board feet. However, a peculiarity of dimension lumber is that its volume is expressed as a nominal size that is larger than the actual finished size. For example, a 2-by-4's actual dimensions are really 1.5 inches by 3.5 inches. This difference in dimension lumber's nominal and actual sizes means that a cubic foot of wood in a mass timber panel requires an estimated 22.5 board feet of nominally tallied lumber, after accounting for the differences between nominal and actual sizes and yield loss when converting lumber into mass timber panels.

Table 1.1 compares the board feet per piece based on nominal size with the actual cubic volume per piece of dry, surfaced framing lumber sold in North America. For consistency, 20-foot-long pieces are used for all examples. The resulting conversion factors (board feet per cubic foot, and vice versa) are shown in the 2 columns on the right side of the table.

The second type of solid-sawn lumber used in mass timber structures is heavy timber; it is used as structural support for mass timber panel systems. Heavy timbers may either be sawn to sizes similar to nominal-dimension lumber sizes (standard-sawn) or to the full stated size (full-sawn). Most heavy timbers are custom-made where the buyer and seller agree on the specified sawn dimensions. For timbers that are full-sawn, the appropriate conversion would be 12 board feet per cubic foot.

Globally, lumber practices can vary. In contrast to the North American market, structural lumber in Europe and in many other regions is offered in a variety of thicknesses. Although all lumber imported to the US from overseas conforms with US

2 A board foot is defined as a piece of wood measuring 1 inch thick by 12 inches wide by 12 inches long.

NOMINAL SIZE				ACTUAL (DRY, SURFACED) SIZE				Conversion Factor (CF/BF)	Conversion Factor (BF/CF)
Thickness (inches)	Width (inches)	Length (feet)	Volume (board feet)	Thickness (inches)	Width (inches)	Length (feet)	Volume (cubic feet)		
2	4	20	13.33	1.5	3.50	20	0.73	0.055	18.3
2	6	20	20.00	1.5	5.50	20	1.15	0.057	17.5
2	8	20	26.67	1.5	7.25	20	1.51	0.057	17.7
2	10	20	33.33	1.5	9.25	20	1.93	0.058	17.3
2	12	20	40.00	1.5	11.25	20	2.34	0.059	17.1

TABLE 1.1: NOMINAL DIMENSION LUMBER SIZES VS. ACTUAL CUBIC MEASUREMENT

standards, mass timber panels produced overseas will freely incorporate layers of various thicknesses to meet the required engineering specifications with better efficiency.

Log-to-Lumber Volumes

In the sawmill industry, lumber yield—the volume of lumber produced from a given volume of logs—is expressed in a variety of ways, with regional differences based on local conventions for measuring logs. A full description of these various lumber yield measurements is beyond the scope of this report. But, to understand how lumber volumes relate to log demand and harvest, it is most useful to consider cubic yields.

Cubic lumber yields (i.e., the percentage of a log's total cubic volume that is recovered as lumber) at sawmills vary depending on several factors, with the most important being the log size (diameter). In North America, typical cubic lumber yields for sawmills producing dimension lumber are in the range of 35 percent to 60 percent, meaning that 35 percent to 60 percent of the log volume comes out as finished (dry, surfaced) lumber, and the balance is a by-product (chips, sawdust, and shavings), with some volume lost to drying shrinkage. The regions with the largest logs (9 inches to 11 inches average bucked sawmill-length log diameter in the US West) achieve higher cubic lumber yields, while those with the smallest logs (4.5 inches to 6 inches average bucked log diameter in Eastern Canada) are on the lower end of the range.

For a quick but rough conversion, multiply a known lumber volume by 2 to estimate the log volume required. For example, to produce 100 cubic feet of dimension lumber, a mill needs 200 cubic feet of logs.

Mass Timber Panels and Glulam

Most measurements of mass timber panels and glulam beams are expressed in terms of cubic feet or cubic meters. These figures are based on the actual size of the finished product (although cutouts and channels are typically not deducted). For example, a CLT panel that is 6 inches thick by 10 feet wide and 40 feet long would measure 200 cubic feet ([6 ÷ 12] x 10 x 40), or 5.66 cubic meters (200 cubic feet ÷ 35.315).

When considering the amount of lumber used in mass timber or glulam products, it is important to

WOOD VOLUME	VOLUME OR CONVERSION FACTOR	UNIT	DESCRIPTION
Mass Timber Volume	100,000	Cubic Feet	Total CLT and glulam used in building project
	22.5	BF per CF	CLT/glulam to nominal lumber conversion
Dimension Lumber Volume	2,250,000	Board Feet	Purchased dimension lumber
	0.057	CF per BF	Conversion from nominal to cubic volume
Cubic Lumber Volume	128,250	Cubic Feet	Equivalent cubic volume of lumber used
	0.5	CF per CF	Cubic lumber yield from logs
Log Volume	256,500	Cubic Feet	Log demand from mass timber project

TABLE 1.2: SUPPLY CHAIN CONVERSIONS EXAMPLE

consider the nominal versus the cubic size of the lumber feedstock (see **Table 1.1**), as well as any volume lost during the mass timber manufacturing process. In CLT, DLT, and glulam, the lumber is surfaced during the manufacturing process, with about $^1/_{16}$ inch removed from all 4 sides (exact amounts vary by manufacturer). Also, some volume is lost when defects are trimmed from lumber feedstock, and when panels or beams are trimmed to final dimensions.

For typical CLT or glulam manufacturing, a total of 20 to 25 nominal board feet of dimension lumber is used per cubic foot of finished product.

Example of Mass Timber to Logs

Given all the preceding measurement and conversion conventions, it is possible to approximate the total amount of timber (logs) required for a mass timber project. **Table 1.2** follows the wood back through the supply chain to estimate the total lumber, and then the logs, required for a hypothetical building project that uses 100,000 cubic feet of CLT and glulam. This calculation is only an estimate, and it depends on several assumptions (lumber yield, size of lumber used, and CLT and glulam wood use), but it provides a reasonable indication of the wood volume at various points in the supply chain.

The results show that substantially more log volume is required than will be reflected in the finished product volume. Importantly, the material not used in the final mass timber product is not wasted. Depending on the region where the lumber and mass timber are manufactured, the by-products can be used in a variety of ways. For example, wood chips are typically produced from lumber trim ends, edgings, and the outermost portion of the log. Wood chips are commonly used for making paper. Similarly, processing a log into lumber generates sawdust and/or planer shavings. Both of those materials are commonly used to make composite panels (particleboard or medium-density fiberboard). By-products can also be made into wood pellets for heating or power generation, or combusted in a boiler to generate power and/or provide thermal energy for lumber drying or other uses.

THE BUILDING FEATURES A MASSIVE 130-FOOT CLEAR SPAN.
Source: Timberlyne Group; Credit: Reginald Thomas

CASE STUDY: VICTORY CAPITAL PERFORMANCE CENTER

GLULAM BEAMS SPAN SPURS' PRACTICE COURTS

PROJECT OWNER: SAN ANTONIO SPURS

PROJECT LOCATION: 1 SPURS WAY, SAN ANTONIO, TX 78256

COMPLETION DATE: MARCH 1, 2024

ARCHITECT/DESIGNER: ZGF ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: SMARTLAM NORTH AMERICA

GENERAL CONTRACTOR: JOERIS

STRUCTURAL ENGINEER: ARUP

OTHER CONTRACTORS: TIMBERLYNE

THE LARGEST MASS timber constructed training facility in US professional sports history is now home to the San Antonio Spurs. The 134,000-square-foot building is also the largest mass timber structure in Texas.

This state-of-the-art project features 20 glulam beams 130 feet long and 6.5 feet tall, weighing over 13 tons each. There are practice courts, training rooms, therapy pools, a float tank, a team dining room, and a performance kitchen, all focused on advancing human performance.

CHAPTER 2: THE FOREST RESOURCE

ROY ANDERSON
VICE PRESIDENT, THE BECK GROUP

2.1 CHARACTERIZING THE NORTH AMERICAN FOREST RESOURCE

Forests are a key component of the landscape in many regions. They are important to society because they provide fresh water. This occurs as the roots of trees and other plants bind the soil while rain and surface water percolate through it. Plants also absorb water from the soil, which is then lost into the atmosphere by transpiration. Water ultimately returns to earth in the form of rain. Forests also serve as a major carbon sink. Trees remove carbon from the atmosphere as they grow. Forests also provide outdoor recreation, which allows people to participate in activities that promote mental and physical health. And finally, as we will see in the remainder of this chapter, forests provide a variety of wood products that play important roles in our economy and serve as the raw materials for mass timber building construction.

Figure 2.1 illustrates the portions of North America with more than 15 percent tree cover. As shown by the color shadings, there are 2 main forest types including coniferous (softwood) trees in the coastal and mountainous areas of the West; mixed hardwood and coniferous trees in the US Midwest, Eastern US, and Eastern Canada; and coniferous trees in the US Southeast. Also note that the far northern regions of Canada and Alaska have vast areas of boreal forests. But, given their distance from major population centers and their generally smaller tree sizes, these forests have little commercial value for conversion to lumber. Finally, although not shown in the figure, it is worth noting that, in Central Europe, Germany and Austria are leading in production of high-performing mass timber elements, including glulam and Laminated Veneer Lumber (LVL) made of local hardwoods, mostly beech and oak. These technologies are commercialized, and similar development may be expected in North America, with a focus on hardwood species abundant in the US where hardwoods predominate.

As further discussed in chapter 3, lumber-producing regions are often defined by the types of softwood they commonly produce. The 5 main regions in North America are the US West, US South, US Other, Eastern Canada, and Western Canada. Forests in the US West are dominated by Douglas-fir, Western hemlock, and various pine species. In the US South, 4 types of pine—loblolly, slash, shortleaf, and longleaf—are the leading species of note for mass timber. When sold as lumber, those 4 species are lumped into a group called Southern Yellow Pine (SYP). The US Other region includes the Upper Midwest and Northeast. These forests are more heavily stocked with hardwood trees and therefore, up to this point, have been less significant from a mass timber industry perspective. In both Eastern and Western Canada, forests are largely composed of various mixtures of spruce, pine, fir (SPF).

Extent of US Forests

The total US land area is about 2.3 billion acres. As illustrated in **Table 2.1**, forests in the United States total about 822 million acres, or roughly one-third of the US land area. Note that this data is from *Forest Resources of the United States,*

FIGURE 2.1: EXTENT OF FORESTS IN NORTH AMERICA

FOREST TYPE	NORTH	SOUTH	WEST	TOTAL
Timberland	164,894	208,092	141,437	514,423
Reserved	9,447	5,827	65,290	80,564
Other/Woodland	1,448	54,114	171,846	227,408
Total	175,789	268,033	378,573	822,395

TABLE 2.1: EXTENT OF FORESTS IN THE UNITED STATES BY TYPE & REGION (ACRES IN 1000S)

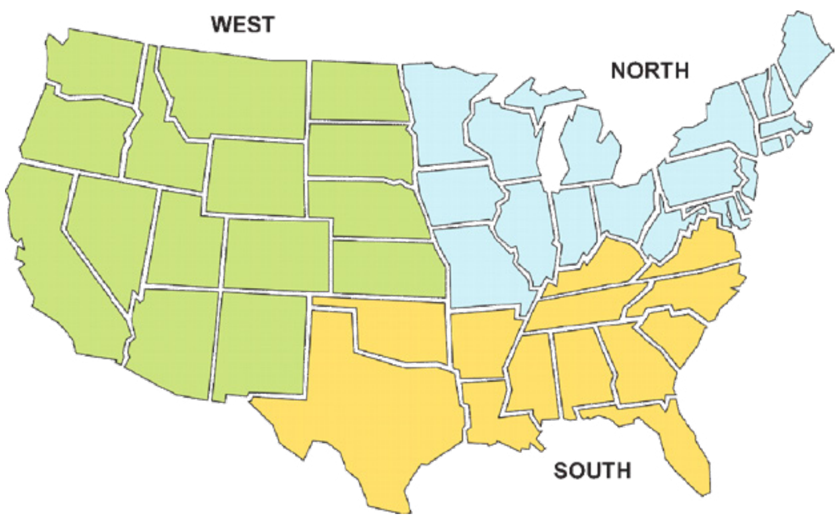

FIGURE 2.2: MAP OF US FOREST REGIONS

2017.[1] The total forest area increased from 766 million acres in the 2012 assessment to 822 million acres in the most recent assessment. The area of forested land in the US has been stable (or increasing, per the most recent analysis) since the early 1900s, despite the US population more than quadrupling since 1900. Despite the massive growth in US population and the associated increase in demand for wood fiber, it's encouraging to consider that the forest area in the US has remained stable for more than 100 years.

The broad category of forested land includes several subcategories: timberland, or forests that are well stocked and capable of producing at least 20 cubic feet of wood fiber per acre per year; reserved forestland, or forests where harvesting of trees is prohibited, mainly wilderness areas and national parks; and woodland/other, where tree cover ranges between 5 percent and 10 percent, tree growth is marginal, and timber production is not a priority. **Figure 2.2** shows the location of the regions listed as columns in **Table 2.2.**

1 Sonja Oswalt, W. Brad Smith, Patrick D. Miles, and Scott Pugh, *Forest Resources of the United States, 2017* (2019), https://www.fs.usda.gov/research/treesearch/57903.

REGION	NATIONAL FOREST	OTHER PUBLIC	PRIVATE CORPORATE	PRIVATE NONCORPORATE	TOTAL
North	10,147	26,852	30,196	97,700	164,895
South	12,258	13,699	63,504	118,632	208,093
West	73,733	18,584	23,455	25,665	141,437
Total	**96,138**	**59,135**	**117,155**	**241,997**	**514,425**

TABLE 2.2: OWNERSHIP OF US FORESTS DESIGNATED AS TIMBERLAND BY REGION AND OWNER TYPE (ACRES IN 1000S)

YEAR	SAWTIMBER	POLETIMBER	SEEDLING/ SAPLING	NONSTOCKED	TOTAL
1953	201,491	170,688	94,565	42,110	508,854
1977	223,210	136,694	115,842	16,607	492,353
1987	242,864	137,981	97,413	8,057	486,315
1997	258,680	127,169	110,283	7,533	503,665
2007	280,265	128,896	96,177	8,875	514,213
2012	294,964	123,144	93,140	9,906	521,154
2017	299,716	117,637	87,395	9,676	514,424

TABLE 2.3: HISTORY OF TIMBERLAND AREA IN THE US BY STANDING SIZE CLASS (ACRES IN 1000S)

Ownership of US Forests

The timberland forest classification is the most productive forest acreage in the US. **Table 2.2** categorizes it by 2 types of public owners and 2 types of private owners. As the data in the table shows, higher percentages of timberland are in private ownership in the North and South than in the West. Ownership is important because it affects how land is managed. In general, corporate timberlands are managed to maximize timber production, while public and noncorporate private lands are managed for a broader set of objectives.

Table 2.3 shows a history of the area of US forest designated as timberland classified by tree size, including sawtimber, poletimber, seedlings/saplings, and nonstocked. Note that sawtimber includes trees big enough to be sawed into lumber; poletimber trees are too small for use as sawlogs; seedlings/saplings are very young stands; and nonstocked is bare land that typically has yet to be replanted just after harvest. As the data shows, the area of sawtimber that could be used to make lumber for mass timber has increased by nearly 100 million acres since 1953. This is an encouraging finding.

REGION	SOFTWOOD	HARDWOOD	TOTAL
North	68,278	245,926	**314,204**
South	149,800	227,981	**377,781**
West	380,794	43,232	**424,026**
Total	598,872	517,139	**1,116,011**

TABLE 2.4: US STANDING TIMBER INVENTORY ON TIMBERLAND BY REGION AND SPECIES GROUP (CUBIC FEET IN MILLIONS)

REGION	1953	1977	1987	1997	2007	2017
North	27,053	43,850	47,618	49,374	55,864	60,601
South	60,462	101,208	105,613	104,846	118,472	141,307
West	344,279	321,902	314,344	329,622	357,264	358,617
Total	**431,794**	**466,960**	**467,575**	**483,842**	**531,600**	**560,525**

TABLE 2.5: HISTORY OF US SOFTWOOD STANDING TIMBER INVENTORY ON TIMBERLAND BY REGION (CUBIC FEET IN MILLIONS)

US Standing Timber Inventory

The US Forest Service is a federal agency charged with managing nearly 190 million acres of national forests and grasslands. In addition, its Forest Inventory and Analysis (FIA) program was established nearly 100 years ago to monitor the conditions of all the nation's forests (i.e., both publicly and privately owned forestlands). A key accomplishment of the FIA was to establish more than 325,000 permanently located growth plots in US forests at the initiation of the program. Thus, for about 100 years, each plot has been revisited regularly. The data collected about the trees within the plots' boundaries allows the FIA system to track changes in the forests' statuses. The FIA tracks, for example, key metrics such as species composition, diameter, age, and cubic volume as part of its inventory of standing trees.

Table 2.4 shows the most recently available (2019) estimate of standing timber volume in the US on timberland acres. As shown, the US has an estimated 1.1 trillion cubic feet of standing timber. The standing volume is relatively evenly split between hardwoods and softwoods. As a point of reference, and as further discussed in chapter 3, the annual harvest of softwood sawtimber associated with the US annual softwood lumber production is equal to about 1.4 percent of standing volume.

More specific to the mass timber industry is **Table 2.5**. It shows the history of softwood standing timber inventory by region. Note that, over roughly the last 65 years, the volume of standing timber in the US has increased by nearly 30 percent in total, and by more than 230 percent in the South—both positive findings given the anticipated increased demand from the mass timber industry.

FIGURE 2.3: CANADIAN FOREST REGIONS

Source: Natural Resources Canada. Accessed at:http://cfs.nrcan.gc.calassets/file/92

2.1.1 CANADIAN FORESTS

The Extent of Canada's Forests

Canada's total land area is about 2.467 billion acres. Of that total, about 857 million acres are forested. Canada and the US have roughly the same total land areas and total forested areas. Canada's forest area has been very stable for more than 3 decades. **Figure 2.3** shows that there are several distinct types of forest in Canada. The largest and most commercially important types include a vast boreal forest that stretches the length of the country from east to west and is composed mainly of spruces, firs, and, to a lesser extent, pines; the forests around the Great Lakes, which are primarily hardwoods, including maple and birch; the montane forests of Western Canada, which are populated with Douglas-fir, hemlock, and pines; and the coastal forests in

OWNER TYPE	PERCENT OWNED
Provincial Crown Land	77%
Territorial Crown Land	13%
Federal Crown Land	2%
Private	6%
Indigenous	2%
Total	**100%**

TABLE 2.6: OWNERSHIP OF CANADIAN FORESTS

YEAR	CUBIC FEET (IN MILLIONS)
1990	1,882,413
1995	1,881,530
2000	1,866,062
2005	1,806,911
2010	1,787,171
2015	1,770,891
2016	1,769,090
2017	1,762,169
2018	1,751,504
2019	1,748,502
2020	1,750,232

TABLE 2.7: HISTORICAL TOTAL STANDING TIMBER VOLUME IN CANADA (CUBIC FEET IN MILLIONS)

Western Canada, which are heavy with cedar, hemlock, and firs.

Ownership of Canadian Forests

Over 90 percent of Canadian forests are publicly owned. **Table 2.6** shows a categorization by owner type that includes provincial Crown land, territorial Crown land, federal Crown land, private land, and indigenous land.

Canada's Standing Timber Inventory

The standing timber inventory in Canada as of 2020 was 1.750 trillion cubic feet, nearly 60 percent more standing timber volume than the United States, according to *The State of Canada's*

SPECIES GROUP	1 TO 20	21 TO 40	41 TO 60	61 TO 80	81 TO 100	101 TO 120	121 TO 140	141 TO 160	161 TO 180	181 TO 200	201+	TOTAL
Coniferous	8,665	31,452	70,477	139,785	312,436	224,080	105,282	50,915	33,388	24,018	205,958	1,206,457
Mixed	9,510	17,712	47,769	64,457	83,107	21,329	9,663	4,354	1,488	470	884	260,743
Broadleaf	4,857	11,009	53,038	65,236	44,725	16,482	5,892	1,856	536	33	162	203,827
Total	**23,035**	**60,181**	**171,294**	**269,482**	**440,289**	**261,893**	**120,837**	**57,126**	**35,414**	**24,521**	**207,003**	**1,671,075**

TABLE 2.8: CANADIAN STANDING TIMBER VOLUME BY SPECIES GROUP AND STAND AGE CLASS (CUBIC FEET IN MILLIONS)

Forests: Annual Report 2022.[2] Note, however, that the standing volume in Canada was about 8 percent less in 2020 (the most recent available data) than 1990 standing volume levels. This trend is displayed in the data in **Table 2.7.** The causes of this are many, but 2 key factors are extensive insect outbreaks and wildfires.

Table 2.8 provides a more detailed estimate of standing timber volume, with categorizations by forest type and stand age as of 2019. As the data shows, more than 70 percent of Canada's forests are coniferous (i.e., softwoods).

2.2 FOREST SUSTAINABILITY

People across the globe are interested in access to clean air and water. Forests are key to providing access to both. Thus, assuring forest sustainability is critical to all global citizens. Sustainability is defined as meeting society's current needs via the consumption of natural resources without jeopardizing the ability of future generations to meet their needs through consumption of the same natural resources.

2.2.1 GROWTH-TO-DRAIN

One measure foresters use to monitor sustainability is growth-to-drain. Growth-to-drain is a ratio of the amount of wood fiber a given area can grow annually (net of natural mortality from insects, disease, fire, etc.) to the amount of wood fiber harvested annually. A ratio greater than 1 indicates that the area is adding more wood fiber each year through net growth than is being removed by harvesting. Although many other considerations relate to sustainability, growth-to-drain is frequently a key consideration in forest management and timber harvest planning. The following sections provide an analysis of growth-to-drain for US and Canadian forests.

US Timberlands Growth-to-Drain

As described in the preceding section, as long as the ratio of growth-to-drain is greater than 1, forests can supply fiber in perpetuity. **Table 2.9** provides information about historical growth-to-drain ratios in the United States. At the top of the table is data for all softwoods in the US; in the middle is information about hardwoods; and, at

2 *The State of Canada's Forests: Annual Report 2022,* https://natural-resources.canada.ca/our-natural-resources/forests/state-canadas-forests-report/how-much-forest-does-canada-have/17601.

	1976	1996	2006	2016
Softwoods: Annual Mortality (ft^3 in 1000s)	2,466,137	3,959,580	4,510,607	5,899,508
Softwoods: Annual Harvest (ft^3 in 1000s)	10,020,449	10,084,714	9,883,421	8,901,491
Softwoods: Total Drain (ft^3 in 1000s)	12,486,586	14,044,294	14,394,028	14,800,999
Softwoods: Annual Growth (ft^3 in 1000s)	12,501,271	14,715,427	15,241,092	15,467,789
Softwood Growth-to-Drain Ratio	*1.00*	*1.05*	*1.06*	*1.05*
Hardwoods: Annual Mortality (ft^3 in 1000s)	1,626,733	2,755,701	3,315,862	4,298,579
Hardwoods: Annual Harvest (ft^3 in 1000s)	4,215,500	5,971,328	5,690,561	4,139,708
Hardwoods: Total Drain (ft^3 in 1000s)	5,842,233	8,727,029	9,006,423	8,438,287
Hardwoods: Annual Growth (ft^3 in 1000s)	9,425,003	10,232,615	11,503,274	9,541,561
Hardwood Growth-to-Drain Ratio	*1.61*	*1.17*	*1.28*	*1.13*
All Species: Annual Mortality (ft^3 in 1000s)	4,092,870	6,715,281	7,826,469	10,198,087
All Species: Annual Harvest (ft^3 in 1000s)	14,235,949	16,056,042	15,573,982	13,041,199
All Species: Total Drain (ft^3 in 1000s)	18,328,819	22,771,323	23,400,451	23,239,286
All Species: Annual Growth (ft^3 in 1000s)	21,926,274	24,948,042	26,744,366	25,009,350
All Species Growth-to-Drain Ratio	*1.20*	*1.10*	*1.14*	*1.08*

TABLE 2.9: HISTORY OF US GROWTH-TO-DRAIN RATIOS FOR SOFTWOODS AND HARDWOODS

the bottom, softwoods and hardwoods are combined. As the data indicates, the ratio is greater than 1 in all cases.

This is a positive finding for the mass timber industry; it indicates that US forests are not being overharvested. However, the data shows a troubling trend. Natural mortality—trees dying from causes such as wildfire, drought, insects, and disease—increased by 250 percent from 1976 to 2016. There is considerable debate about whether the cause was climate change or lack of management, especially in publicly owned forests in the US West. In any case, pressure on growth-to-drain ratios would ease considerably if more of the standing tree volume were used through harvesting rather than being lost to natural mortality. Another issue to note is that, over approximately the last decade, the amount and severity of wildfires have increased. Some foresters believe this is beginning to take a toll on the standing timber volume in the states where wildfires have hit the hardest, like California. Since the US Forest Service's FIA program remeasures only about 10

	NATURAL STANDS	PLANTATIONS	TOTAL
US South: Softwood Annual Growth (ft^3 in 1,000,000s)	2,886	5,972	8,858
US South: Softwood Annual Harvest (ft^3 in 1,000,000s)	721	3,225	3,946
US South: Softwood Annual Mortality (ft^3 in 1,000,000s)	603	323	926
US South: Total Drain (ft^3 in 1,000,000s)	1,324	3,548	4,872
Growth-to-Drain Ratio	2.2	1.7	1.8

TABLE 2.10: US SOUTH GROWTH-TO-DRAIN RATIO FOR SOFTWOODS IN 2017

percent of the permanent growth plots each year in the US West, there is a lag in the occurrence of widespread mortality events (like fire) and the ability of the FIA data to capture the impacts of such events.

Also note that growth-to-drain ratios can vary dramatically by region and species. In the US South, for example, the growth-to-drain for softwoods is significantly higher than for softwoods in the entire US. **Table 2.10** shows the data that supports that statement; with both naturally regenerated and plantation stands of SYP (i.e., the overwhelming majority of softwoods in the US South), the growth-to-drain ratio is well over 1. This means that, each year, 80 percent more wood is added to the standing volume than is being used or is dying from natural mortality. As is further discussed in chapter 3, the combination of a high percentage of privately owned lands and a large amount of excess growth is leading to extensive investment in new sawmilling capacity across the region.

Canadian Timberlands Growth-to-Drain

Table 2.11 provides a 30-year history of growth-to-drain for Canadian forests. Note that total wood supply is the Annual Allowable Cut (AAC), a calculated value that projects the amount of timber that can be harvested sustainably based on the capacity of the forests to grow new fiber and their annual natural mortality. As the data shows, in all cases, the actual harvest levels have been lower than the AAC by an average factor of 1.4 for all species, 1.3 for softwoods, and 2.3 for hardwoods. This is a positive finding for the mass timber industry, as it indicates that Canadian forests are not being overharvested and could supply more fiber if warranted by increasing market demand.

2.2.2 ENVIRONMENTAL FOREST MANAGEMENT CERTIFICATION

Many forest landowners manage with multiple objectives in mind and consider sustainability in their forest management planning and deci-

YEAR	TOTAL WOOD SUPPLY	TOTAL HARVEST	TOTAL GROWTH-TO-DRAIN	SOFTWOOD SUPPLY	SOFTWOOD HARVEST	SOFTWOOD GROWTH-TO-DRAIN	HARDWOOD SUPPLY	HARDWOOD HARVEST	HARDWOOD GROWTH-TO-DRAIN
1990	8,747	5,523	1.6	6,367	4,986	1.3	2,246	537	4.2
1991	8,687	5,445	1.6	6,371	4,891	1.3	2,182	554	3.9
1992	8,518	5,781	1.5	6,247	5,184	1.2	2,133	597	3.6
1993	8,405	5,989	1.4	6,166	5,315	1.2	2,101	674	3.1
1994	8,408	6,265	1.3	6,145	5,445	1.1	2,129	819	2.6
1995	8,267	6,470	1.3	6,035	5,558	1.1	2,094	908	2.3
1996	8,285	6,282	1.3	6,028	5,343	1.1	2,122	939	2.3
1997	8,373	6,484	1.3	6,078	5,431	1.1	2,161	1,052	2.1
1998	8,295	6,141	1.4	6,028	5,043	1.2	2,175	1,098	2.0
1999	8,454	6,946	1.2	6,169	5,749	1.1	2,186	1,197	1.8
2000	8,281	7,045	1.2	6,099	5,767	1.1	2,140	1,278	1.7
2001	8,369	6,512	1.3	6,215	5,294	1.2	2,147	1,218	1.8
2002	8,415	6,900	1.2	6,254	5,636	1.1	2,161	1,261	1.7
2003	8,472	6,406	1.3	6,289	5,078	1.2	2,179	1,328	1.6
2004	8,730	7,349	1.2	6,540	5,950	1.1	2,182	1,398	1.6
2005	8,641	7,109	1.2	6,431	5,834	1.1	2,207	1,275	1.7
2006	8,733	6,445	1.4	6,547	5,251	1.2	2,179	1,190	1.8
2007	8,881	5,724	1.6	6,696	4,753	1.4	2,186	964	2.3
2008	8,836	4,884	1.8	6,692	4,033	1.7	2,140	844	2.5
2009	8,507	4,089	2.1	6,413	3,330	1.9	2,091	756	2.8
2010	8,362	4,979	1.7	6,314	4,146	1.5	2,041	830	2.5
2011	8,186	5,181	1.6	6,162	4,269	1.4	2,016	911	2.2
2012	8,115	5,269	1.5	6,116	4,400	1.4	1,992	869	2.3
2013	8,023	5,332	1.5	6,053	4,450	1.4	1,967	886	2.2
2014	8,112	5,308	1.5	6,060	4,404	1.4	2,052	901	2.3
2015	8,052	5,488	1.5	5,993	4,524	1.3	2,059	961	2.1
2016	7,875	5,484	1.4	5,791	4,520	1.3	2,084	968	2.2
2017	7,741	5,445	1.4	5,693	4,450	1.3	2,052	996	2.1
2018	7,695	5,516	1.4	5,633	4,531	1.2	2,062	985	2.1
	242,466	**171,792**	**1.4**	**179,625**	**143,566**	**1.3**	**61,468**	**28,195**	**2.2**

TABLE 2.11: COMPARISON OF ANNUAL ALLOWABLE CUT TO ACTUAL HARVEST IN CANADA (CUBIC FEET IN MILLIONS)

sion-making. Environmental forest management certification programs offer landowners a formal process for ensuring that their plans are consistent with sustainability objectives related to fiber production; wildlife habitat; clean water; recreation values; and the wide range of plants, animals, insects, and fungi that make up the web of life in a forest ecosystem.

Concerns about sustainability and the protection of myriad forest values emerged in the United States and Canada during the 1960s, ’70s, and ’80s. As a result, laws such as the National Environmental Policy Act (NEPA), Endangered Species Act (ESA), Clean Water Act, Clean Air Act, and National Forest Management Act (NFMA) were passed. All these laws help ensure a baseline of sustainability and accountability in forest management, especially on public lands. In the 1990s, however, concerns arose about the sources of wood from private lands and from countries where illegal logging was prevalent or where forest management practices were lax.

Those concerns, spurred by buyers of wood products who wanted assurance that their products were sourced from well-managed forests, led to the development of environmental forest management certifications. Through the Earth Summit in Rio de Janeiro and the Montreal Process meetings in the early 1990s, forest health and management criteria and indicators were developed. They were to be monitored by independent, third-party verification groups. The intent was to create a market-driven reward for complying with the criteria and indicators judged to represent sound, sustainable forest management. Wood is the only building material that has third-party certification programs in place to demonstrate compliance with sustainability principles.

In the decades since, only about 11 percent of the world’s forests have been certified as complying with one of several programs, according to the *Global Forest Atlas* from the Forest School at the Yale School of the Environment. Despite accounting for only 11 percent of the certified acreage, those certified forests provide an estimated 29 percent of global timber production. More than 92 percent of all certified forestland is in the northern hemisphere, with the US and Canada accounting for more than half that total. The acreage of certified land in tropical forests is approximately 2 percent. Thus, even though certification was conceived as a means of stopping deforestation—primarily a tropical forest issue—little forest management has been certified among the world’s tropical forests. Note that the species and lumber products produced from tropical forests are not used in the production of mass timber products. Thus, the mass timber industry has little direct impact on tropical forest management and deforestation.

Forest Certification in the US and Canada

Across the US and Canada, more than 480 million acres of forestland, or roughly 28.5 percent of all nonreserved North American forests, have been certified under various third-party forest certification programs. The 4 main certification programs operating in North America are listed here:

- American Tree Farm System (ATFS): ATFS is managed by the American Forest Foundation and is designed to serve relatively small family forest ownerships. Currently, there are about 74,000 members who manage a collective 19 million acres of forestland. ATFS is endorsed by the Programme for the Endorsement of Forest Certification (PEFC), a global umbrella organization that endorses a variety of national forest certification systems. Through ATFS's association with PEFC, ATFS-certified landowners have global certification status. See additional information here: https://www.treefarmsystem.org/.

- Forest Stewardship Council (FSC): FSC was initiated in 1993 and is a global forest certification program. As of July 2022 (the most recent available data), nearly 533 million acres have been certified globally. In North America, FSC certificate holders include publicly owned forests, native forest enterprises, family forest trusts, and industrial timberlands. Roughly 160 million acres are FSC-certified in the US and Canada. See additional information here: https://www.fsc.org.

- Sustainable Forestry Initiative (SFI): SFI was started in 1994, and organizations certified under this program include private landowners, forest product companies, managers of public lands, indigenous communities and their businesses, conservation organizations, state and local public agencies, community interests, and universities. It is endorsed by PEFC. As of fall 2023, about 350 million acres of North American forestland has been certified to the SFI standard. See additional information here: https://www.forests.org/.

- Canadian Standards Association (CSA): CSA Group is the Canadian standards system established in 1996. Like SFI and ATFS, CSA is PEFC-endorsed. See more information here: https://www.csagroup.org.

Certification of Public Lands in the United States

Most federal land in the United States—including national parks, national forests, Bureau of Land Management (BLM) lands, and wildlife refuges—is not certified to the standards of any of the above programs. Rather, federal laws guide management planning and activities. Large areas of federal land have been permanently set aside from timber harvest. These include wilderness areas, national parks, and inventoried roadless areas. Such reserved areas play an important role in sustainability by providing habitat conditions not always found on forestlands managed for timber production.

Generally, state and municipally owned lands are managed to generate sustained revenue from the harvest of timber and the use of other resources. Revenue from management activities often supports school systems and other rural, local government needs. Unlike federal lands, several states and municipal governments have enrolled in one or more of the previously described forest management certification programs. Landowners who have not pursued third-party certification are guided by state and municipal laws and/or best management practices (BMP) that govern or guide forest management within a jurisdiction. The nature and extent of these laws vary considerably across the US. Common to all, though, are principles designed to assure clean water and long-term sustainability. Thus, at a minimum, end users can be assured that forest management in the US overwhelmingly complies with local, regional, and federal forest management laws.

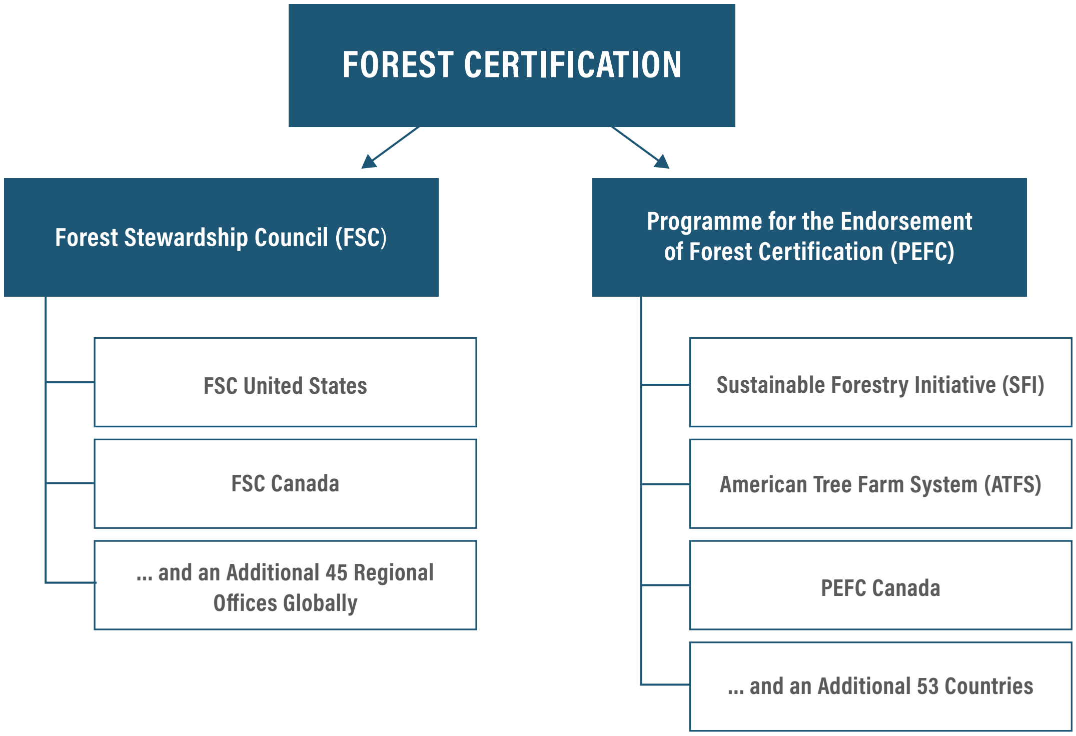

FIGURE 2.4: RELATIONSHIPS AMONG FOREST CERTIFICATION PROGRAMS

Certification of Public Lands in Canada

Most Canadian forestland is publicly owned. However, a tenure system allows private companies to carry out sustainable forest management on public lands. Under the tenure system, the right to harvest a public resource (timber) is transferred to a private entity. Although details vary from province to province, the basic concept is that a company signs a long-term agreement with the Canadian government. The agreement encompasses a designated forest acreage and dictates certain forest management guidelines (i.e., applicable forestry laws, regulations, and policies) with which the company must comply. In addition to those standards, about 420 million acres of forest in Canada have been certified by third parties, including FSC, SFI, and CSA. Canada also has 59 million acres reserved from harvest in the form of parks and other protective designations. The reserved areas represent about 6 percent of Canada's forests.

Future of Forest Certification

A report[3] released by Dovetail Partners, a nonprofit that provides authoritative information about the impacts and trade-offs of environmental decisions, analyzes what the future of forest certification might look like. A key takeaway is that competition among forest certification programs may hinder the ability of forest certification to continue having a meaningful impact on

3 Dovetail Partners, *Forest Certification Update 2021: The Pace of Change* (January 2021), https://www.dovetailinc.org/portfoliodetail.php?id=60085a177dc07.

forest management. **Figure 2.4**, adapted from the Dovetail Partners report, shows the divergence among forest certification programs: the FSC program stands alone, while the PEFC program acts as an umbrella organization for numerous global programs.

Key drivers cited as threats to the programs are the steady growth within supply chains of private- and public-sector alternative approaches to forest certification, technological innovation, and government policies. The report offers ways to ratchet down competition, including the suggestion that supply chain influencers adopt either a neutral position about material sourced from the different programs or rank their choices to sourcing certified fiber in order of preference. According to Dovetail Partners, ranked choice is an alternative to the all-or-nothing approach that is apparently a common practice among some sectors of end users.

2.3 FOREST DIVERSITY

Species richness (the number of unique species in an area) is frequently used as a measure of forest sustainability. In the US, there are many different ecological zones, translating into numerous species of trees. During US Forest Service FIA timber cruises in 2017, cruisers identified nearly 1,000 unique species. Most abundant were red maple, loblolly pine, balsam fir, sweet gum, and Douglas-fir. However, when considered on the basis of biomass rather than tree count, Douglas-fir makes up the largest portion, accounting for about 1 percent of all the aboveground biomass.

Almost all US forests are native species, and most are naturally regenerated, with planted forests accounting for just 10 percent to 15 percent of the total. In the past 25 to 30 years, government agencies and nonprofit groups have warned that some forest types—and the plant and animal species associated with them—are in decline. Coalitions were formed to reverse the declines. In the Eastern US, they include longleaf pine and shortleaf pine restoration efforts. In the West, restoration projects have focused on Western white pine, whitebark pine, quaking aspen, and ponderosa pine. These groups recognize the desirability of restoring native forests and their associated species. Similarly, a parallel program resulted in restocking Central European forests with native hardwoods (earlier replaced by monoculture softwood plantations). The efforts to find a high-end market for these species resulted in commercialization of the high-performance hardwood mass timber products (mainly beech and oak glulam and beech LVL). In Canada, most forests are made up of native species. A little over half of the harvested acreages are replanted, while half rely on natural regeneration. Canada boasts several different forest types.

2.4 FOREST HEALTH

What is a healthy forest? The answer is nebulous, but the primary disturbance agents are clear: insects, disease, and wildfire. How landowners view the impacts of those disturbance agents differs depending on their management goals. If the forest is reserved (i.e., wilderness or a national park) and the purpose is to manage for natural processes, the definition of healthy is different than that for land managed by a publicly traded company seeking a return on investment for shareholders. A noncorporate family forestland manager with diverse goals will provide yet another definition. The answers reflect different objectives. What is healthy also varies by forest ecosystem, requiring different management practices.

In reserved forests, insect outbreaks, wildfires, and chronic endemic diseases lead to patterns of high natural mortality followed by natural regeneration. While disastrous from a wood utilization viewpoint, these patterns may be considered healthy from other vantages because they are part of a forest's natural processes. Dead trees, for example, become habitats for birds, plants, mammals, and insects. These natural agents of change can be considered desirable in some forests and undesirable in others—for example, where they destroy valuable timber, damage a municipal watershed, or spoil scenic vistas.

The owner of a forest managed for timber production wants to manage tree mortality to reap an economic benefit and provide a renewable product that supports society's need for human habitats in the form of homes, shops, and offices. Some timberlands are managed to blend different objectives. As described earlier, many family forests and public lands are managed for a mixture of goals, so some mortality from fire, insects, and diseases may be acceptable and even desirable. Even so, severe die-offs are not desirable. Maintaining a balance is an important part of managing the forest.

2.5 FOREST FIRE RESILIENCE

Forest fires and the smoke they generate have been constant during recent summers. Wildfire risks are driven by 2 synergistic factors. As the climate warms and wildfire seasons lengthen, the risk of "megafires" increases. The problem is exacerbated by limited management activity on some ownerships and by 100 years of aggressive wildfire suppression. Forests that once burned frequently now have ab-

FIGURE 2.5: EXAMPLE OF A HIGH-INTENSITY FOREST FIRE

normally large quantities of green and dead trees, and thickets of brush. The fuel buildup is particularly acute in western North America. High-intensity wildfires are ever more common, with proportionately severe consequences (see **Figure 2.5**).

Many land managers, scientists, wildfire managers, and increasingly, the public are calling for action to mitigate these risks. Two common treatments are thinning (removal of forest fuels, including some trees and underbrush) and controlled burning (intentional burning with a low-intensity fire to reduce ground fuel buildup without damaging the overstory of large trees). Many of the forests in need of treatment are not traditional industrial forestlands. More often, they are public lands and family forests where the public's tolerance for cutting or burning trees is low. Some treatment areas are in municipal watersheds with reservoirs that serve domestic and agricultural water users.

Thinning and prescribed burning are both costly because the cost of removing smaller trees is almost always greater than their commercial value. However, when thinning and burning costs are weighed against the immense cost of firefighting and the associated loss of lives, property, and resources, these forest health treatment projects may make sense economically. There are many examples around the country where proactively treating forests has saved property, lives, and even communities.

For example, **Figure 2.6** shows how forest management from the Black Hills Project affected the Bootleg Fire's behavior in Oregon. The fire occurred in 2021. The forest on the left side of the photo was only mechanically thinned, the center portion was thinned and treated with prescribed fire, and the forest on the right side of the photo was untreated. The Bootleg Fire burned through all three areas. The post-fire aerial photo shows the fire's differing

FIGURE 2.6: AERIAL PHOTOGRAPHY SHOWS HOW DIFFERENT TREATMENTS MODERATED THE IMPACT OF OREGON'S 2021 BOOTLEG WILDFIRE

https://www.nature.org/en-us/about-us/where-we-work/united-states/california/stories-in-california/californias-wildfire-future/

impact on each area. The thinning only area was moderately impacted, the no treatment area was severely impacted, and the thinning and prescribed fire area had little impact because of low fuel volume.

Thinning can be accomplished with mechanical harvesting equipment, by crews sawing trees and piling them for burning, or with planned low- to moderate-intensity burns completed under prescribed conditions. Often, thinning and burning are used in conjunction with each other for greatest efficacy. Some trees in need of removal can be used for forest products, including mass timber. When such markets exist, it becomes considerably more affordable to manage forests for the desired outcomes.

The increased use of mass timber products can expand markets for some small and medium trees that should be thinned to reduce the risk of wildfires, insect outbreaks, and diseases. The use of more wood in commercial buildings helps create new demand, leading to more logging and manufacturing capacity. In addition to the forest health benefits, the increased activity can lead to new jobs in forests and at manufacturing plants, especially in rural communities with limited opportunities for building viable economies.

2.6 FOREST CARBON

Forests are a key component of the Earth's natural carbon capture and storage system. The Intergovernmental Panel on Climate Change (IPCC) has identified forests and wood products from sustainable management as a major component of meeting the world's climate change goals. Chapter 9 is devoted to outlining the 3 S's of carbon management—sequestration, storage, and substitution—and their interactions.


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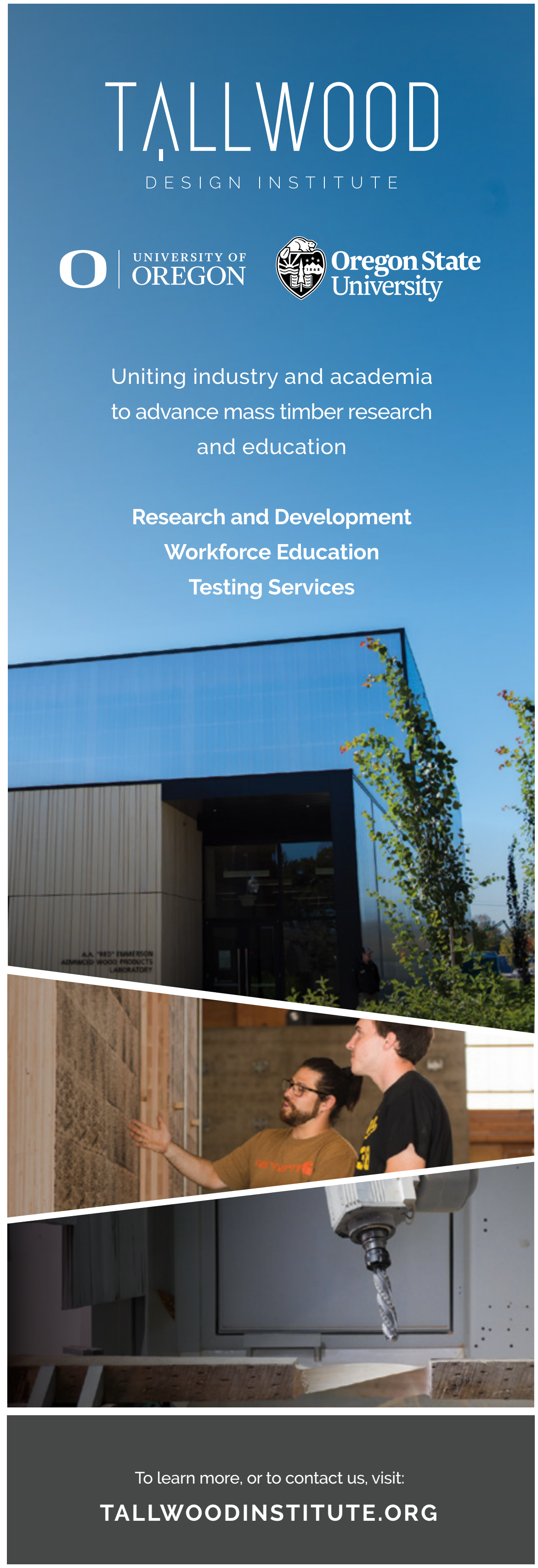
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619 PONCE AT GLEN IRIS CORNER

Source: Jamestown, L.P.; Credit: Tiltpixel

CASE STUDY: 619 PONCE

GEORGIA-GROWN: OFFICE BUILDING FOCUSES ON SUSTAINABILITY AND THE REGIONAL ECONOMY

PROJECT OWNER: JAMESTOWN, L.P.

PROJECT LOCATION: 619 PONCE DE LEON AVE, ATLANTA, GA 30308

COMPLETION DATE: MARCH 15, 2024

ARCHITECT/DESIGNER: HANDEL ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: STRUCTURECRAFT (ENGINEER)/SMARTLAM NORTH AMERICA (MANUFACTURER)

GENERAL CONTRACTOR: JE DUNN

STRUCTURAL ENGINEER: DESIMONE & STRUCTURECRAFT

MECHANICAL, ELECTRICAL, AND PLUMBING: INTROBA

OTHER CONTRACTORS: MALMBERG PROJECTS (CONSULTANT TO OWNER); ASPECT STRUCTURAL ENGINEERS (ADVISER)

619 PONCE IS a 4-story mass timber loft office building at Ponce City Market in Atlanta, Georgia, developed by Jamestown, a design-focused real estate investment and management firm. The building, which includes 87,000 square feet of office space and 27,000 square feet of retail space, was constructed with Georgia-grown timber, and it is targeting Leadership in Energy and

SECTION THROUGH 619 PONCE

Source: Jamestown, L.P.; Credit: Tiltpixel

Environmental Design (LEED) v4 Core and Shell certification and Fitwel certification.

Though most timber for mass timber construction is sourced from Canada, Austria, or Germany, Jamestown is using timber sourced and produced locally. Jamestown's use of Georgia-grown timber and a regional supply chain—a first for mass timber construction in Georgia—reduces the project's transportation emissions and the overall environmental impact of its construction, maximizing the sustainability benefits of mass timber and growing the regional economy.

The building's columns, beams, and floor slabs are made of Southern Yellow Pine (SYP) harvested from Georgia forests, including from timberland Jamestown owns and sustainably manages near Columbus, Georgia. Jamestown owns and sustainably manages more than 100,000 acres of timberlands across Georgia, Alabama, South Carolina, New York, Pennsylvania, and Indiana under the 2022 Sustainable Forestry Initiative (SFI) Forest Management Standard that provides third-party verification of sustainable forestry management.

The timber was transported to Georgia-Pacific's sawmill in Albany, Georgia, where it was converted into lumber. The lumber was then transported to SmartLam North America's mass timber plant in Dothan, Alabama, where it was made into Cross-Laminated Timber (CLT) panels and glulam columns, beams, and purlins.

Some glulam members required additional fabrication before installation, and they were transported to a specialty timber facility in Rockwood, Tennessee, before they were transported to the site for installation. The timber gravity structure was erected on-site at Ponce City Market by StructureCraft and JE Dunn, with full building completion expected in early 2024.

The project aims to leverage best practices for material specification and prioritize human health by minimizing chemicals of concern in building materials with a special focus on interior high-touch elements. Material selections, like mass timber accented by a natural zinc facade, prioritize the reduction of embodied carbon and support the local economy by sourcing materials from within 100 miles when possible.

StructureCraft worked with Jamestown and Handel Architects to evaluate the carbon impact of the final project design of the timber elements compared with a concrete baseline. The timber gravity system in the final design resulted in an almost 75 percent reduction in carbon emissions when compared with the equivalent concrete gravity system, even when carbon captured by the trees during their growth is ignored.

When that embedded carbon is included, the gravity system for the final building has a net negative 1,266 tons of carbon emissions—equivalent to eliminating about 300 cars from the road for a year.

CHAPTER 3: RAW MATERIALS

ROY ANDERSON
VICE PRESIDENT, THE BECK GROUP

As the number of buildings constructed with mass timber continues growing year over year, the industry is widely viewed as a potentially significant market for North American softwood lumber producers. However, mass timber also represents a somewhat unusual market for sawmillers because the lumber must be dried to a lower moisture content than lumber used in other applications. This is important because kiln-drying is often the bottleneck in a sawmill's annual lumber output capacity. Therefore, the sawmiller's ability and willingness to do extra drying is an important factor in mass timber's raw material supply chain. This chapter explores the drying issue and other key features of the softwood lumber supply chain. Accordingly, this chapter includes a technical analysis of the specifications for use in mass timber, a look at the production capacity among raw material manufacturers (e.g., sawmills), and an estimation of the demand for raw materials that mass timber's development could create for suppliers.

3.1 RAW MATERIAL SPECIFICATIONS

The following sections summarize the specifications for sawn lumber and Structural Composite Lumber (SCL)[1] used in mass timber products. More detailed information is available in the design standard reference specific to each product type.

FIGURE 3.1: ILLUSTRATION OF A MASS TIMBER PANEL'S MAJOR (PARALLEL OR LONGITUDINAL) AND MINOR (PERPENDICULAR OR TRANSVERSE) STRENGTH DIRECTIONS

3.1.1 CROSS-LAMINATED TIMBER

Before launching into a technical discussion about how lumber can be used in mass timber, we'll first discuss the terminology. Every Cross-Laminated Timber (CLT) panel has major and minor strength axes. The major axis is the direction with the greatest number of layers of wood grain in a parallel orientation. For example, **Figure 3.1** shows a 3-layer panel. The grain of the wood in the 2 outer layers is *parallel*, and thus the longest axis of the panel is the major strength direction. Sometimes, the parallel axis is also called the *longitudinal* axis. The wood grain in the middle layer is oriented *perpendicular* to the adjacent layers. Because there is only 1 perpendicular (or *transverse*) layer, it is the panel's minor strength direction. The following technical sections reference these italicized terms.

The Engineered Wood Association (often referred to as APA, the initials of the group's former name)

1 Structural Composite Lumber (SCL) is a family of engineered wood products that includes Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL), Laminated Strand Lumber (LSL), and Oriented Strand Lumber (OSL). These products are created by combining wood veneers, wood strands, or wood flakes with moisture-resistant adhesives to form blocks of material known as billets. The billets are then sawn into sizes roughly analogous to sawn lumber.

developed a standard that addresses the manufacturing, qualification, and quality assurance requirements of CLT panels. It's called *ANSI/APA PRG 320–2019: Standard for Performance-Rated Cross-Laminated Timber*. The most recent edition was approved by the American National Standards Institute (ANSI) on January 6, 2020.

Section 6, subsection 6.1 of *ANSI/APA PRG 320-2019* is the portion of the standard that specifies the characteristics of sawn lumber and SCL approved for use in CLT panels. The following list summarizes key aspects; see the *PRG 320-2019* report for full details.

Species

Specific to the North American mass timber market, lumber from any softwood species[2] or species combination (e.g., hem-fir; fir-larch; or spruce, pine, fir [SPF]) recognized by the American Lumber Standards Committee (ALSC) under PS 20 or by the Canadian Lumber Standards Accreditation Board (CLSAB) under CSA-0141 with a minimum published specific gravity of 0.35 is permitted. Any given layer (lamination) in a CLT panel must be made from lumber of the same thickness, type, grade, and species or species combination. Adjacent layers in a CLT panel can be made from differing thicknesses, types, grades, and species or species combinations. If SCL is made from any species with a specific gravity greater than 0.35 and meets the standards of *ASTM D5456*[3], it is permitted. Finally, note that strict enforcement of species and grade restrictions in panels imported from overseas manufacturers as integral project parts may not be practical or even desirable.

Lumber Grade

The distinction between major and minor strength axes is important because differing lumber grades are required, depending on whether they are in a longitudinal or transverse layer. Lumber is graded in 1 of 2 ways: (1) visually—where strength/grade is estimated from a visual inspection, or (2) machine stress rated (MSR)—where pieces of lumber are measured for resistance to bending and assigned a strength rating. In a CLT panel's longitudinal layers, the lumber grade must be visual grade No. 2 (or better), or MSR grade 1200f-1.2E. Perpendicular layers must be visual grade No. 3 or better. Any proprietary lumber grades meeting or exceeding the mechanical properties of the approved CLT lumber grades can be used if they meet an approved agency's qualifications.

Thickness

The minimum thickness of any lumber layer in a CLT panel is ⅝ inch (16 millimeters) at the time of gluing. Maximum thickness is 2 inches (51 millimeters) at the time of gluing. Thickness must be consistent across each individual layer. Thickness consistency is defined at the time of bonding as plus or minus 0.008 inch (0.2 millimeters) across the width of the layer, and plus or minus 0.012 inch (0.3 millimeters) across the length of the layer. Per *PRG 320*, any bow or cup present in lumber "should be small enough to be flattened out by

2 The higher a species' specific gravity, the denser the wood; and generally, the denser the wood, the greater its strength properties. Douglas-fir, larch, Western hemlock, Southern Yellow Pine (SYP), lodgepole pine, Norway pine, various spruce species, and various true firs are common North American softwoods that have good strength properties.

3 ASTM International, formerly known as the American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

LONGITUDINAL LAYERS				TRANSVERSE LAYERS			
Nominal Size (inches)	Actual Thickness (inches)	Actual Width (inches)	Ratio (Actual Width to Actual Thickness)	Nominal Size (inches)	Actual Thickness (inches)	Actual Width (inches)	Ratio (Actual Width to Actual Thickness)
1x2	0.75	1.5	2	1x2	0.75	1.5	2
1x3	0.75	2.5	3.33	1x3	0.75	2.5	3.33
1x4	0.75	3.5	4.67	1x4	0.75	3.5	4.67
1x6	0.75	5.5	7.33	1x6	0.75	5.5	7.33
2x2	1.5	1.5	1	2x2	1.5	1.5	1
2x3	1.5	2.5	1.67	2x3	1.5	2.5	1.67
2x4	1.5	3.5	2.33	2x4	1.5	3.5	2.33
2x6	1.5	5.5	3.67	2x6	1.5	5.5	3.67
2x8	1.5	7.25	4.83	2x8	1.5	7.25	4.83
2x10	1.5	9.25	6.17	2x10	1.5	9.25	6.17
2x12	1.5	11.25	7.5	2x12	1.5	11.25	7.5

TABLE 3.1: ALLOWABLE AND UNALLOWABLE THICKNESS-TO-WIDTH RATIOS FOR LUMBER USED IN CLT PANELS

**Any cell in red font is a lumber size with a thickness-to-width ratio that renders that size unacceptable for use in CLT panels.*

pressure in bonding." Many overseas national or regional lumber markets offer much broader selections of thicknesses. Overseas CLT manufacturers take advantage of that variety by offering panel lay-ups more efficiently adjusted to project requirements. Some CLT manufacturers in Central Europe use laminations as thin as 0.4 inches (10 millimeters). These lay-ups would not meet the *PRG 320* minimum lamination thickness requirement.

Width

For longitudinal layers, the net lamination width for each board must not be less than 1.75 times the net lamination thickness. For transverse layers, the net width of a board must not be less than 3.5 times the net thickness of the board. **Table 3.1** illustrates the thickness-to-width ratios for the longitudinal and transverse layers of common lumber sizes. Note that it is common practice for CLT manufacturers to plane about 1/16 inch off all 4 sides of a piece of lumber prior to panel lay-up. Thus, the thickness-to-width ratio of a board's final dimensions may differ slightly from those shown in the table. Notably, 2-by-4, a common size in North America, cannot be used in transverse layers. Exceptions to these thickness-to-width ratios are allowed if the pieces in a layer are both face- and edge-glued. Laminations made from SCL are permitted to be full CLT width.

Moisture Content

The moisture level of lumber used in CLT panels must be 12 percent, plus or minus 3 percentage points (i.e., 9 to 15 percent), when the panel is manufactured. Because lumber shrinks or swells as it loses or gains moisture, the lumber's moisture content is a key focus area for mass timber manufacturers. It is also an important part of the manufacturing process because most of the lumber is sold after it has been kiln-dried. The grading rules require that lumber be dried to 19 percent moisture content or lower. Given these circumstances, sawmills may be reluctant to reduce their kiln capacities by running batches of mass timber lumber for longer-than-normal drying cycles when demand for lumber is strong. This issue is further discussed in section 3.4 and from the perspective of the mass timber panel manufacturer in chapter 4.

Surfacing

Any sawn lumber used in a CLT panel must be planed or sanded—at least on any surfaces to be bonded—and the planed or sanded surface must not have any imperfections that might adversely affect the bonding process (e.g., raised grain, torn grain, skips, burns, glazing, or dust). The ANSI and the APA, noting the intricacies of bonding the layers in a CLT panel, state that the bonding surfaces on some species need to be planed within 48 hours of the bonding process. Planing or sanding of face-bonded surfaces of SCL used to make CLT panels is not required unless it's needed to meet thickness tolerances.

3.1.2 NAIL-LAMINATED TIMBER

The International Building Code (IBC) recognizes Nail-Laminated Timber (NLT) as a structural material and provides guidance on structural design and fire safety. No product-specific ANSI standard has been developed, but design guides are available for both the US and Canada, and they can be downloaded for free at https://www.thinkwood.com/. NLT is commonly manufactured at the building site by nailing pieces of lumber together after they have been arranged so that their wide faces are touching. Almost any properly graded softwood dimension lumber can be used to make NLT. However, considerations such as cost, availability, species, structural performance (grade), and aesthetics come into play when selecting material. Most NLT panels manufactured to date use No. 2 grade dimension lumber in 2-by-4, 2-by-6, and 2-by-8 sizes. The lumber's moisture content must be below 19 percent before fabrication.

3.1.3 DOWEL-LAMINATED TIMBER

The structural design of each lamination in a Dowel-Laminated Timber (DLT) panel is covered by both the IBC and the National Building Code of Canada (NBC). The *International Code Council Evaluation Service Report ESR-4069*, published in November 2020, provides guidance on the use of DLT, given the material's structural and fire-resistance properties. The report evaluates DLT's compliance with the 2018, 2015, 2012, and 2009 IBC; and the 2018, 2015, 2012, and 2009 *International Residential Code (IRC).* Additionally, StructureCraft, a North American mass timber manufacturer of DLT, has developed a design guide.

Species and Grades

DLT panels are made from SPF, Douglas-fir, and hem-fir species or species groupings. Panels made from other species are available on request. The structural grades include select structural, No. 2 and better, 2400f-2.0E MSR for Douglas-fir, and 2100f-1.8E MSR or 1950f-1.7E MSR for SPF.

Moisture

Lumber must be kiln-dried to 19 percent or less moisture content at the time of manufacture. Note that the hardwood dowels used to join the DLT laminations are at a much lower moisture content at the time of manufacture. When the drier dowels are exposed to the wetter softwood laminations, they gain moisture and swell, thereby forming a tight connection between laminations.

Thicknesses and Widths

From a global perspective, in Europe, Massiv-Holz-Mauer (MHM) and dowel-bonded CLT favor thinner (nominal 16 millimeters to 25 millimeters, equivalent to ⅝ inch to 1 inch) and wider (200 millimeters and more, equivalent to 8 inches) dimensions. Both technologies can, however, accommodate rough (undressed) lumber. MHM uses rough-sawn boards rather than nominal 2-by stock. The surface is not considered for visual quality. That means there should be greater potential for using lower-quality lumber than that required for adhesive-bonded CLT. The process favors wider laminations (200 millimeters or more, equivalent to 8 inches). Laminations are grooved on one side along the grain to increase thermal insulation. The final thickness of grooved laminations is about 16.5 millimeters (⅝ inch). Dowel-bonded CLT also uses rough-sawn lumber in core layers, but it needs dressed lumber for the face layers, which often are meant to be visible in structures. Also, bonding with dowels requires wide-face lumber (likely more than 200 millimeters, or about 8 inches) to form 2 rows of successful dowel bonds in each surface layer. This likely limits the prospect of using small logs.

GRADES	PREMIUM	SELECT	STANDARD	INDUSTRIAL
COMMON APPLICATION	Residential; Hotels; Feature Walls	Residential; Libraries; Schools; Museums; Offices	Offices	Nonvisual; High Ceilings
SPECIES	SPF; Douglas-fir; (other species available)			
COATINGS	Upon request, a penetrating clear sealer and tinted top coatings can be shop-applied to exposed side of panel. Our team focuses on working with designers to determine the best coating system for durability and ease of maintenance.			
WANE*	Width < or = 1/4"; Length < or = 2'; No bark	Width < or = 3/8"; W/O bark length < or = 5'; W bark length < or = 2'; Max 1 in every 5 boards	Width < or = 1/2"; W/O bark length < or = 10'; W bark length < or = 7'; Max 1 in every 4 boards	Permitted
KNOTS	No open knots; tight knot permitted	Open Smooth < or = 3/4" diameter; Open Jagged < or = 1/2" diameter; Tight knot permitted	Permitted	Permitted
BLUE STAIN	Max 1 every 10 boards; Up to 10% surface area; No dark/black coloring	Max 1 every 7 boards; Up to 15% surface area; No dark/black coloring	Max 1 every 5 boards; Up to 20% surface area; No dark/black coloring	Permitted
CHECKS IN STRAND EDGE	Nonpermitted	Width < or = 1/16"; Length < or = 12"	Width < or = 1/16"; Length < or = 24"	Permitted
CHARACTERISTICS DISTRIBUTION	Distributed	Distributed	Some distribution	No redistribution required
PANEL SURFACE	Deviation on board-to-board elevation < or = 1/8"		Deviation on board-to-board elevation < or = 1/4"	Deviation permitted
UNNATURAL BLEMISHES	Except for Type 4 (Industrial), the underside of the DLT panel shall be free of "unnatural" characteristics, e.g., black marks, scuffs, damage, and glue. Such blemishes shall be sanded/repaired as needed.			
CHARACTER OF WOOD	All wood, as a natural material, will exhibit characteristics such as knots/holes, wane, grain, checks, coloration, etc. The intent of the above appearance grading is to provide a degree of predictability/limitation to these characteristics. However, some variations in the visual appearance will be apparent.			

TABLE 3.2: LUMBER CHARACTERISTICS ALLOWED WITHIN STRUCTURECRAFT DLT PANEL GRADES

**Wane is the presence of bark or lack of wood fiber along the edge of a piece of lumber.*

Lumber Size

DLT panels come in thicknesses ranging from 4 inches to 12.17 inches. Lumber widths are available from 2 inches to 6 inches (nominal).

Appearance

StructureCraft has developed 4 grades of DLT panels: premium, select, standard, and industrial. **Table 3.2** specifies the lumber characteristics of each of StructureCraft's grades.

SPECIES GROUP	SPECIES INCLUDED IN GROUP
ALASKA CEDAR	Alaska Cedar
DOUGLAS FIR-LARCH	Douglas-Fir, Western Larch
EASTERN SPRUCE	Black Spruce, Red Spruce, & White Spruce
HEM-FIR	California Red Fir, Grand Fir, Noble Fir, Pacific Silver Fir, Western Hemlock, & White Fir
PORT ORFORD CEDAR	Port Orford Cedar
SOUTHERN YELLOW PINE	Loblolly Pine, Longleaf Pine, Shortleaf Pine, Slash Pine
SPRUCE-PINE-FIR	Alpine Fir, Balsam Fir, Black Spruce, Engelmann Spruce, Jack Pine, Lodgepole Pine, Norway Pine, Norway Spruce, Red Spruce, Sitka Spruce, White Spruce
SOFTWOOD SPECIES	Alpine Fir, Balsam Fir, Black Spruce, Douglas-Fir, Douglas-Fir South, Engelmann Spruce, Idaho White Pine, Jack Pine, Lodgepole Pine, Mountain Hemlock, Norway Pine, Norway Spruce, Ponderosa Pine, Sitka Spruce, Sugar Pine, Red Spruce, Western Larch, Western Red Cedar, White Spruce

TABLE 3.3: SOFTWOOD SPECIES (OR SPECIES GROUPINGS) COMMONLY USED IN GLULAM TIMBERS

3.1.4 GLULAM

ANSI A190.1-2017, Standard for Wood Products—Structural Glued Laminated Timber and *ANSI 117-2020, Standard Specification for Structural Glued Laminated Timber of Softwood Species* are the 2 documents published by the APA that describe the specifications of lumber to be used in glulam timbers.

Key specifications include the following:

Species

The *ANSI A190.1-2017* standard states that any softwood or hardwood species is approved for use in structural glulam timber if stress indices and knot distributions are established as described in *ASTM D3737*. The *ANSI 117-2020* standard is more specific about allowable species or species groupings, as shown in **Table 3.3**.

Moisture Content

The moisture content of lumber used in glulam timbers shall not exceed 16 percent at the time of bonding.

Wane

Wane is a defect in a piece of lumber characterized by bark or insufficient wood at a corner or along an edge. For dry conditions when the material is placed into use, wane up to one-sixth the width at each edge of interior laminations is permitted in certain grade combinations. In those cases, the basic shear design value shall be reduced by one-third. When wane is limited to one side of a member, the basic shear design value is reduced by one-sixth. Other instances of wane are allowed, but the circumstances are complicated. See *ANSI 117-2020* for details.

Grade

Lumber used in glulam timbers is graded visually or mechanically, and it is identified by grade before bonding. Rules approved by the Board of Review of the ALSC or written laminate grading rules apply to visually graded lumber. Rules approved by the Board of Review of the ALSC or special rules that conform with the *ANSI A190.1* standard apply to mechanically graded lumber. An accredited inspection agency oversees the qualification of proof-graded lumber, subjecting it to full-size tension tests as set forth in the American Institute of Timber Construction (AITC) test 406. A number of more specific grading rules apply, depending on the position of the piece in the glulam timber, its species, whether the lumber is ripped before bonding, and other factors. See *A190.1-2017* for details.

Bonding

All bonding surfaces—including face, edge, and end joints—are smooth and, except for minor local variations, free of raised grain, torn grain, skips, burns, glazing, or other deviations that might interfere with the contact of sound wood fibers.

Thickness

Laminations are not to exceed 2 inches in net thickness, unless a gap-filling adhesive is used for face and edge bonds.

Dimensional Tolerances

At the time of bonding, variations in thickness across the width of a lamination shall not exceed plus or minus 0.008 inches (2 millimeters). Variations in thickness along the length of an individual piece of lumber or along a lamination shall not exceed plus or minus 0.012 inches (3 millimeters).

3.1.5 POST AND BEAM

Traditionally, post and beam construction uses timbers of at least 6 inches in nominal width and thickness. Less guidance is available for the specification of lumber (timbers) for this category of mass timber than for others. Nevertheless, the *Code of Standard Practice for Timber Frame Structures* developed by the Timber Framers Guild (TFG) (https://www.tfguild.org/) in 2018 does provide some. A few specifications follow:

Grade

Grades are select structural, No. 1, or No. 2. All structural timbers are to be graded by an approved lumber grading agency, certified grader, or a person who has completed a timber grading training course. The lumber grader is to provide a grade stamp or a certificate of grade for each piece of timber. Knots and other natural timber features shall not be construed as defects unless their magnitude exceeds the limits prescribed in the applicable lumber grading rules. Checks are a natural feature resulting from ordinary timber drying and seasoning. Checks that develop after the timber frame has been raised are not construed as defects.

Species

Acceptable species include Douglas-fir, Eastern white pine, red oak, white oak, Southern Yellow Pine (SYP), and Alaska cedar.

Moisture

Timbers are to be dried to a maximum moisture content of 19 percent.

Size

Timbers 8 inches by 12 inches and smaller are to be Free of Heart Center (FOHC). Timbers larger than 8 inches by 12 inches are to be boxed heart. All timber sizes are nominal (actual dimensions are typically ½ inch smaller than the nominal size in both thickness and width). Pith is the center of a tree that extends along its long axis. The wood around the pith typically is not as strong as wood nearer to the bark. Therefore, a quality factor for smaller timbers is that the pith (heart center) should not be included in the timbers, or that the pith be boxed in the center of the timber on larger timbers.

Surfacing

Timbers may be surfaced four sides (S4S), rough-sawn, or hewn. "Surfaced four sides" refers to timbers that are planed smooth on all 4 sides; rough-sawn are timbers that have been sawn but not planed; and hewn timbers have been shaped using an axe or other similar tool.

3.1.6 HEAVY TIMBER DECKING

Specifications for heavy timber decking are less prescriptive than other mass timber products. Some guidance is provided in *Heavy Timber Construction*, published by the American Wood Council (AWC). Key excerpts include the following:

Grading

The lumber used in heavy timber framing and decking must be graded in accordance with the rules customarily used for the species. These are generally regional grading agencies, including the Northeastern Lumber Manufacturers Association (NELMA), California Redwood Inspection Service (RIS), Southern Pine Inspection Bureau (SPIB), West Coast Lumber Inspection Bureau (WCLIB), Western Wood Products Association (WWPA), and Canadian National Lumber Grades Authority (NLGA).

Sizing

The decking used in heavy timber floor decks is to be of sawn or glulam plank, splined, or tongue-and-groove planks not less than 3 inches (nominal) thick; or of planks not less than 4 inches (nominal) wide when set on edge. Splining and tongue-and-groove refer to protrusions and indentations on the sides of lumber pieces so that adjacent lumber pieces can be interlocked. For roof applications, the timbers are to be sawn or glulam, splined, or tongue-and-groove plank not less than 2 inches (nominal) thick; or of planks not less than 3 inches (nominal) wide when set on edge.

3.1.7 VENEER

Veneer-based mass timber products are *ANSI/APA PRG 320*-certified and include Mass Plywood Panels (MPP) up to 11 feet 10 inches wide, 12 inches thick, and 48 feet long. Freres Lumber Co. Inc. can also manufacture beams and columns made from veneer up to 12 inches wide, 72 inches deep, and 48 feet long that are *ANSI/APA PRG 320*-certified.[4]

4 The equipment Freres uses to make the columns and beams can handle widths up to 24 inches. Freres is working to achieve APA certification for the larger widths. Additionally, columns and beams can be produced up to 60 feet in length, but current production of longer beams is limited by the length of Freres's press.

The veneers are first formed into Laminated Veneer Lumber (LVL) billets (an LVL plank of standardized size), which are then made into MPP. Because the veneers are first formed into LVL billets, certification of MPP falls under the classification of SCL, which includes LVL and is covered under *ASTM D5456*.

More specifically, the manufacturer uses wood veneers to make LVL billets. These billets are 1.6E, 1.55E, or 1.0E Douglas-fir LVL as recognized by the APA in the product report *PR-L324*; the billets also are in accordance with custom lay-ups of *ANSI/APA PRG 320* that employ product qualification and mathematical models that use principles of engineering mechanics. The LVL billets can range in thickness from 1 inch to 24 inches and in width from 1.5 inches to 72 inches. Depending on the billets' dimensions and MPP design needs, the billets are parallel laminated, bonded with qualified structural adhesives, and pressed to form a solid panel (i.e., MPP).

Freres uses Douglas-fir veneers classified by moisture content and a grade (G1, G2, or G3) that's dependent on their strength, as measured by Ultrasonic Propagation Time (UPT) testing, which correlates the time it takes for sound to pass through wood veneers with key strength determinants, such as specific gravity and modulus of elasticity (ratio of stress to strain). Freres also manufactures veneer and plywood and thus controls the raw material supply for its MPP manufacturing operations from standing timber through the finished product.

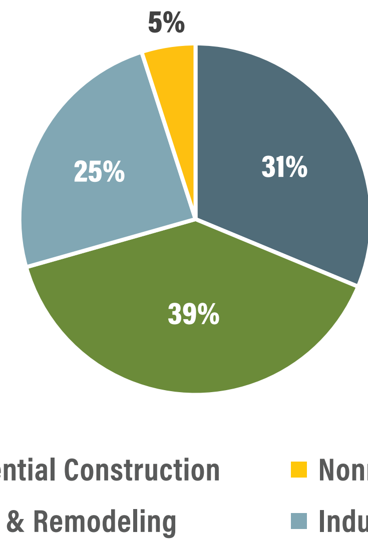


FIGURE 3.2: LUMBER CONSUMPTION BY END-USE MARKET SEGMENT (2014 TO 2023)
Source: Forest Economic Advisors

3.2 NORTH AMERICAN LUMBER SUPPLY

As the number and sizes of mass timber construction projects grow, the capacity of sawmills to supply lumber is of considerable interest. Thus, this section focuses on softwood lumber production and use in North America.

3.2.1 END USES FOR SOFTWOOD LUMBER

Historically, softwood lumber has been used in 4 key end-use market segments: residential construction, repair and remodeling, nonresidential construction, and industrial/other. **Figure 3.2** shows the average portion of softwood lumber consumed by each end-use market segment in the US from 2014 to 2023. As the data shows, for those 10 years, on average, 39.4 percent of all softwood lumber consumed was for repair and remodeling, followed by just over 31 percent for

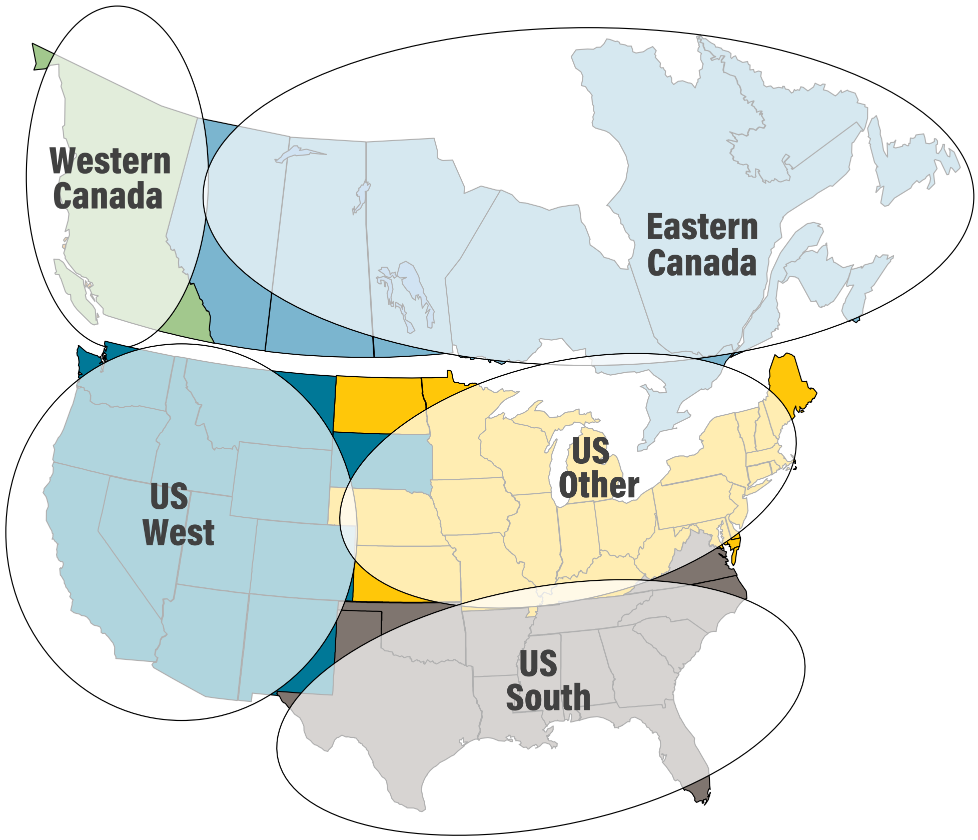


FIGURE 3.3: NORTH AMERICAN SOFTWOOD LUMBER-PRODUCING REGIONS

residential construction. Thus, historical softwood lumber demand has largely been tied to either new home construction, or the repair and remodeling of existing homes.

The industrial end-use segment has averaged about 25 percent of all lumber consumed and is typically lumber used for applications such as packaging, pallets, and furniture, which use the lower grades of lumber. Nonresidential construction averaged about 5 percent of all lumber consumption during the period 2014 to 2023. However, the percentage is on the rise, moving from about 4.5 percent in 2014 to about 5.5 percent in 2023. The advent of mass timber and the new demand it places on softwood lumber in nonresidential construction is the focus of the remainder of this chapter.

3.2.2 WHERE SOFTWOOD LUMBER IS PRODUCED IN NORTH AMERICA

Softwood lumber in North America is produced in 5 geographical regions: US West, US South, US Other, Western Canada, and Eastern Canada, as shown in **Figure 3.3.** Note that in the US South, 4 species of pine (loblolly, longleaf, shortleaf, and slash) are commonly manufactured into lumber and sold as a species grouping called SYP. In Eastern Canada and Western Canada, the predominant lumber grouping is SPF, but the makeup of

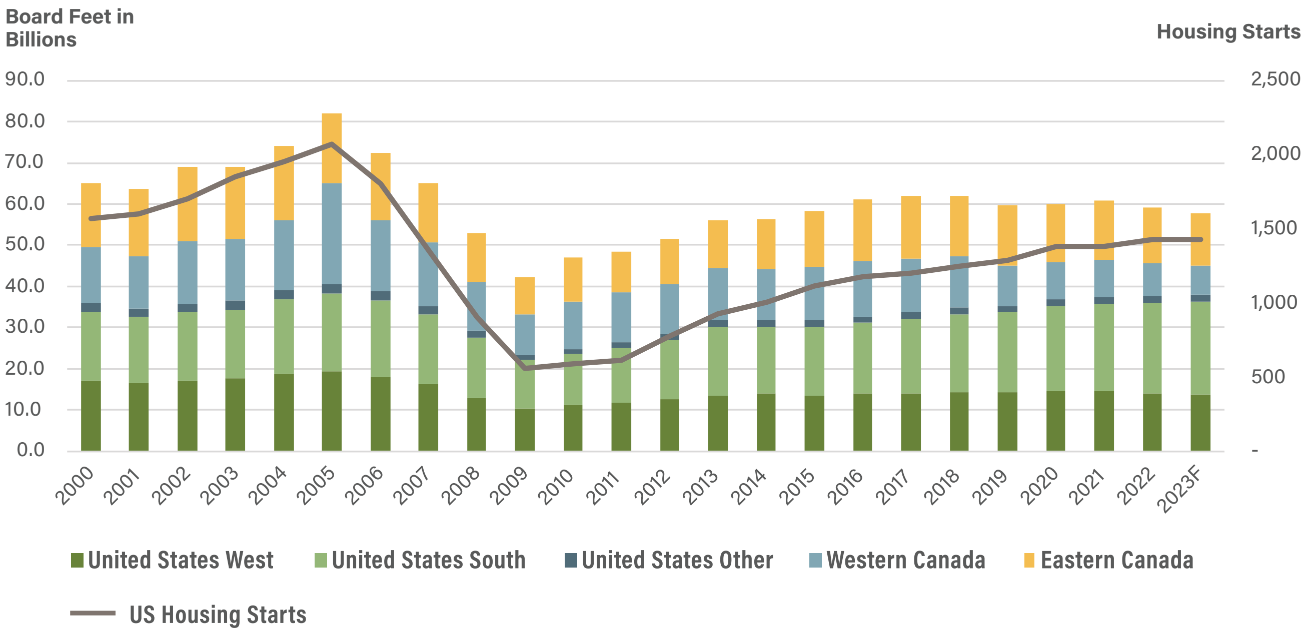


FIGURE 3.4: HISTORICAL UNITED STATES AND CANADIAN SOFTWOOD LUMBER PRODUCTION BY REGION (BOARD FEET IN BILLIONS) & HOUSING STARTS

Source: Western Wood Products Association

species within the SPF lumber grouping differs by region. In the US West, the predominant lumber species or species groupings are Douglas-fir, Douglas-fir-larch, and hem-fir.

The volume of softwood lumber produced in each North American region from 2000 to 2023 as reported by the WWPA (2023 is a forecast based on the first 6 months of the year) is shown in **Figure 3.4.** Note that there are some differences in lumber production and consumption (i.e., some lumber produced hadn't been sold when data was collected). To simplify the discussion, we treat production and consumption as being equal because the volume in inventory is typically a small portion of the total annual production.

There are several things to note about the data in the figure:

- North American softwood lumber production peaked in 2005 at more than 82 billion board feet. At that time, Western Canada was the top-producing region with nearly 25 billion board feet. At the time, the US West and US South were nearly equal in production, with about 19 billion board feet each.

- Lumber production across North America decreased dramatically during the Great Recession, with totals in 2009 dropping to about 50 percent of the 2005 peak. Note that North American lumber production has historically been driven by the level of housing starts in the US. This is shown in the figure by the line that corresponds to the right-hand axis of the graph, which shows annual US housing starts in thousands. The data shows that, over the long term, lumber production is highly correlated to the level of US housing starts. However, in recent years, that relationship appears to be weakening. Housing starts have been slightly increasing since 2018, while North American lumber production/consumption reached 62.1 billion board feet per year in 2018 but has since been declining despite the increasing housing starts. This is an important issue in North American lumber supply-and-demand dynamics and is discussed in more detail in the following sections, which describe the dynamics occurring in each region.

Western Canada

One of the most dramatic changes is that Western Canada went from producing about 30 percent of North America's lumber in 2005 to producing only an estimated 12 percent in 2023. That change was driven mainly by reductions in the Annual Allowable Cut (AAC) of timber in the interior region of British Columbia. In that region, a massive mountain pine beetle epidemic affected nearly 45 million acres and killed nearly 60 percent of the standing pines. The outbreak started in the 1990s; and during the 2000s, timber harvests were significantly increased to salvage the dead timber.

The salvage efforts are complete, but current and future harvests have been significantly reduced to allow the forest to grow to a standing inventory that will once again allow for higher levels. Rebuilding is a long process, meaning reduced timber harvest rates will remain in place for the foreseeable future. The sawmill industry built up during the salvage period, and the existing capacity became too large for the available log supply. As a result, many sawmills have permanently closed.

More recently, in late 2022 and early 2023, the province of British Columbia, in partnership with First Nations, announced plans to defer timber harvests on 2.1 million hectares (or about 5.2 million acres) of forests identified as old-growth that were not already set aside from logging. Those harvest deferral plans will constrain log supply in the regions and are estimated to translate into about 1.4 billion board feet per year less lumber production in the region than 2022 levels.

US South

There are also major changes well underway in the US South. Before the Great Recession, the US South and the US West produced roughly equal amounts of lumber each year. Since the Great Recession, however, the US South has bounced back while the US West has been flat. For example, in 2023 the US South's production reached 22.5 billion board feet, which is 3.5 billion board feet higher than US South production in the peak North America-wide production year of 2005. The US South now accounts for nearly 40 percent of all North American lumber production.

There are 2 key drivers in the US South lumber production ramp-up. First, more widespread forest management and improved forest management have reduced timber harvest rotations in the region to about 30 years and have increased per-acre timber yields. During the significant yearslong drop in lumber production during the Great Recession, a massive amount of sawtimber inventory built up "on the stump" across the US South. Second, about 85 percent of the timber in the US South region belongs to private landowners. This means that sawtimber harvest levels are largely dictated by economic drivers, rather than by policy/regulatory drivers. These conditions

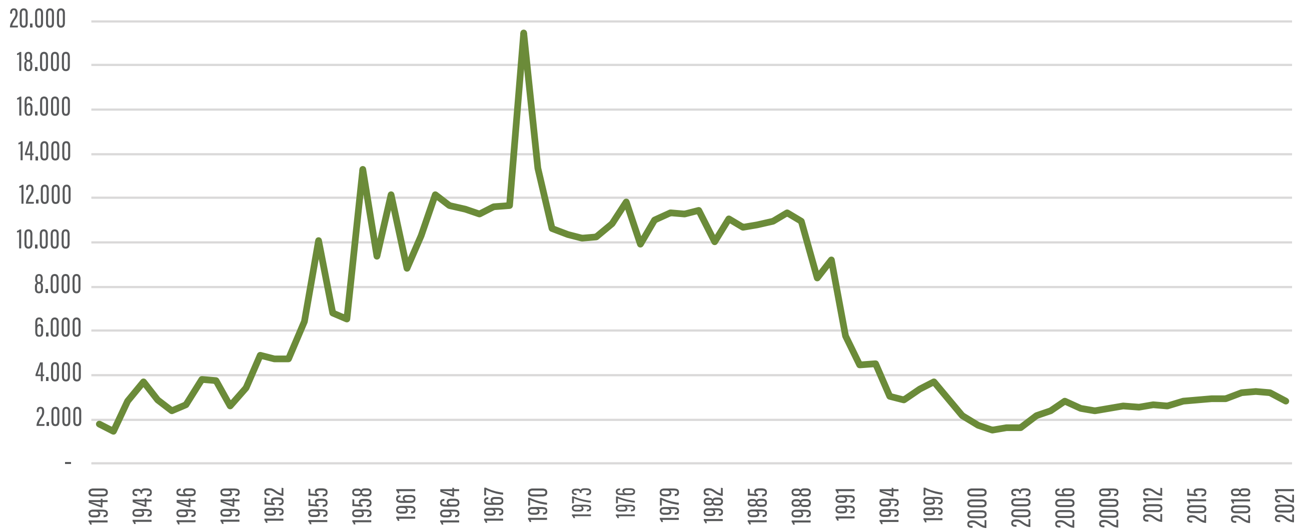


FIGURE 3.5: HISTORY OF US FOREST SERVICE TIMBER SALES FISCAL YEAR 1940 TO FISCAL YEAR 2021 (ANNUAL VOLUME BOARD FEET [LOG SCALE] IN BILLIONS)

Source: https://www.fs.fed.us/forestmanagement/products/cut-sold/index.shtml

have spurred massive capital investment in new sawmilling capacity through upgrades to existing mills and greenfield (i.e., new mill at a new site) sawmill development. Nearly 5 billion board feet of new capacity was added over the last several years, driven by $2.5 billion of capital investment in new and upgraded sawmilling infrastructure in the region. The nearly 5 billion board feet of new/upgraded capacity and associated capital investment are a first wave because, despite the increased capacity, there are still regions with excess sawtimber supply. US South lumber production capacity will reach nearly 27 billion board feet per year by 2026 with projects that have already been announced.

US West

Lumber production in the US West totaled 13.8 billion board feet in 2023, a decrease of about 200 million board feet compared to 2022. It continues a downward trend in the US West that started after the region reached a post-Great Recession high of 14.7 billion feet of production in 2021.

A long-standing issue in the US West constraining lumber production is that log supplies are a function of who owns the timberland. Privately held timberland accounts for about 70 percent of the total harvest. Industrial timberland owners manage their timberlands intensively and generally harvest near the maximum allowable sustainable rates. Thus, harvests on industrial lands cannot increase without beginning to deplete the supply of standing timber. Although small private timberland owners contribute a considerable portion of the annual harvest, this segment is made up of many thousands of individuals and families. As a group, these landowners typically do not act in sync because individuals have a variety of management objectives, and timber production is not always a top priority. They could supply additional logs, but because they do not act collectively, their supply is constrained. The balance of the land is under public ownership: the US Forest Service, the Bureau of Land Management (BLM), and miscellaneous states, counties, and municipalities. About 70 percent of all timberland acres are publicly owned, a high percentage relative to public ownership in the US South. For about the last 30 years, forest management policies on federally owned public lands have constrained log supplies across the US West and limited lumber production.

For nearly 4 decades starting in the mid-1950s, the US Forest Service sold 10 billion to 12 billion board feet of logs each year. The passage of the Endangered Species Act (ESA) required changes to federal policies, resulting in the listing of the northern spotted owl, various salmon species, and the marbled murrelet. That led to a dramatic decline in the annual volume of timber sold since 1988, as shown in **Figure 3.5.** US Forest Inventory and Analysis (FIA) data suggests that, despite the massive tree mortality from the many wildfires in recent years, federal lands are growing 3 times more wood fiber than is being removed by harvesting and natural mortality. That suggests timber harvests could be increased significantly without endangering the sustainability of the resource. In the meantime, increased lumber production is largely held in check by limited log supply.

The log supply situation is not expected to improve in the US West. In Oregon, the single largest lumber-producing state in the US, 2024 brings the full implementation of the Oregon Private Forest Accord. It is an agreement between timber and conservation groups to change the state's Forest Practices Act (FPA). Several measures in the Private Forest Accord are expected to further constrain log supply. The most impactful is the expansion of riparian buffer zones along waterways, which will prevent harvesting of any timber located in the buffer zones. Additionally, the widespread 2020 Labor Day wildfires are estimated to reduce Oregon timber harvests by more than 7 billion board feet over the next 40 years. Finally, the State of Oregon is developing the Habitat Conservation Plan (HCP) that is also expected to reduce timber harvests. The net effect of these phenomena is that, beginning in 2024, Oregon will produce an estimated 1.5 billion fewer board feet of lumber per year than it has in recent years.

Eastern Canada

Lumber production in Eastern Canada between 2016 and 2021 was relatively flat, hovering around 15 billion board feet per year. However, in 2022, Eastern Canada's production dropped to 13.6 billion board feet. In 2023, it dropped further, to 13.8 billion board feet. The drop in 2022 was surprising since, unlike Western Canada, where timber supply is constrained by the lingering effects of the mountain pine beetle, standing timber is readily available in Eastern Canada. A factor affecting 2023 lumber production in Eastern Canada is that widespread wildfires across the region affected the ability of logging crews to operate.

Another factor affecting Eastern Canada is that parts of the region are long distances from markets, and the small average tree size in those parts increases sawmill manufacturing costs because productivity is constrained by a small average piece size. In general, larger mills enjoy economies of scale, allowing for lower manufacturing costs. Historically, Eastern Canada has concentrated on pulp and paper mills that produce newsprint. Those pulp mills were largely supplied with residue from sawmills. As demand for newsprint dwindled, producing lumber

REGION	% DIMENSION (2"NOMINAL)	ESTIMATED 2023 PRODUCTION OF DIMENSION (BBF)	% SMALL TIMBERS (3"–5")	ESTIMATED 2023 PRODUCTION OF SMALL TIMBERS (BBF)	% LARGE TIMBERS (6"+)	ESTIMATED 2023 PRODUCTION OF LARGE TIMBERS (BBF)	% OTHER	ESTIMATED 2023 PRODUCTION OF ALL OTHER SIZES	TOTAL 2023 PRODUCTION (BBF)
US West	55%	7.6	5%	0.7	5%	0.7	35%	4.8	13.8
US South	80%	18.0	10%	2.3	5%	1.1	5%	1.1	22.5
US Other	20%	0.3	n/a	n/a	n/a	n/a	80%	1.3	1.6
Western CA	75%	5.3	n/a	n/a	n/a	n/a	25%	1.8	7.1
Eastern CA	50%	6.4	n/a	n/a	n/a	n/a	50%	6.4	12.8
North America Total		**37.7**		**2.9**		**1.8**		**15.4**	**57.9**

TABLE 3.4: ESTIMATED NORTH AMERICAN SOFTWOOD LUMBER THICKNESS MIX IN 2023 (BOARD FEET IN BILLIONS)

from small logs has become more difficult economically, constraining milling capacity.

The smaller tree sizes also mean that lumber tends to be narrower and shorter. To produce a reasonable annual lumber volume, the mills must operate their lines at very high throughput rates (i.e., a large number of logs through processing equipment per unit of time), and because of limited ability to increase feed speeds and still maintain good lumber quality, they likely have little ability to increase those rates.

3.2.3 2023 NORTH AMERICAN SOFTWOOD LUMBER PRODUCTION DETAILS

As described in section 3.1, mass timber product standards specify the use of certain lumber sizes and grades. Thus, the grades and sizes of lumber produced are also important. **Table 3.4** shows lumber production by thickness, based on the WWPA's estimated North American softwood lumber production volumes for 2023. The percentages of production by size values are estimates from sawmill industry benchmarking data collected by the Beck Group. Of the estimated 57.9 billion board feet of lumber produced in North America in 2023, about 37.7 billion board feet (or about 65 percent) is nominal 2-inch-thick dimension lumber (i.e., boards nominally 2 inches thick and 8 feet to 20 or more feet long). Of the remainder, only small portions are made into thicker and wider timbers, and another 25 percent or so are in other miscellaneous sizes. Note that most of the volume in the "Other" category is stud-grade lumber. It is the same thickness as dimension lumber, but it is produced only in 4-inch and 6-inch widths, and mainly in lengths of less than 12 feet. Most stud-grade lumber is used as vertical structural components in wall systems for homes. The balance of the "Other" category includes industrial and common boards (i.e., nonstructural lumber), and miscellaneous products.

REGION	% ABOVE #2	ESTIMATED BBF ABOVE #2	% OF #2	ESTIMATED BBF OF #2	% OF #3	ESTIMATED BBF OF #3	% BELOW #3 AND OTHER	ESTIMATED BBF OF BELOW #3 & OTHER	TOTAL PRODUCTION OF DIMENSION (BBF)
US West	35%	2.7	55%	4.2	5%	0.4	5%	0.4	7.6
US South	40%	7.2	40%	7.2	10%	1.8	10%	1.8	18.0
US Other	10%	0.0	55%	0.2	20%	0.1	15%	0.0	0.3
US Total		**9.9**		**11.6**		**2.2**		**2.2**	**25.9**

TABLE 3.5: ESTIMATED US SOFTWOOD DIMENSION LUMBER GRADE MIX IN 2023 (BOARD FEET IN BILLIONS)

Similarly, it is useful to understand the grade mix, as shown in **Table 3.5**. Using the WWPA's 2022 production estimates and the Beck Group's sawmill benchmarking data, the table shows that over 80 percent (21.5 billion board feet out of 25.9 billion board feet) of dimension lumber production in the US is No. 2 grade or better. Data for Canada is not included because the information was not readily available, but the grade yields are likely similar.

Finally, **Table 3.6** displays the estimated width mix. As the data shows, about 7.7 billion board feet (about 30 percent) of all dimension lumber is estimated to be 4 inches wide, followed by another 30 that is 6 inches wide. A significantly higher percentage of 2-by-4s is produced in the US West than in the US South. Lumber width is a significant consideration for mass timber manufacturers, as prices vary among widths, and productivity improves (which, in turn, lowers production cost) when wider pieces of lumber are used to manufacture CLT panels.

3.2.4 SOFTWOOD LUMBER PRICING

The purchase of raw material is the single largest cost associated with manufacturing mass timber products, accounting for more than 50 percent of a plant's total operating cost. Lumber pricing, therefore, is a key focus area for manufacturers. In the US over the past 10 years, demand for lumber in the residential construction and repair and remodeling market segments combined has ranged from a low of 32.6 billion board feet per year in 2014 to a high of 44.3 billion board feet per year in 2021. Those changes in demand create associated swings in supply; this, in turn, creates considerable volatility in lumber prices, a phenomenon that is less pronounced in the rest of the world because, in many countries, lumber is less commonly used to construct homes.

Price volatility was in full swing in 2021, ranging from a second-quarter high with average prices approaching $1,300 per 1,000 board feet to third-quarter prices just under $500 per 1,000. 2022 started out much the same, with prices in the first quarter averaging over $1,200 per 1,000

REGION	% 2-BY-4	ESTIMATED 2-BY-4 PRODUCTION (BBF)	% 2-BY-6	ESTIMATED 2-BY-6 PRODUCTION (BBF)	% 2-BY-8	ESTIMATED 2-BY-8 PRODUCTION (BBF)	% 2-BY-10	ESTIMATED 2-BY-10 PRODUCTION (BBF)	% 2-BY-12	ESTIMATED 2-BY-12 PRODUCTION (BBF)	TOTAL 2020 DIMENSION PRODUCTION (BBF)
US West	40%	3.0	30%	2.3	10%	0.8	10%	0.8	10%	0.8	7.6
US South	25%	4.5	30%	5.4	20%	3.6	15%	2.7	10%	1.8	18.0
US Other	40%	0.1	30%	0.1	10%	0.03	10%	0.03	10%	0.03	0.3
US Total		7.7		7.8		4.4		3.5		2.6	25.9

TABLE 3.6: ESTIMATED US SOFTWOOD DIMENSION WIDTH MIX IN 2023 (BOARD FEET IN BILLIONS)

board feet but then trending steadily downward through the remainder of the year to finish around $500 per 1,000. 2023 saw further reductions in average lumber prices as demand dwindled along with the level of housing starts. Prices averaged about $450 per 1,000 during the year.

For a longer-term perspective, for about the past 25 years, the price of dimension lumber in North America has averaged roughly $350 per 1,000 board feet. The low point occurred in 2009, in the depths of the Great Recession, when dimension lumber was selling for around $200 per 1,000 board feet. The high point had been in mid-2018 when prices approached $600 per 1,000 board feet. In 2021, however, COVID induced higher demand in the home repair and remodeling sector and drove down supply with COVID-related labor shortages and other supply constraints related to shipping. Prices skyrocketed to all-time highs. During different periods in 2021 and 2022, dimension lumber prices in North America approached levels nearly 4 times the long-term average price.

3.2.5 ENVIRONMENTAL CERTIFICATION OF SOFTWOOD LUMBER

In chapter 2 of this report, we explained how forested land is certified when managed under certain protocols judged to represent sustainable forest management. Such forest management programs also offer chain-of-custody certification to participants in the supply chain. Chain-of-custody is the process of certifying that, as products move from the forest to the end user, material originating from certified forests is identified or kept separate from noncertified material. Chain-of-custody certification generally involves detailed logistics and materials-handling protocols, inventory management, batch processing, filings, and third-party audits.

Forest management and chain-of-custody certification fulfills the end user's desire for assurances that the products they are using are from well-managed forests. This is especially true for developers seeking to certify a building under Leadership in Energy and Environmental Design (LEED) and similar programs. In addition, large tech companies, like Google and Facebook, that have expressed interest in mass timber are keenly interested in using environmentally certified raw materials. But it isn't yet clear which environmental certification programs these large and influential mass timber users will prefer.

Forest landowners and wood product manufacturers who follow the forest management and chain-of-custody guidelines can market their products as being environmentally certified. It is difficult to track the volume of environmentally certified lumber (and veneer/plywood) sold annually in North America because a high percentage of these forest products could be environmentally certified under one or more of the programs. But, frequently, they are not marketed in that manner; and thus, there is no well-documented record of their sales volumes.

One of the main reasons these sales are not well-tracked is that, for most consumers, this attribute is relatively unimportant. Considerations such as price, quality, species, and grade are much more important. In addition, landowners and manufacturers must expend considerable effort and money to acquire and maintain these certifications. Given the limited market demand and the expense, many landowners and manufacturers decide not to certify their products, even though they could. Others elect to certify their material on a case-by-case basis as dictated by customer expectations. A small number of producers choose to certify as much of their product as possible, regardless of the level of demand from customers.

For producers of mass timber products, this means that market demand for environmentally certified materials—aside from mass timber products—is relatively low. Therefore, finding environmentally certified material may be a challenge but likely is not a roadblock. In interviews with the Beck Group, the general feeling of mass timber producers is that only a small portion of their demand is for certified mass timber products, and when those orders need to be filled, they can usually oblige. It may cost more, however, to acquire certified lumber.

As previously noted, a big wild card is whether one of the large tech companies will announce plans for a large mass timber project (or projects) and give preference to raw materials from a given environmental certification program. Such an event would likely trigger a rise in the price of environmentally certified raw materials until the supply chain is able to adjust to the increased demand.

3.3 THE MASS TIMBER INDUSTRY'S ESTIMATED DEMAND FOR RAW MATERIALS IN 2023

Definitive data about lumber consumption among mass timber producers is not readily available. However, an analysis by the Softwood Lumber Board[5] suggests that, in the near term, lumber demand associated with mass timber can reach about 1 billion board feet per year and could

5 Softwood Lumber Board, *Mass Timber Outlook (2020)*, https://softwoodlumberboard.org/wp-content/uploads/2021/03/SLB-Mass-Timber-Outlook-2021-Final-Condensed.pdf.

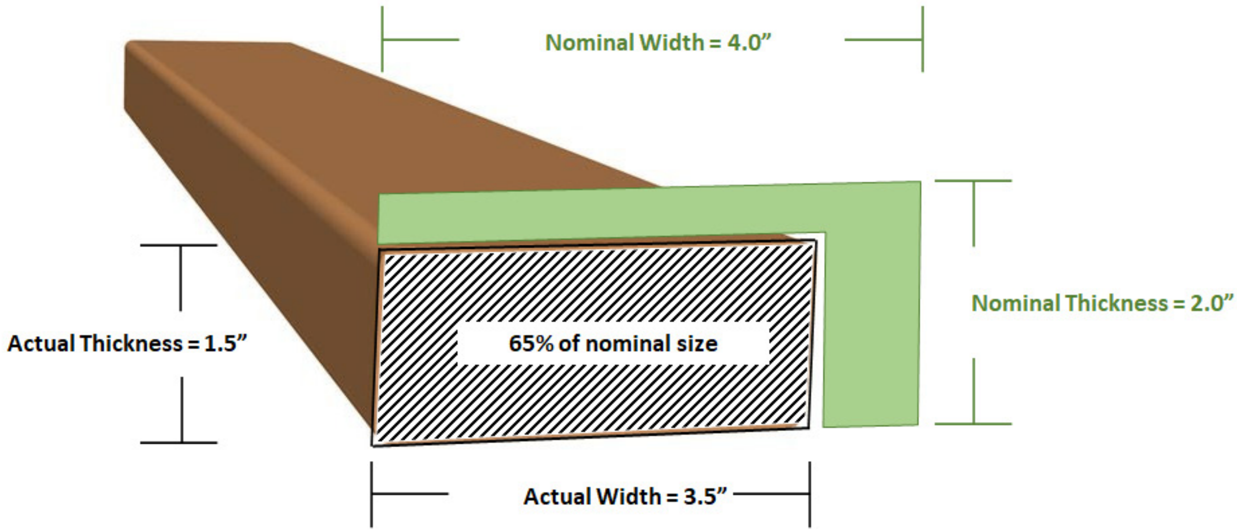


FIGURE 3.6: COMPARISON OF NOMINAL AND ACTUAL DIMENSIONS FOR BOARD FOOT LUMBER TALLY

Source: The Beck Group

grow to nearly 5 billion board feet per year by 2035. This topic is analyzed in further detail in chapter 4.

3.3.1 NOMINAL VERSUS ACTUAL LUMBER SIZES

As described in chapter 1, an estimated 22.5 board feet (nominal tally) is needed to produce 1 cubic foot of finished mass timber panel. Some readers may be thinking that 22.5 board feet per cubic foot seems like too much lumber input per cubic foot of finished panel. Such thoughts likely stem from the knowledge that a board foot is defined as 1 inch thick by 12 inches wide by 12 inches long. Thus, it may seem that 1 cubic foot of mass timber should be equal to an input of 12 board feet of lumber as raw material.

This is not the case, for several reasons. First and most importantly, softwood lumber in North America is bought and sold on a nominal board foot basis. For example, a common lumber size is 2 inches thick by 4 inches wide. Those dimensions, however, are nominal, meaning in name only. The actual dimensions are 1.5 inches thick by 3.5 inches wide. As shown in **Figure 3.6**, this means that about 35 percent of the area in a 2-inch by 4-inch space is air. Because so much of a tally is airspace, more than 12 board feet of lumber will be needed to produce a cubic foot of mass timber panel. Additionally, about 8 to 10 percent of a board's thickness is planed away before it is glued up. Planing activates the wood surface for the adhesive to bond it. Also, during finger-jointing, a portion of the incoming lumber becomes waste as defects are cut out with a chop saw. Finally, a portion of a mass timber panel is lost to trim around the perimeter and cutouts for windows, doors, and other openings.

The percentage of airspace decreases as lumber width increases, as shown in **Table 3.7.** Nevertheless, a significant portion of the board foot tally for every piece of lumber is airspace.

	ACTUAL			NOMINAL				
Lumber Size (Thickness x Width)	Actual Thickness (Inches)	Actual Width (Inches)	Cross-Sectional Area (Inches Squared)	Nominal Thickness (Inches)	Nominal Width (Inches)	Cross-Sectional Area (Inches Squared)	Actual Fiber % (Actual/ Nominal)	Air Space %
2-by-4	1.5	3.5	5.25	2	4	8	65.60%	34.40%
2-by-6	1.5	5.5	8.25	2	6	12	68.80%	31.30%
2-by-8	1.5	7.25	10.88	2	8	16	68.00%	32.00%
2-by-10	1.5	9.25	13.88	2	10	20	69.40%	30.60%
2-by-12	1.5	11.25	16.88	2	12	24	70.30%	29.70%

TABLE 3.7: COMPARISON OF THE PERCENTAGE OF ACTUAL FIBER TO AIRSPACE AMONG LUMBER SIZES FOR NOMINALLY TALLIED LUMBER

3.4 SUPPLYING LUMBER TO THE MASS TIMBER MARKET: A NEW APPROACH?

Sawmillers are always interested in developing new lumber markets. However, dimension lumber is a commoditized product in North America, where much of the competition among manufacturers is based on sales price. Therefore, manufacturers face the constant discipline of producing at a low cost. This means many sawmillers operate their mills in a manner that emphasizes high productivity and minimizes production-slowing distractions.

For the mass timber market, the low-cost mindset common among sawmillers limits their interest in producing lumber for mass timber manufacturers, mainly because lumber used in mass timber manufacturing must be dried to 12 percent moisture content rather than the standard 19 percent moisture content for dimension lumber. The additional drying ties up valuable kiln capacity and significantly increases the risk of lumber degrading (e.g., excessive bowing, cupping, or twisting) during the extra drying time. Deals can be structured in many ways, but it is most likely the sawmiller who takes on the risk of lower-grade yields, and therefore less revenue, when drying to a lower moisture content.

Another issue affecting the mass timber industry supply chain is that *dimension lumber* is the raw material for CLT and glulam manufacturing. In North America, dimension lumber is almost always produced at 1.5 inches thick. This is important because it affects the amount of panel thickness options that CLT manufacturers can cost-effectively produce. For example, 3 is the minimum number of lamellas that can be used for making CLT. Since the raw material is 1.5 inches thick, the smallest-thickness CLT panel available from dimension lumber finishes at about 4.25 inches thick. (It doesn't finish at 4.5 inches because a small amount is planed from each board before lay-up, to assure uniform thickness and to activate the lumber surface to ensure proper glue bonding.) In some applications, a 4.25-inch-thick CLT panel is overkill because a thinner panel would meet the required strength properties and at the same time reduce project cost because less fiber is used.

One potential solution that would allow CLT and glulam manufacturers more flexibility in their panel thickness/strength options is for sawmills to produce thinner (e.g., 1 inch thick), structurally graded lumber. However, as previously described, sawmills largely compete on cost in a commodity-driven marketplace. Producing thinner boards means less volume per piece which, in turn, means a sawmill takes a dramatic hit in throughput when producing thinner boards. Less throughput translates into higher cost. The hit on throughput occurs because, for many processes such as primary breakdown, planing, edging, resawing, etc., the processing is linear, along the long axis of each piece. Throughput speed doesn't appreciably change with thinner piece sizes. Therefore, the result of running thinner material is dramatically less throughput and higher cost.

Additionally, as previously described, the convention in North America is to produce lumber to smaller actual sizes than the nominal sizes used to tally lumber. If sawmills were to produce a larger volume of thinner lumber (1 inch thick, for example) they would not only lose productivity; they would also lose much of their tally advantage that currently arises from the difference between 1.5-

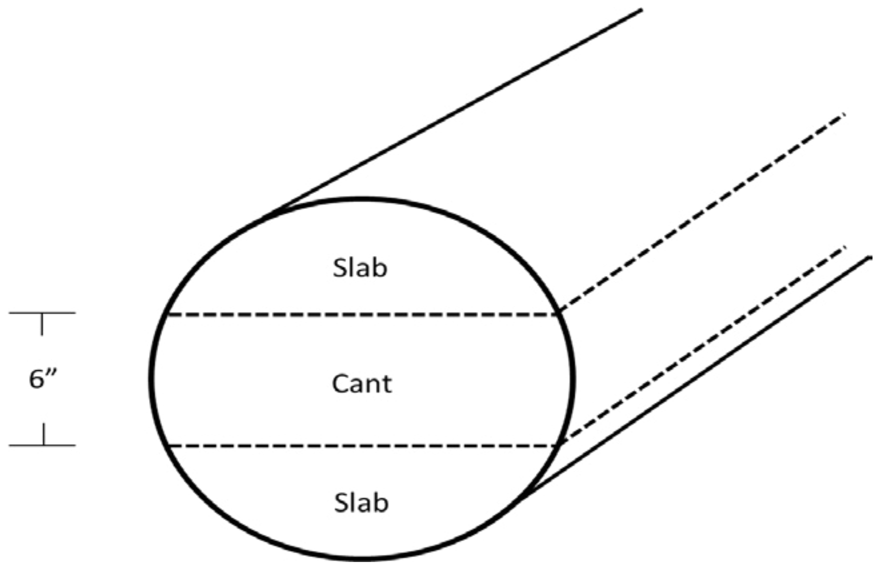


FIGURE 3.7: 2-SIDED CANT

inch actual thickness and 2-inch tally thickness. In summary, for a sawmill, the combination of lost productivity and a less favorable tally when producing thinner lumber may be a difficult proposition because of its negative impacts on sawmill economics.

Fortunately, there is another potential solution that the Beck Group will be investigating over the coming year via a US Forest Service Wood Innovations Grant. It is the concept of sawmills producing and selling cants[6] rather than boards to CLT manufacturers. The cants would then be processed into boards at the CLT manufacturer's operation. **Figure 3.7** provides an illustration of a 2-sided cant. The dotted lines represent saw lines. The two parallel saw lines 6 inches apart produce the cant. Normally, in a sawmill, the cant would be sent to a gang edger, which is a bank of saws on an arbor; they are spaced to produce a 1.5-inch-thick board between them. Thus, in the cant in the figure, in one pass of the cant through the gang edger, a number of 1.5-by-6-inch boards would be produced. The exact amount depends on the width of the cant. The slabs would go to resaws to capture as many 1.5-inch-thick boards as can be produced from the slab.

If the process of breaking down the cant were shifted to CLT manufacturers instead of sawmills, the CLT manufacturers could control the lumber thicknesses produced, as dictated by their CLT panel order files. Key to the operation would be that the CLT manufacturer would adjust the spacing between the saws in the gang edger to produce boards to thicknesses that match their CLT panel order files and allow more optimal use of fiber. Having the ability to control lumber thickness would have several advantages for CLT and glulam manufacturers. First, the size/strength of the panels and glulams could be better optimized to use only as much fiber as is needed to meet the needs of a given application, instead of using an overbuilt beam/panel. This approach would

6 A cant is a log that has been slabbed on at least 2 sides, and sometimes up to all 4 sides.

also be efficient in the use of fiber since lumber would not be planed twice. Currently, lumber is planed at the sawmill and then again at the CLT manufacturer. Eliminating double-planing would save fiber. Also, sawmills trim lumber to lengths of 2-feet multiples. Material lost to end-trimming could be avoided if the CLT manufacturer could control the breakdown of the cant. For the sawmiller, this approach would still allow them to make products that don't negatively impact their production rate. In fact, production may increase if steps such as drying and planing are eliminated at the sawmill.

For this to work, CLT manufacturers would have to strengthen their lumber remanufacturing capabilities to include processes such as gang edging, sorting, stacking, and drying. Some CLT manufacturers already have some of these capabilities, but most do not. Stay tuned to this section in the 2025 report for an update on the outcome of this feasibility research.

3.5 CARBON CONSIDERATIONS

The September 2017 issue of *Forest Products Journal* included an article[7] that analyzed the carbon impact associated with the production of softwood dimension lumber in the Pacific Northwest and Southeastern US. Key conclusions from the study were that the global warming impact indicator is that 129 pounds of carbon dioxide equivalent was released for each cubic meter of lumber produced in the Pacific Northwest, and 179 pounds of carbon dioxide equivalent was released for each cubic meter of lumber produced in the Southeastern US. An additional key finding was that, in the Pacific Northwest, nearly 1,900 pounds of carbon dioxide equivalent is stored per cubic meter of lumber produced; and in the Southeastern US, nearly 2,100 pounds of carbon dioxide equivalent is stored per cubic meter of lumber. Thus, there is a net carbon benefit of nearly 1 ton of carbon dioxide equivalent associated with wood use for the duration of the product's useful life.

These findings are a stark contrast to other common building materials (e.g., steel and concrete) that do not store any carbon dioxide equivalent during their useful life and that require considerable energy and associated carbon emissions be expended in their manufacture. The study also notes that, in lumber production, well over 90 percent of the global warming impact arises from the process of manufacturing (e.g., sawing, planing, kiln-drying, and packaging). Only a very small percentage of the impact arises from the energy expended in log processing and transport (i.e., forest operations).

7 Michael Milota and Maureen E. Puettmann, "Life-Cycle Assessment for the Cradle-to-Gate Production of Softwood Lumber in the Pacific Northwest and Southeast Regions," *Forest Products Journal* 67, no. 5/6 (2017).

THE MUSEUM IS MADE OF TIMBER AND SHAPED LIKE AN AIRCRAFT.
Source: StructureCraft; Credit: Shawn Talbot

CASE STUDY: KF AEROSPACE CENTRE FOR EXCELLENCE

TIMBER TAKES FLIGHT WITH KELOWNA AEROSPACE MUSEUM

PROJECT OWNER: KF AEROSPACE

PROJECT LOCATION: 5800 LAPOINTE DR KELOWNA, BC, CANADA V1X 7V5

COMPLETION DATE: AUGUST 31, 2022

ARCHITECT/DESIGNER: MEIKLEJOHN ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: STRUCTURECRAFT

GENERAL CONTRACTOR: SAWCHUK DEVELOPMENTS

STRUCTURAL ENGINEER: STRUCTURECRAFT

THE KF AEROSPACE Centre for Excellence, situated in Kelowna, British Columbia, embodies 5 decades of aerospace history. The aerospace-inspired design features a central 2-story "fuselage" hub flanked by 2 wing-shaped hangars that house historical planes.

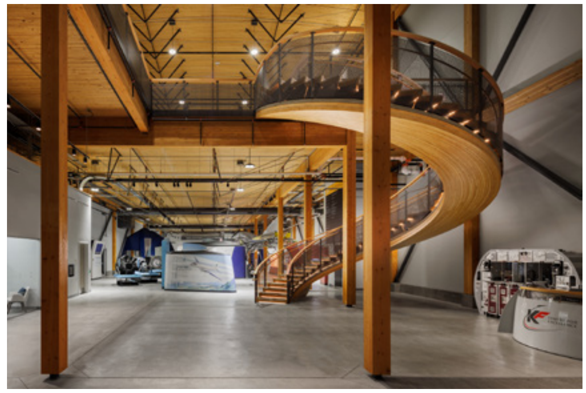
The facility serves as a space for meetings and receptions, and more significantly, as an aviation museum. At over 65,000 square feet, the complex offers visitors an immersive experience through interactive exhibits, the display of rare aircraft, and the chance to explore the history of flight locally and abroad.

Many unusual structural concepts are integrated throughout the space, including a Cross-Laminated Timber (CLT) spiral stairway, 115-foot clear-span folding glass hangar doors, and 90-foot wing-shaped timber and steel roof trusses.

The engineering team used cutting-edge structural analysis and modeling software, such as RFEM/

THE 65,000-SQUARE-FOOT MUSEUM HOUSES HISTORIC PLANES.

Source: StructureCraft; Credit: Shawn Talbot



THE FEATURE TIMBER STAIRWAY WINDS 70 FEET IN AN UNSUPPORTED SPIRAL.

Source: StructureCraft; Credit: Shawn Talbot

Karamba and Rhino/Grasshopper, to both conceptualize and iterate structural options for the hub and hangar.

One key design challenge was the two hangar spaces that flank the hub. The folding glass hangar doors had to create a clear span of 115 feet to allow aircraft such as the Convair CV-580 and the DC-10 to enter. The design approach drew inspiration from aircraft of the past, including the wings of the Spitfire.

The truss clear-spanning the hangar door was designated the “spar truss,” and the trusses spanning the hangar in the other direction were the 90-foot “rib trusses.” These set the shape of the aircraft “wings,” so the structural engineers referenced aeronautical engineering basics and the NACA airfoil equation to derive a parametric shape that could be passed into structural analysis software.

The solution was explored through both two-dimensional (2D) studies and three-dimensional (3D) parametric optimization studies of the individual wing profiles as well as the entire hangar roof structure, including the spar truss.

A feature of the KF Aerospace Centre is the spiral stairway at the entrance that rises 21 feet between the main and second floors through a 70-foot spiral. The engineers proposed a design concept that is believed to be the first of its kind: a freestanding spiral CLT stairway. This approach posed significant structural challenges; the spiral shape requires the CLT to bend and warp, and it creates forces in a combination of strong- and weak-axis bending as well as torsion.

A special application of a timber-concrete composite solved the challenges. The result was a stair made of doubly curved CLT with a concrete topping throughout the full spiral. The concrete provides the required mass to control vibrations in the 70-foot free span. And creating composite action between the concrete and the CLT increases the overall stiffness of the stairway, removing the need for any support columns.

The team brought diverse perspectives and expertise to the table, enriching the design process. All wood used in the center was sourced locally, resulting in a clean life-cycle story. The center is a nod to efficient timber design, craftsmanship, and the love of all machines that fly.

CHAPTER 4: MASS TIMBER MANUFACTURING

ROY ANDERSON
VICE PRESIDENT, THE BECK GROUP

This chapter focuses on manufacturing mass timber panels and glulam. Included is a review of the manufacturing processes for key mass timber products; a list of North American manufacturers and their production capacities, products, and services; and a discussion of strategic and technical mass timber manufacturing issues.

The past few years have been turbulent in the mass timber industry with COVID-related slowdowns in building projects during 2020 and 2021 and soaring lumber prices during 2021 and 2022. Several firms did not withstand the storm. Nevertheless, the industry continues moving forward. Mass timber manufacturers continue to refine their services, their supply chains, and the means of bringing products to market. Fabrication of panels and beams to their final dimensions, including cutouts for doors, windows, plumbing, electrical, and other features, continues to be a much-needed service area. It also continues to be cited as a bottleneck in the manufacturing process. Additionally, mass timber manufacturers continue to add staff with timber engineering/design expertise, establish partnerships up and down the supply chain, develop design guides, and create supporting businesses that better link the mass timber manufacturing and building construction communities.

4.1 MASS TIMBER PANEL TYPES

There are 2 basic types of mass timber panels: those for use in buildings and those for use as industrial matting. Each is described in more detail in the following sections.

4.1.1 BUILDING PANELS

Manufacturers have developed 2 common building panel grades based on appearance rather than strength: architectural grade, for use when a panel surface will be exposed to the building's occupants; and industrial grade, for use when a panel surface will not show. Either grade can be PRG 320[1] certified, if needed. Each manufacturer offers an array of finishes; in most cases, the finishes can be customized.

Architectural-grade panels are designed to ensure that the lumber is of the proper grade and species for visual exposure. The panels may require special sanding, epoxy finishes, stains, or coatings, and the filling of holes, gaps, or knotholes. In addition, lumber grain orientation may be varied. The panel's face layer typically does not include physical defects; to accomplish that objective, an appearance-grade layer of lumber (hardwood or softwood) may be laminated on. Each manufacturer offers its own set of architectural-grade finishes.

Industrial-grade panels are likely to have the same strength characteristics as comparable architectural-grade panels, but they may not meet the same aesthetic standards because the

1 *ANSI/APA PRG 320: Standard for Performance-Rated Cross-Laminated Timber*, https://www.apawood.org/ansi-apa-prg-320.

surface of the panel is usually covered when it's installed. Visual defects on the face layer of industrial-grade panels may include unfilled voids on the edge of laminations, loose knotholes on face layers, or wane (lumber pieces that are not fully square-edged on all 4 corners). Industrial-grade panels are typically less expensive than architectural-grade panels because the costs of materials, labor, and machining are lower.

In addition, the panel's application plays a significant role in its grade type. A floor may have architectural grade on the bottom side to serve as an exposed ceiling in the room below but industrial grade on the top side because a floor covering will be installed over the top side. Similarly, many exterior walls will be covered with a siding; therefore, the panel might have only one face that is architectural grade. Mass timber panels used in roofs and elevator shafts are typically industrial grade.

4.1.2 MATTING

Matting panels are intended not for use in buildings, but for protection of soils and sensitive areas. These mats typically are placed on the ground to form temporary roads to prevent environmental degradation caused by the heavy machinery used in mining, drilling, pipelines, utility right-of-way maintenance, and construction in remote areas. Traditionally, mats have been made of lower-value hardwood timbers nailed or bolted together. In recent years, CLT mats have become more common because they offer superior value. They are lighter and have longer useful life spans. CLT mats also may include built-in hardware—making them easier to lift and place using a forklift, excavator, or crane, and thereby reducing setup time.

4.2 MASS TIMBER PANEL MANUFACTURING PROCESS DESCRIPTIONS

Each of the following subsections describes the basic manufacturing steps for key mass timber panels.

4.2.1 CROSS-LAMINATED TIMBER

CLT is produced in a dedicated industrial-scale manufacturing facility. Although CLT is an innovative product, the major steps in its manufacturing process use well-established technologies borrowed from other segments of the wood products industry. Even though the technologies are well established, some processes (like lay-up and pressing) are performed on assemblies of unprecedented scales. Though many major variations are practiced, the basic manufacturing process typically includes the following:

Raw Material Receiving

Lumber is received into inventory at the mass timber manufacturing facility.

Raw Material Preparation

Lumber is sorted by grade, width, and species; and moisture content is checked to ensure that it is within specifications and that moisture variation among pieces is not too great. Pieces that are too wet are separated for additional drying. Excessive defects (e.g., knots, wane) on the lumber pieces designated for the CLT manufacturing process are removed using a crosscut/chop saw.

Finger Jointing

Once free of excessive defects, the pieces of lumber are glued together end to end, using a machine that cuts finger joints into the lumber ends and applies an adhesive to the joint to securely bond the pieces.

In processes that use different grades or thicknesses of materials for alternating layers, the material flow for the longitudinal and transverse layers has to be split. As a result, many plants have parallel finger jointing, crosscutting, and surfacing lines that join at the lay-up station.

Cutting to Length

The finger-jointing process creates a "continuous" piece of lumber that can be cut to any length called for by the dimensions of the mass timber panel. These lengths range from 4 feet to 12 feet for the panel's transverse axis and 20 feet to 60 feet for its longitudinal axis.

Surfacing

Surfacing, also known as planing, removes a small amount of material (typically about $^{1}/_{16}$ inch) from all 4 sides of the piece of lumber. This gives all pieces the same dimensions and activates their surfaces to ensure good absorption and bonding of the adhesive used to glue the panel layers together. In particular, the thickness has to be within a 0.2-millimeter tolerance of adjacent pieces to avoid bridging over thinner laminations in cross-laminated lay-ups. Such bridging would result in an inadequate pressure and poor bond integrity in that location.

Panel Lay-Up

The finger-jointed, surfaced, and cut-to-length lumber pieces are assembled into a panel one layer at a time. In a 3-layer panel, for example, all the long pieces that make up the longitudinal axis are assembled. Next, a glue spreader travels over them, applying a layer of glue to the wide surfaces. Note that, for some panels, glue is applied to the narrow surfaces of lumber as well. Then the short pieces are assembled into the layer making up the panel's transverse axis. Another layer of glue is applied. And finally, the long pieces making up the second major axis layer are assembled. In a global perspective, some manufacturers apply adhesive on the narrow edges of laminations as well and include pressure in 2 or 3 directions to produce effective edge-bonding. Many panels fabricated by a few major manufacturers in Europe begin the process with edge-bonding the layers before they are used to build lay-ups ready for face-bonding.

Pressing

After the adhesive has been applied and the lumber has been formed into a lay-up, it is pressed while the adhesive cures. Several variations in the adhesive and pressing technology affect the press time and the amount of energy consumed. Most of the processes use glue that does not require heat to cure, which makes the press times longer. Some processes use glue that needs heat to activate, which reduces press time. Heated presses use radio frequency waves to penetrate the panel and cure the glue. Since adding radio wave energy complicates the process, these types of presses typically cure the lay-up piecewise, one segment at a time.

Final Manufacturing

When the mass timber panels come out of the press, their edges are typically irregular and overrun by adhesive that has bled out between the layers. In addition, the "raw" panels are slightly oversized. All of this means the panel is cut to its final dimensions in a secondary process. Typically, the final manufacturing is accomplished with robotic Computer Numerical Control (CNC) machine centers. They can add the necessary connection nests on panel perimeters, and cut openings for windows and doors, as well as heating, ventilation, and air conditioning (HVAC), plumbing, and electric networks. Many CLT plants use a sander to surface the visible face of the panel if an architectural finish is required.

Packaging and Shipment

The final step involves placing pick points, metal hardware that allows cranes at the construction site to pick up a panel and place it in the building. For shipping, panels are organized into a sequence, so that, when they are delivered to the construction site, they can be moved directly into place rather than being unloaded and stored. That requires precise management and timing of the production and transportation sequences, and manufacturers often synchronize with the contractors or the assembly teams.

The equipment needed to complete the preceding tasks includes the following:

- **Moisture meter:** Tests the moisture content of each piece of lumber, ensuring that any lumber not meeting the target range (12 percent +/- 3 percentage points) is rejected.
- **Optical-grade scanner:** Photoelectric sensors, also known as "photo eyes," that identify any lumber with unacceptable defects (rot, splits, wane).
- **Stress grading machine:** A piece of high-throughput equipment, where resistance to the bending of pieces of lumber moving at high speeds is measured in flight to assign a machine stress rated (MSR) value. Note that it is not typical for lumber to be both optically graded and stress graded. The common practice is for each piece of lumber to be graded by one of the two methods.
- **Defect trim saw:** Cuts out the short, linear sections of lumber identified for removal by grade scanning.
- **Finger jointer:** Cuts finger joints in the ends of each piece of lumber, applies glue to each joint, and presses the pieces together, making one continuous piece.
- **Crosscut saw:** Cuts the finger-jointed lumber to lengths appropriate for the final size of the CLT panel. The only limits on the length of a CLT panel are size of the press and the highway/truck restrictions on the delivery of panels from the manufacturer to the building site.
- **Planer or molder line:** Removes a thin layer of wood from the surface of the lumber to ensure all pieces are of uniform thickness and to "activate" it so it can react to the glue. This step must be completed less than 48 hours before applying the glue.
- **Panel lay-up station:** Arranges pieces of lumber into layers in accordance with the CLT panel design. Glue is applied to each layer at this step. The level of automation varies greatly between operations.

- **Pressing**
  - Hydraulic press: Uses hydraulic pressure on the face and sides to hold a panel in place as the glue cures. Press time varies based on glue formulation and panel lay-up time.
  - Vacuum press: Uses a clamshell and silicone blanket to encapsulate a panel and then sucks out the air to tighten gaps between boards.
- **CNC finishing center:** Uses computer-controlled saws and router heads to precisely trim the edges of each panel and cut openings as needed for doors, windows, utility channels, etc.
- **Sanding machine:** Puts a smooth finish on the surface of the panel.
- **Overhead crane(s) and high-capacity conveyor system(s):** Handles integrated panels that can weigh up to 6 tons each.

4.2.2 DOWEL-LAMINATED TIMBER PANEL MANUFACTURING

Dowel-Laminated Timber (DLT) is produced in a dedicated manufacturing facility. As with CLT, incoming lumber is checked for grade and product consistency, and defective sections are removed. The lumber is then finger jointed, cut to the desired lengths, and molded/planed to the desired thicknesses. The cut-to-length boards are assembled into a panel, holes are drilled along the edges, and dowels are pressed into the holes. The entire panel is surfaced to ensure the dowels do not protrude. In the final steps, panels are finished on a CNC machine, packaged, and shipped. Unlike CLT, all the lumber in a DLT panel is oriented in the same direction. This orientation means DLT panels do not have the same shear strength properties as those derived from cross-lamination.

4.2.3 NAIL-LAMINATED TIMBER PANEL MANUFACTURING

Unlike CLT and DLT, Nail-Laminated Timber (NLT) can be manufactured either at a building site or at an industrial-scale production facility. The layout of an NLT panel is similar to a DLT panel, with all the lumber oriented in the same direction. The lumber is stacked on its side with randomly staggered joints, or it can be finger jointed to create continuous layers over 20 feet long. The boards are then nailed together in various lay-up configurations to create panels.

Industrial-scale makers of NLT employ jigs to guide the lumber through the saw blades and maintain panel dimensions and straightness. The jigs can be made from pony walls, back and end stops, and fences. Boards are joined using a pneumatic-powered nailer, and the process is repeated until the panel is complete. Like CLT, the panel is then cut to length and fabricated to match shop drawings. Nail placement is crucial, as nails will negatively impact cutting tools, such as saws and drills.

4.2.4 MASS PLYWOOD PANELS MANUFACTURING

Mass Plywood Panels (MPP), a recent addition to the list of mass timber products, are a veneer-based engineered wood product. The first step in manufacturing MPP is to produce appropriately sized and graded veneer of an appropriate species. Freres Lumber Co. Inc. produces its own veneer for use in MPP and is considered the only MPP manufacturer in the world. Note that in fall 2022 Boise Cascade introduced a veneer-based panel to the market; however, it is categorized as CLT. The MPP is created in a 2-stage process. First, billets of Structural Composite Lumber (SCL), each 1 inch thick by 4 feet wide and up to 48 feet long, are created from multiple plies of veneer. The number of plies, their grain orientation, and the grades of veneer used to create the billets vary depending on the desired strength. In the second stage, the SCL billets are assembled into larger and thicker MPPs, with dimensions and strength engineered to meet the requirements of a given project.

Scarf joints (i.e., joints connecting 2 billets in which the ends are beveled so that they fit over each other while maintaining a flat surface across the billets) are used to join the SCL billets, irrespective of the size of the MPP. These joints are staggered throughout the panel, so they do not create weak points. A 6-inch-thick MPP, for example, is made up of six 1-inch billets, each made of 9 plies of veneer. Thus, the total panel is made of 54 veneer plies. Throughout the manufacturing process, the entire MPP and each 1-inch SCL billet are engineered to specific strengths. In principle, different adhesives may be used to bond veneer plies in the SCL billets and to bond SCL billets in one MPP panel.

4.2.5 SOLID WOOD WALL (MHM)

Massiv-Holz-Mauer (MHM), translated literally as "mass wood wall," is a massive, prefabricated cross-laminated panel with layers made of rough-sawn boards bonded with nails. This product should not be confused with NLT, described above. MHM is fabricated on small-scale, turnkey 3-step Hundegger production lines. The lines consist of specialized molders to produce longitudinal grooves on one side of the laminations, an automated lay-up and nailing station, and a CNC finishing center. Relatively short, fluted aluminum nails that penetrate 3 layers do not interfere with cutting tools. Panels may consist of 9, 11, 13, or 15 layers (each about 16.5 millimeters or $^{10}/_{16}$ inch). Typically, a thick bitumen paper layer would be integrated in the lay-up to provide airtightness.

4.2.6 DOWEL-BONDED CLT

Dowel-bonded CLT is a massive, prefabricated cross-laminated panel with layers of rough-sawn boards bonded with hardwood dowels. It should not be confused with DLT, described above. The panels are assembled in highly automated lines. The dowels are arranged in a carefully designed pattern and inserted in the lay-up by CNC equipment. Low moisture content and tight fitting of the dowels at the time of assembly ensure a durable, tight connection when the dowels swell as they gain moisture in ambient conditions. Only 2 commercially successful systems are known to date: (1) one developed by the Thoma Holz company in Austria; and (2) one developed by Swiss industrial hardware manufacturer TechnoWood AG. By mid-2019, TechnoWood had installed 8 highly automated lines in Europe. Unlike other CLT products, some layers of the dowel-bonded CLT are arranged at 45 or 60 degrees to the surface layer direction. The lay-ups may also include a thick bitumen paper layer integrated between the layers of lumber to provide airtightness.

4.3 NORTH AMERICAN MASS TIMBER PLANTS

This section provides an assessment of mass timber manufacturing capacity. Manufacturer information was collected through personal com-

EDMONTON'S NEW RECREATION CENTER WILL FEATURE 60,000 SQUARE FEET OF MPP.

Source: Clark Builders

CASE STUDY: CORONATION PARK SPORTS AND RECREATION CENTRE

EDMONTON'S NEW SPORTS AND RECREATION CENTER SHOWCASES MASS PLY

PROJECT OWNER: CITY OF EDMONTON

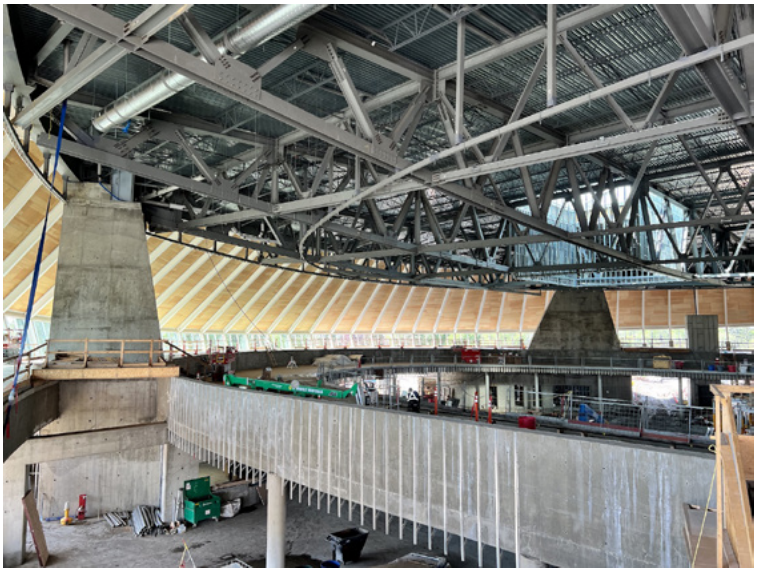
PROJECT LOCATION: 13808 111 AVE NW
EDMONTON, AB, CANADA T5M 2P2

COMPLETION DATE: JANUARY 1, 2026

ARCHITECT/DESIGNER: FAULKNERBRWNS (DUB ARCHITECTS),
HUGHES CONDON MARLER (ARCHITECTS)

MASS TIMBER ENGINEER/MANUFACTURER:
CUTMYTIMBER, METSÄ

GENERAL CONTRACTOR: CLARK BUILDERS



INSIDE CORONATION CENTRE

Source: Clark Builders

A MASSIVE STATE-OF-THE-ART sports facility in Edmonton, Alberta, will showcase 60,000 square feet of exposed Mass Plywood Panels (MPP) in its roof and walls, forming the largest installation of MPP in Canada to date.

The panels shipped for the Coronation Park Sports and Recreation Centre measure 4 feet wide by 43 feet long with a thickness of 2 inches. Freres Engineered Wood and another mass timber fabricator, CutMyTimber, equipped this facility and paved the way for the use of more sustainable mass timber products in Canada.

The facility will serve as a recreation hub for the community, and it will create opportunities for year-round triathlon and cycling training and events. Design plans include a fitness center, walking/jogging track, gymnasiums, multipurpose rooms, and more.

In addition, the facility will feature the third Union Cycliste Internationale (UCI)-sanctioned indoor cycling track, also known as a velodrome, in all of North America. With seating capacity for 750 spectators, the new velodrome will provide ample space to host international cycling competitions as well as serve as a high-performance training resource. The Argyll Velodrome Association and World Triathlon Edmonton partnered to help design and fund this new track.

The award-winning Peter Hemingway Fitness and Leisure Centre—an aquatic center undergoing rehabilitation—will be connected to Coronation Park, and it's set to reopen when the latter is complete.

The project was officially approved in 2021 after a decade of planning. Construction started in the spring of 2022, and crews installed the first MPP in early 2023. The anticipated completion date for this project is 2026.

COMPANY	LOCATION	STATUS	ESTIMATED THEORETICAL MAXIMUM PRODUCTION CAPACITY OF OPERATING PLANTS (M³/YEAR)	ESTIMATED EFFECTIVE PRODUCTION CAPACITY OF OPERATING PLANTS (M³/YEAR)
Boise Cascade	White City, OR	Operating		
Element5 #1	Ripon, QC, Canada	Operating		
Element5 #2	St. Thomas, ON, CA	Operating		
Freres	Lyons, OR, US	Operating		
Kalesnikoff	South Slocan, BC, CA	Operating		
Mercer International	Spokane, WA, US	Operating		
Nordic Structures	Chibougamau, QC, CA	Operating		
SmartLam North America	Dothan, AL, US	Operating		
SmartLam North America	Columbia Falls, MT, US	Operating		
Sterling Lumber	Lufkin, TX, US	Operating		
Sterling Lumber	Phoenix, IL, US	Operating		
StructureCraft	Abbotsford, BC, CA	Operating		
Mercer International	Okanagan Falls, BC, CA	Operating		
Mercer International	Conway, GA, US	Operating		
Texas CLT	Magnolia, AR, US	Operating		
Vaagen Timbers	Colville, WA, US	Operating		
Euclid	Heber City, UT, US	Small Scale - Operating		
International Timberframes	Golden, BC, CA	Small Scale - Operating		
Timber Age Systems	Durango, CO, US	Small Scale - Operating		
Total			**1,767,500**	**1,152,000**
binderholz	Live Oak, FL, US	Potential Plant Site	n/a	n/a
binderholz	Enfield, NC, US	Potential Plant Site	n/a	n/a
Stoltze Mass Timber	Columbia Falls, MT, US	Planned	n/a	n/a
Confidential	Confidential	Planned	n/a	n/a
Confidential	Confidential	Planned	n/a	n/a

TABLE 4.1: CURRENTLY OPERATING NORTH AMERICAN MASS TIMBER PRODUCTION PLANTS

OPERATING	UNDER CONSTRUCTION	PLANNED	CANCELED/UNCERTAIN	TOTAL
19	0	3	**2**	**24**

TABLE 4.2: NUMBER OF OPERATING FACILITIES IN NORTH AMERICA

munication with manufacturers, publicly available research, information compiled by industry experts, and company profiles from websites and other published information sources. Please note that the status of manufacturing operations is constantly changing, with shifting operating schedules, some plants reaching completion, and other plants getting underway. The information that follows was current as of December 2023.

4.3.1 NORTH AMERICAN MASS TIMBER PLANTS' CAPACITIES AND OPERATIONAL STATUSES

Table 4.1 shows that the estimated theoretical maximum production capacity of the North American mass timber manufacturing facilities as of late 2023 is 1.77 million cubic meters per year (62.4 million cubic feet per year). Importantly, theoretical capacity is a calculation of a plant's capacity assuming that the available space in each company's press is completely filled during every press cycle and that the plant operates on a 2-shift basis 250 days per year.

The table also shows that after accounting for the average difference in press size and the size of panels called for by customer orders, the estimated effective press capacity is 1.15 million cubic meters per year (40.7 million cubic feet per year). As an example of the capacity reduction that occurs because of the difference in press size and actual order size, consider that a number of CLT manufacturers have presses that are about 60 feet long by 10 feet wide by 1 foot thick. Next, assume a large project calls for panels that are 5.5 inches thick by 8 feet wide by 40 feet long. In such a scenario, 33 percent of the press's full capacity is not used because the panel length doesn't match the press length. In other words, the last 20 feet of the press is not filled. The same is true for panel width. In this scenario only 8 feet of the 10-foot press width is used. And finally, if the press has a total depth of 1 foot, but the panels are 5.5 inches thick, then 2 layers of panels fit in the press, which in turn, means that only $^{11}/_{12}$ of the press's depth is utilized. Based on the experience reported by a number of CLT and glulam manufacturers, it is estimated that, on average, only about 65 percent of a press's full capacity is utilized. Therefore, the difference in theoretical maximum capacity and effective capacity shown in **Table 4.1** is the application of the 65 percent capacity factor.[2]

At the time of this writing (late 2023), there has been no increase in press capacity since the same time last year. However, report authors are aware of at least two CLT/glulam projects that are well-advanced in terms of planning and are likely to be constructed. If completed, those projects are estimated to add another 150,000 to 200,000 cubic meters of theoretical maximum capacity to the North American total.

2 Note the Estimated Effective Production Capacity may very slightly differ from 65% because of rounding the capacities for the individual plants.

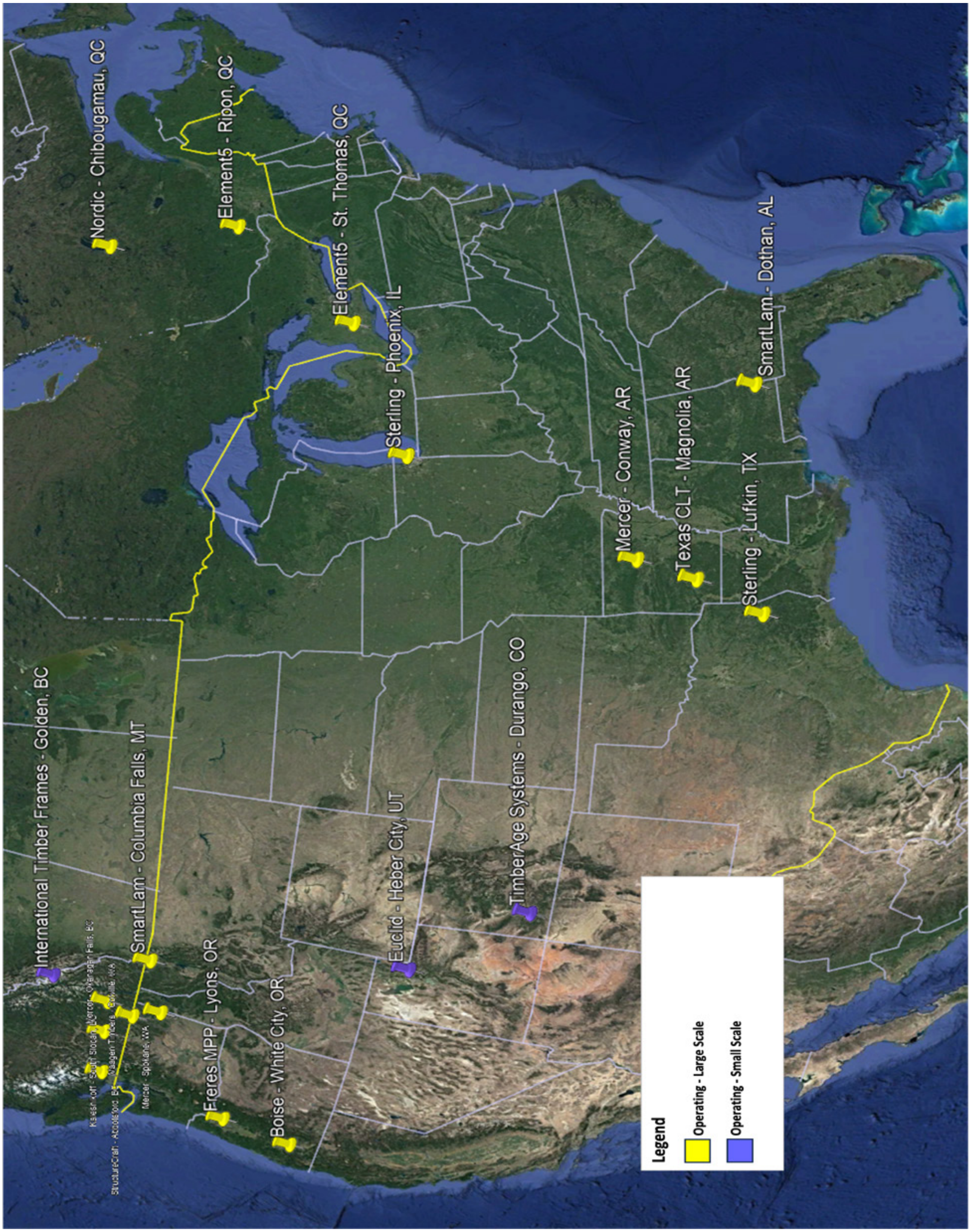


FIGURE 4.1: LOCATION OF NORTH AMERICAN MASS TIMBER MANUFACTURING FACILITIES

Source: The Beck Group

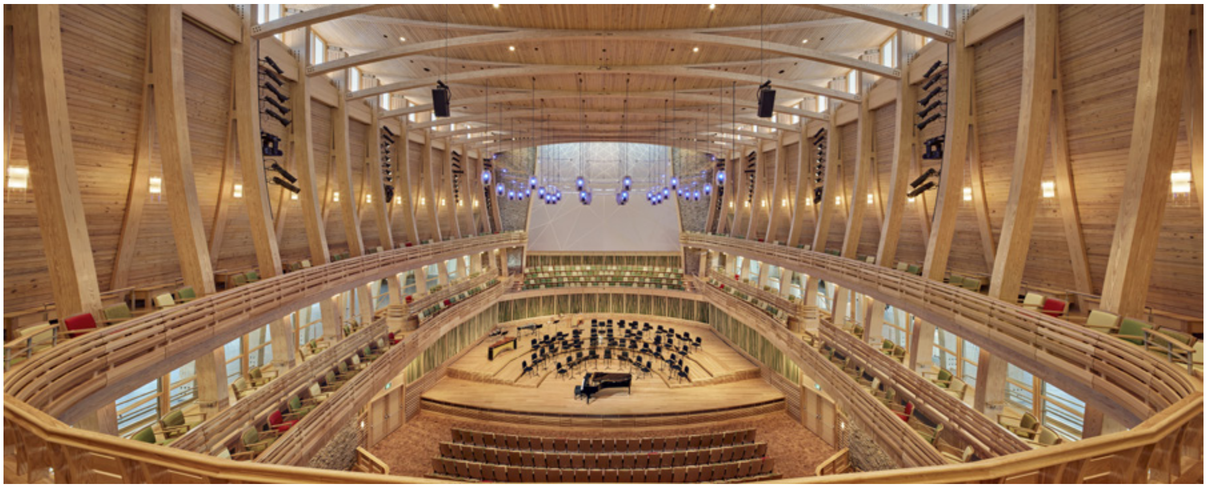
As shown in **Table 4.2**, at the time of this writing (late 2023), there are 19 operating facilities in North America. This is the same number of operating facilities as the prior year. However, different from the prior year is that there are now 14 companies operating the plants instead of 15. During the past year, Mercer International acquired Structurlam's operations in British Columbia and Georgia. The table also shows no plants are currently under construction; 3 plants are in planning stages (including the 2 mentioned in the preceding paragraph), and the 2 plants at sites owned by binderholz are categorized as canceled/uncertain. It is also worth noting that Sterling Structural, the largest mass timber manufacturer in the world, obtained PRG 320 certification in 2022 and announced plans to begin producing panels for use in buildings. The company has followed through on those plans, announcing in October 2023 that it will be providing about 37,000 square feet of floor panels and 18,000 square feet of roof panels to an affordable housing project in Springdale, Arkansas.

Figure 4.1 shows the locations of North American mass timber plants. Note the cluster of plants in the mountainous region of the Inland US West and Interior British Columbia. That location is advantageous from a raw material supply perspective because a diversity of available species is growing in the region, including Douglas-fir, Western larch, hemlock, spruce, and various true firs. Other manufacturers are on the US West Coast, where Douglas-fir dominates; scattered in Eastern Canada, where the available species are spruce, pine, and fir; and in the US South, where the available species is Southern Yellow Pine (SYP), which is a mix of longleaf, loblolly, slash, and shortleaf pines. There is still no mass timber manufacturing facility in California, despite its large timber resource and its significant sawmilling industry. It is also one the largest building construction markets in North America. Finally, note that 3 small-scale mass timber manufacturers are included (designated by the purple pins), but their production volumes are very small.

4.3.2 NORTH AMERICAN GLULAM PLANTS' CAPACITY AND OPERATIONAL STATUSES

While many timber manufacturers can also produce glulam, there are numerous glulam-only manufacturers in North America. The glulam-only manufacturers and their locations are shown in **Figure 4.2**.

There are several things to note about the North American glulam manufacturers. First, since 2017, their aggregated annual output has averaged about 300 million board feet (MMBF) per year, but output dropped slightly in 2023. As a point of reference, a single large softwood sawmill in North America typically produces about 300 MMBF of lumber per year. Thus, the current output of the whole glulam industry is equivalent to the output of a single large sawmill. Just before the Great Recession, North American glulam production reached nearly 500 MMBF per year. In addition, a significant portion of the annual glulam output is dominated by 2 companies that specialize in making stock beams (i.e., standardized sizes, lengths, etc.). These are Rosboro, which operates 2 plants in Oregon in the Western US; and Anthony Forest Products (owned by Canfor), which operates 2 plants in the US South (one in Arkansas and another in Georgia). Each company operates under a vertically integrated model, meaning that company-owned sawmills produce lamstock, the lumber raw material used in glulam manufacturing, for the laminating plants. In contrast, the



CAPTURING THE ESSENCE OF THE CONCERT HALL: 'TUNING FORK' COLUMNS HARMONIZING WITH HYBRID TRUSSES AND A CONVEX TIMBER DECKING CEILING DESIGN

Source: Architect: Epstein Joslin + Picardy Architects, Inc.
Credit: Photo courtesy of Robert Benson Photography

CASE STUDY: GROTON HILL MUSIC CENTER

A STRUCTURE THAT RESONATES: GROTON'S INNOVATIVE MASS TIMBER CONCERT HALL

PROJECT OWNER: GROTON HILL MUSIC CENTER

PROJECT LOCATION: 122 OLD AYER RD, GROTON, MA, 01450

COMPLETION DATE: DECEMBER 3, 2022

ARCHITECT/DESIGNER: EPSTEIN JOSLIN + PICARDY ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: UNALAM

GENERAL CONTRACTOR: GOGUEN CONSTRUCTION

STRUCTURAL ENGINEER: ODEH ENGINEERS

MECHANICAL, ELECTRICAL, AND PLUMBING: BR+A CONSULTING ENGINEERS

OTHER CONTRACTORS: THRESHOLD ACOUSTICS WITH LKACOUSTICS DESIGN STUDIO IN CONCEPT DESIGN (ACOUSTIC/AV CONSULTANT), THEATRE CONSULTANTS COLLABORATIVE (THEATER CONSULTANT)

GROTON HILL MUSIC Center in eastern Massachusetts seamlessly integrates structural engineering and mass timber elements in a 126,000-square-foot music education and performance facility. The not-for-profit organization was founded in 1985 to create a world-class venue that blends acoustics, structure, and aesthetics in a rural setting.

From the early design stages on, the project's distinctive feature is its commitment to exposed mass timber. Unlike conventional structures that isolate the performance space from the acoustic, Groton Hill Music Center aims to let concertgoers "listen to the structure." The architect's vision, expressed in early concept design sketches, sought to use mass timber to unite acoustics, structure, and finishes, creating a building that resonates with its surroundings.

EIGHT STRUCTURAL 'BRANCHES' SPRING FROM THE LOBBY TO SUPPORT THE ORCHARD ROOF ABOVE.

Source: Architect: Epstein Joslin + Picardy Architects, Inc.
Credit: Photo courtesy of Robert Benson Photography

Inspired by the local landscape, Epstein Joslin + Picardy Architects envisioned abstract timber frames resembling barns and orchards. Mass timber, chosen for its warmth, ambiance, and sustainability, became the focal point. Collaborating with structural engineers, acoustic consultants, timber fabricators, and builders, the team engineered abstract forms to meet acoustic, aesthetic, and functional goals.

The superstructure, a hybrid of curved and straight lines supported by steel and glulam framing, includes repeatable elements like "tree" and "tuning fork" columns. Southern Yellow Pine (SYP), selected for its structural and aesthetic qualities, was used in collaboration with fabricator Unalam. Odeh Engineers played a crucial role in designing the entire superstructure, including the connections detailed to meet architectural and acoustic requirements.

To ensure lateral stability, cast-in-place concrete shear walls and reinforced shotcrete shear walls were employed, serving as integral components of the acoustic strategy. The use of mass timber challenged conventional approaches, offering a modern solution that balances amplified and orchestral sound while taking into account embodied carbon concerns.

The acoustical analysis involved large- and small-scale studies using ODEON software for room shaping and MATLAB for diffusion evaluations. Departing from the traditional rectangular concert hall shape, the design embraces curvature, creating an intimate environment. The team navigated acoustical challenges, using the curvature to avoid the pitfalls of acoustic focusing.

Despite a reduction in mass compared to traditional concert halls, the structural design compensated through the laminated curved columns' inherent stiffness and the strategic use of shotcrete. The result is a set of acoustically versatile rooms that cater to various musical genres.

Groton Hill Music Center's success is evident in the positive responses from audiences and performers. The impact extends beyond architectural prowess to thriving music school enrollments and full houses.

In the serene Nashoba Valley countryside, Groton Hill Music Center stands as a testament to mass timber's viability in performance spaces. It showcases explorations in material efficiency and alternative forms. It is also a wooden symphony, both seen and heard, enfolding audiences in a structural masterpiece at the intersection of engineering, aesthetics, and acoustics.

FIGURE 4.2: LOCATION OF NORTH AMERICAN GLULAM MANUFACTURING PLANTS

Source: The Beck Group

balance of the glulam manufacturers tend to be smaller operations that specialize in manufacturing custom-made glulam beams. These operations typically purchase their lamstock on the open market from various sawmill producers. **Table 4.3** provides a list of the North American glulam manufacturers, the locations of their plants, the lumber species they commonly use, and, if available, information about the sizes (lengths, widths, depths) of beams they can produce.

4.4 MASS TIMBER MANUFACTURERS: COMPANY AND FACILITY DETAILS

The companies entering the mass timber market have diverse experience levels and strategic orientations. In North America, some firms are vertically integrated on the supply side, with sawmills and/or glulam manufacturing plants located near their panel manufacturing operations. Others are vertically integrated on the building and development end of the supply chain. Still others are stand-alone businesses. **Table 4.4** captures some of the diversity among current manufacturers by illustrating the products they offer, species used, panel sizes, brand names, and so on.

4.5 NORTH AMERICAN MASS TIMBER MANUFACTURER SERVICES

Mass timber is distinct from other wood building materials because its manufacturers tend to work closely with architects and engineers during building design regarding product specifications such as size, thickness, strength, and appearance. An important, but frequently overlooked, section of the mass timber supply chain is the additional support services that mass timber manufacturers can provide their customers. The following list describes a number of these services. Note, however, that this is a rapidly evolving portion of the supply chain, as companies that provide these support services are emerging.

4.5.1 ARCHITECTURAL DESIGN AND PROJECT SUPPORT

Design assist: Mass timber manufacturers assist architects with their design, including how best to incorporate mass timber into their building.

Engineering services: Many manufacturers employ engineers who help building designers review structural, mechanical, electrical, seismic, acoustic, fire, and other aspects of a building as they relate to the properties of mass timber products.

Modeling work: Most manufacturers assist in an array of construction documentation. Computer-aided design (CAD) services (e.g., Building Information Modeling [BIM], SolidWorks, CATIA, cadwork, AutoCAD) have played a significant role in panelizing projects and identifying building assemblies. Using these tools, manufacturers can import engineering documentation into CAD programs and develop robust three-dimensional (3D) models of the project, making mass timber part of the building's structure.

4.5.2 MANUFACTURING AND MATERIAL SUPPLY

Panel manufacturing: The manufacture of various panels at a production facility includes finger jointing lumber into mass timber panel layers (i.e., lamellas); molding/planing or surfacing the lumber; and pressing panels to the desired thicknesses, widths, and lengths.

COMPANY	CITY	STATE	SPECIES	LENGTH (FEET)	THICKNESS AND WIDTH (INCHES)
Alamco Wood Products LLC	Albert Lea	MN	SYP, DF, AC, POC	up to 110'	
Anthony Forest Products Company - Eldorado Laminating	El Dorado	AR	SYP	8' to 60'	3.125" to 5.5" wide and 11.25" to 28.875" deep
Anthony Forest Products Company - Washington Laminating	Washington	GA	SYP	8' to 60'	3.125" to 5.5" wide and 7.25" to 28.875" deep
Arizona Structural Laminators	Eagar	AZ	DF, SYP		
Art Massif Structure De Bois Inc.	Saint-Jean-Port-Joli	QC	SPF		
Boise Cascade	Homedale	ID	DF/L, AC,	Up to 60'	3.125" to 14.25" wide and 6" to 48" deep
Boozer Laminated Beam Co. Inc.	Anniston	AL	SYP	6' to 54'	3.125" to 28.875" wide and 8.75" to 28.875" deep
Diversified Wood Resources (dba American Duco Lam)	Drain	OR	DF, SYP, AC, POC	Up to 130'	up to 16.25" wide and 72" deep
Diversified Wood Resources (dba American Laminators)	Swiss Home	OR	AC, WRC, DF, HF, POC	Up to 130'	up to 18.25" wide and up to 72" deep
Enwood Structures	Morrisville	NC			
Fraser Wood Industries, Ltd.	Squamish	BC	DF, AYC, POC, SPF	Up to 60'	up to 10.75" wide and 73.5" deep
Goodlam, Division of Goodfellow Inc.	Delson	QC	DF, SYP, SPF		
Gruen-Wald Engineered Laminates, Inc.	Tea	SD	SYP, SPF		
Harrison Industries (Structural Wood Systems)	Greenville	AL	SYP	8' to 20'	
Mississippi Laminators	Shubata	MS	SYP	up to 52'	4.0" to 8.0" wide and up to 39" deep
QB Corporation	Salmon	ID	DF, SYP, WRC, AC	up to 130'	up to 20" wide and 108" deep
Riddle Laminators (dba DR Johnson Wood Innovations)	Riddle	OR	DF, AC, POC, SYP	up to 135'	up to 24" wide and 60" deep
Rigidply Rafters	Richland	PA	SYP, DF, AC, POC		
Rigidply Rafters	Oakland	MD	SYP, DF, AC, POC		
Rosboro	Springfield	OR	DF	up to 72'	3.25" wide by 4" deep to 8.75" wide by 40" deep
Rosboro	Veneta	OR	DF	up to 100'	3.125" to 6" wide and 8" to 18" deep
Shelton Lam and Deck	Chehalis	WA	DF		
Stark Truss Company, Inc.	Canton	OH	SYP, SPF		
Starwood Rafters	Independence	WI	DF	6' to 56'	
Timber Technologies Inc.	Colfax	WI	DF, SPF, SYP	8' to 62'	
Unadilla Laminated Products (Unalam)	Unadilla	NY			
Western Archrib	Edmonton	AB	DF, SPF, AC	up to 150'	3.125" to 25.25" wide and 4.5" to 84" deep
Western Archrib	Bossevain	MB			
WFP Engineered Products	Vancouver	WA	DF, SYP, AC, POC	up to 90'	up to 16" wide and 72" deep
WFP Engineered Products	Washougal	WA	DF, SYP	up to 95'	Up to 16" wide and 48" deep
Zip-O-Laminators	Eugene	OR	DF, AC	8' to 115'	up to 16" wide and 60" deep

DF = DOUGLAS-FIR
SYP = SOUTHERN YELLOW PINE
AC = ALASKA YELLOW CEDAR
POC = PORT ORFORD CEDAR
DF/L = DOUGLAS-FIR/LARCH
WRC = WESTERN RED CEDAR
HF = HEM-FIR
SPF = SPRUCE, PINE, & FIR

TABLE 4.3: CURRENTLY OPERATING NORTH AMERICAN GLULAM MANUFACTURERS

COMPANY	WEBSITE	PANEL BRAND NAME	DESIGN GUIDE	PRODUCTS	SPECIES	PANEL TYPES	STRESS GRADE	PANEL THICKNESS	MAX WIDTH	MAX LENGTH	ENVIRONMENTAL CERTIFICATION
Element5 #1	https://elementfive.co/	E5 CLT & E5 Nano CLT	Yes	CLT, GLT, BOXX Panels	SPF	A, I	V2, E1	up to 15"	11.15	52.5'	FSC
Freres	https://frereslumber.com/	MPP	Yes	Mass Ply Panel, Mass Ply Lam, Mass Ply Industrial & Plywood	DF	A, I, M	F16 and F10	1" increments between 2" and 12"	11.83'	48'	American Tree Farm System
Kalesnikoff	https://www.kalesnikoff.com/	Kalesnikoff CLT	Yes	CLT, Glulam, GLT Panels, Japan Zairai, Lumber	SPF, DF-L, Hemlock	A, I, M	V2, V2MG, V2.2, V2.4, E1, E1M8, E1M9, E1.3, E1.1, E1.2	3 to 11 ply (2.00" to 15.15")	11.48'	60'	Publicly available forest stewardship plan
Nordic Structures	https://www.nordic.ca/fr/accueil	X-Lam	Yes	CLT, Glulam, GLT Panels, I-Joists	SPF (90% black spruce)	A, I	E1	3, 5, 7, or 9 ply (3.5" up to 10.5")	8.85'	64'	FSC
Smartlam North America	https://www.smartlam.com/	SmartShaft	Yes	CLT, Glulam	DF-L, SPF, Hem-Fir, SYP	A, I, M	V2 (SPF), V3 (SYP), V4 (SPF-S), V5 (HF), E4 (SYP), E21 (SPF-S)	3, 4, 5, 7, or 9 (4.13", 5.50", 6.88", 9.63", and 12.38")	*10', 11.5'	*51', 51.4'	FSC, SFI
Sterling Solutions	https://www.sterlingsolutions.com/	Terralam	Yes	CLT	SYP, SPF-S, EH-T	M	V3+	3, 5, or 7 ply (4.13" TO 9.57")	8'	18'	SFI Chain of Custody
Structurecraft	https://structurecraft.com/	DowelLam - DLT	Yes	DLT	SPF, DF, Hemlock, Sitka Spruce, Western Red Cedar, Yellow Cedar	A, I		4" up to 12.25"	12'	60.5'	FSC, PEFC
Mercer	https://www.mercermasstimber.com/	Mercer CLT	Yes	CLT, Glulam	SPF, DF-L, SYP	A, I, M	1.4V, 1.8M, 2.2M, E4M1, E4M2, E4M3, E4M3.1, V3, V3.1, V3M1	3, 5, 7, and 9 ply (3.00" to 12.38")	12'	60'	FSC and PEFC
Texas CLT	http://texasclt.com/	Unknown	Unknown	CLT	SYP	A, I, M	Unknown	Unknown	Unknown	Unknown	Unknown
Vaagen Timbers	https://vaagentimbers.com/	Vaagen CLT	Yes	CLT, Glulam	SPF, DF-L	A, I	V1M3, V2M8, V3M8, V5M3(N), E2M5	4.13" to 9.63"	4'	60'	FSC

TABLE 4.4: SUMMARY OF NORTH AMERICAN MASS TIMBER MANUFACTURERS' PRODUCT INFORMATION

**The Columbia Falls, MT, plant produces CLT panels with max dimensions 10' wide and 51' long. The Dothan, AL, plant produces CLT panel with max dimensions 11.5' wide and 51.4' long.*

Panel milling and finishing: This process includes additional manufacturing or CNC milling of panels to shop-specific drawings, and any architectural- or industrial-grade sanding, coating, and visual finishes. Many manufacturers list architectural and industrial finishes and can accommodate special requests for exposed elements. Some independently owned companies unrelated to mass timber manufacturers offer secondary manufacturing (CNC milling, finishing) of panels, glulam, and timbers.

Supplying connectors/hardware/fasteners: If manufacturers do not produce their own connectors and the other hardware required in mass timber buildings, they may source them elsewhere. Most manufacturing firms will provide this service.

4.5.3 CONSTRUCTION AND INSTALLATION SUPPORT

Logistics planning: Several manufacturers offer services that help with construction logistics, including just-in-time delivery of construction panels and sequencing of panel installation.

On-site: Speed and ease of installation are hallmarks of mass timber panels and key reasons for the industry's success. Because mass timber panel installation and construction are new to many building contractors, several manufacturers with construction experience provide on-site support.

4.5.4 OTHER MISCELLANEOUS SERVICES

Consulting services: Many mass timber manufacturers offer consulting services on an hourly basis. If the project requires more support to assess the practicality of mass timber elements, these companies can provide consultants during the design phase.

Steel fabrication: A variety of steel applications may be used in the construction of mass timber buildings. Some mass timber manufacturers offer in-house steel fabrication.

Renovation services and/or interior design options: Some building designs call for a complete package that includes kitchen, baths, appliances, and design elements. Some manufacturers offer such packages.

Environmental protection services: These focus on consultation and industrial matting, using CLT to protect specific areas from soil compaction and the impacts of heavy machinery.

Other: Most manufacturers offer shipping as a part of the package, as well as identifying any special requirements. Note also, that the model adopted by pioneering North American mass timber manufacturers has been to offer a one-stop, turnkey solution for their clients where the manufacturer offers most of the preceding services. However, this has been changing as specialized companies are emerging to provide the services. Thus, these specialized companies act as middlemen among mass timber manufacturers, architects/designers, construction firms, and developers.

Global perspective: In addition to the above services, the industry segment producing structural mass timber panels may also offer general project management and assembly/construction services as part of an integrated package that results in a complete building shell. Some companies may offer packages approaching complete turnkey services for the smaller, more typical projects with which they gained experience. Assistance in all these functions may also be offered to clients who select external designers.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ONE HUNDRED-FOOT OPEN SPAN GLULAM TRUSS SYSTEM.

Source: Vaagen Timbers; Credit: Vaagen Media

CASE STUDY: WAREHOUSE B10

JANICKI'S NEW MASS TIMBER INDUSTRIAL BUILDING LARGEST IN US

PROJECT OWNER: JANICKI INDUSTRIES

PROJECT LOCATION: 34240 STATE ROUTE 20 HAMILTON, WA 98255

COMPLETION DATE: JULY 5, 2023

ARCHITECT/DESIGNER: CARLETTI ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: VAAGEN TIMBERS

GENERAL CONTRACTOR: CHAD FISHER CONSTRUCTION

STRUCTURAL ENGINEER: DCG/WATERSHED

JANICKI INDUSTRIES' BUILDING 10 in Hamilton, Washington, showcases innovation in aerospace manufacturing and assembly. Within its 188,000 square feet of mass timber construction, the facility supports the use of sustainable materials for large-scale industrial buildings. As the largest industrial mass timber building in the United States, Janicki's Building 10 represents a milestone in the construction industry.

TWO-STORY COMPLETE MASS TIMBER OFFICE SPACE.
Source: Vaagen Timbers; Credit: Vaagen Media

THIRTY-TWO-FOOT BAY DOOR OPENINGS.
Source: Vaagen Timbers; Credit: Vaagen Media

DCG/Watershed was the structural engineer for the project and designed all structural aspects with value engineering based on speed and ease of construction. The innovations included eliminating rebar in the industrial slabs; and integrating concrete tilt walls, wood shear walls, and Cross-Laminated Timber (CLT) shear walls for the lateral system. The design and construction schedules for the project were compressed. Schematic design and programing started in February 2022, and the facility was occupied by July 2023, just 17 months later.

Key communication among the team was instrumental. Weekly team meetings between the client and contractor, Chad Fisher Construction, and weekly coordination with mass timber supplier Vaagen Timbers addressed conflicts early on, minimizing construction delays and bringing about well-coordinated construction sequencing.

In addition to its striking architectural design, Janicki's Building 10 is noteworthy in other aspects. The project adhered to a strict schedule and saved at least 9 months of time in design and construction by using mass timber as a sustainable material. A total of 285 acres of overstocked, fire-prone Washington forest was thinned to support the Building 10 project, playing a vital role in reducing the risk of catastrophic wildfires by fostering a biodiverse forest ecosystem. The forestlands involved went from a class 3 fire danger to a class 1, enhancing safety and sustainability.

Janicki's Building 10 showcases the durability, sustainability, and aesthetic appeal of mass timber. By employing this innovative material, Janicki not only spearheaded advancements in the construction industry but also contribute to preserving the environment and mitigating the risks of wildfires. This building technique holds immense promise for the future of sustainable infrastructure. Janicki, an engineering and manufacturing company, caters to a number of industries, including aerospace, defense, marine, and architecture.

CHAPTER 5: DESIGNERS AND SPECIFIERS

EMILY DAWSON
OWNER, SINGLE WIDGET

What is the construction industry's appetite for innovation? The US Green Building Council (USGBC) considers about 5 percent of the industry to be innovators, 20 percent to be leaders, 70 percent to be followers of current codes, and 5 percent to be lawbreakers (who do not follow codes). The 25 percent who are leaders and innovators look for ways to build modern structures focused on sustainability, efficiency, and a reduced carbon footprint. Over time, as we have seen with green building certifications and their effects on building codes, these industry leaders are likely to pull the entire construction industry in their direction.

Mass timber is promising as an environmental solution, but it is also a disruptive technology. The implications of increased off-site fabrication and more collaborative construction approaches are allowing project teams to glimpse a future with greater levels of control over materials procurement and craftsmanship. As such, many designers will find the information addressed to builders in chapter 6 is equally relevant to them as teams become more integrated, optimize designs and schedules, and assess costs together in real time.

This chapter explains how to approach designing and coordinating a mass timber project from the design team perspective.

5.1 ELEMENTS OF DESIGN

Wood is one of the oldest building materials. Wooden longhouses sheltering more than 20 people date to at least 4000 BC, and the earliest wood dwellings date back to at least 6000 BC. To build large wooden structures, humans have long taken advantage of wood's natural strength. Over the millennia, building techniques and capabilities have improved, most recently in the 1990s with the development of mass timber panel systems in Austria and Germany.

Panel Size

Mass timber panels are groundbreaking in the engineered wood market because their scale necessitates prefabrication and creates the potential for use in modular construction. To maximize the benefits, building designers must consider the panel dimensions as they relate to the building's grid system, as well as panel thickness and number of laminations required for a given span. Each manufacturer has different fabrication machinery, and thus, different size limitations. In North America, a typical structural panel might be nominally 10 feet by 40 feet, or even 10 feet by 60 feet, and between 3 inches and 24 inches thick. There are, however, many other options.

Designers must also consider the panel's actual (versus nominal) dimensions. One characteristic of Cross-Laminated Timber (CLT) panels is their dimensional stability, particularly in-plane. Manufacturers can finish panels for construction with submillimeter precision.

Panel sizes are developed around transportation requirements. The transportation and handling costs, and the limitations at any given building site, should be considered when choosing optimum panel sizes. Often, construction efficiency justifies the high cost of shipping oversized elements and assemblies.

Panel Strength

Engineered composite wood products are stronger than solid wood components of the same dimensions because the natural defects in the wood are redistributed. Mass timber panels take advantage of the natural strengths of wood while minimizing its natural weaknesses. Wood is naturally much stronger in the longitudinal direction (aligned with the grain) than in the radial and tangential directions (across the grain), as illustrated in **Figure 5.1**. Products like CLT and Mass Plywood Panels (MPP) take advantage of wood's longitudinal strength by alternating the direction of the grain in each layer, resulting in panels that are strong and dimensionally stable in both in-plane directions; these two-way slabs allow for structural efficiencies not available with slabs that span one direction only, **see Figure 5.2**.

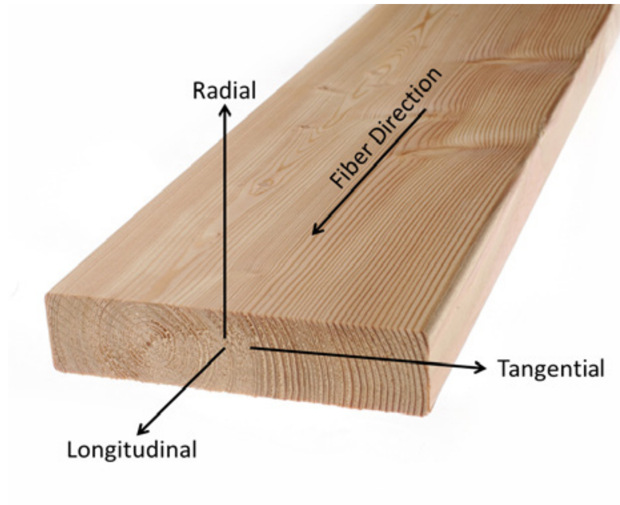


FIGURE 5.1: LUMBER STRENGTH ILLUSTRATION

Ongoing strength, vibration, and fire performance testing expand design opportunities on a regular basis. Because there are innumerable panel variables (number of layers, species of wood, lumber

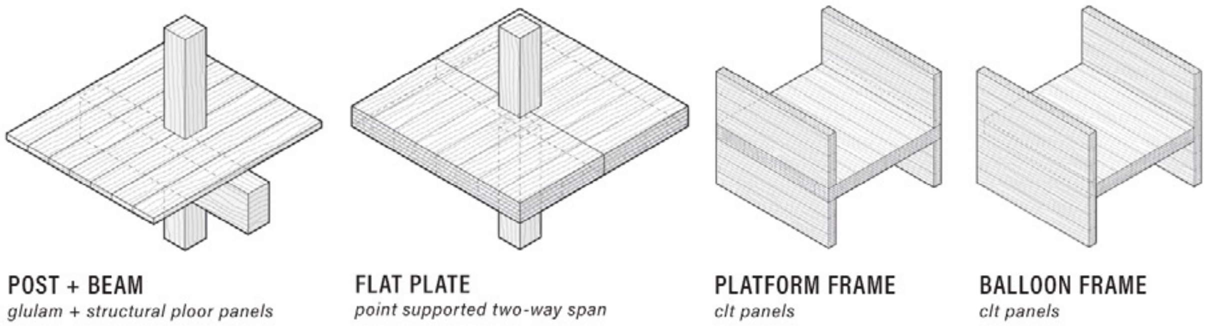


FIGURE 5.2: STRUCTURAL MORPHOLOGIES FOR MASS TIMBER HOUSING

Source: Gray Organschi Architecture

sizes and grades, adhesives versus fasteners), the testing has taken 2 approaches: (1) physically testing specific panel sizes/layers/species configurations, and (2) extending the physical test results to other untested sizes/layers/species configurations through analysis and modeling. The combination of an analytical approach and experimental testing has created a baseline for understanding the performance characteristics of mass timber products.

For detailed information on design standards for mass timber products, refer to **Table 5.8** at the end of this chapter.

Adhesives

Adhesives are used in most Engineered Wood Products (EWPs), including plywood, Laminated Veneer Lumber (LVL), glulam, CLT, and MPP. Standards have been established to ensure that these adhesives are structurally reliable and safe for building occupants.

Requirements for adhesives used in glulam and CLT are nearly identical. Adhesives used in glulam must meet the requirements of the American National Standards Institute's (ANSI) *Standard for Adhesives for Use in Structural Glued Laminated Lumber* (ANSI 405). Under PRG 320, the American National Standard for Performance-Rated Cross-Laminated Timber, adhesives in CLT used in the US and Canada must also conform to ANSI 405, with 2 exceptions, even though, in practice, the adhesives do not differ. One exception does not require weather-testing for long-term exposure because CLT is not recommended for exterior applications. The second exception logically requires that in the small-scale flame test under *CSA O177*, the sample must be CLT rather than glulam.

Internationally, polyurethanes (PUR) are the system of choice for about 67 percent of all existing CLT production lines, compared with 20 percent for melamine urea formaldehyde (MUF) systems. Two other types—emulsion polymer isocyanate (EPI) and phenol-resorcinol-formaldehyde (PRF)—are used in about 13 percent of production lines, mostly in Japan. By combined output volume of panels, the use of PUR is 82 percent globally, followed by MF (melamine formaldehyde)/MUF at 15 percent, then EPI and PRF at 1 percent and 2 percent, respectively. MPP uses a phenol formal-

dehyde adhesive like those used in plywood and LVL. Each of these adhesive approaches is continually being studied and refined to meet increased strength and environmental objectives.

Because formaldehyde and isocyanate bonding agents have been identified as harmful to human health, the Engineered Wood Association (APA) addresses formaldehyde use in EWPs in a technical paper[1] explaining that they "have such low emission levels that they are exempt from the leading formaldehyde emission standards and regulations." Many mass timber products have Environmental Product Declarations (EPDs) available that explain the safety of their adhesives from a health standpoint. Several CLT manufacturers have achieved "Red List-free" or "Red List-declared" status from the International Living Future Institute (ILFI) Declare[2] EPD label, the most rigorous of the sustainable building standards.

Completely bio-based adhesives (made from soy, for example) are an area of interest for designers and manufacturers looking to further lower toxicity and embodied carbon in the products they specify. Options to date remain in the research phase.

5.2 CONNECTORS

Connectors are used to join the structural components to transfer loads throughout a building. As the mass timber construction market expands, so does the need for proper fasteners and connectors. A variety of factors must be considered, including the type of joint, the materials being joined, loads carried through the joint, fire resistance, and aesthetics.

FIGURE 5.3: SELF-TAPPING TIMBER SCREWS

Source: MTC Solutions

Self-tapping screws are among the most widely used fasteners in mass timber projects (**see Figure 5.3**). Proprietary bracket systems are also commonly used to connect beams, posts, and panels. Some are intended to overcome limitations or weaknesses in existing systems or components. Others are created with aesthetics or ease of installation in mind. Each option has developed from a legacy of joining and connecting techniques.

Two primary families of connections have been created for wood construction: traditional joinery and mechanical connectors (including dowels, splines, plates, and other specialized components). Traditional joinery entails cutting and joining wood together to create structural connections without adding other materials. Mechanical connectors are commonly metal and range from nails and screws to more complicated bracket systems. See **Figure 5.4** for examples. Some of these systems are proprietary, while others are traditional and widely available. Proprietary connector systems are numerous and vary significantly in appearance, capacity, and application. These systems range from self-tapping screws with proprietary

1 Engineered Wood Products, "Technical Note: Formaldehyde and Engineered Wood Products," no. J330E (January 2022), https://www.apawood.org/publication-search?q=J330&tid=1.

2 https://declare.living-future.org/

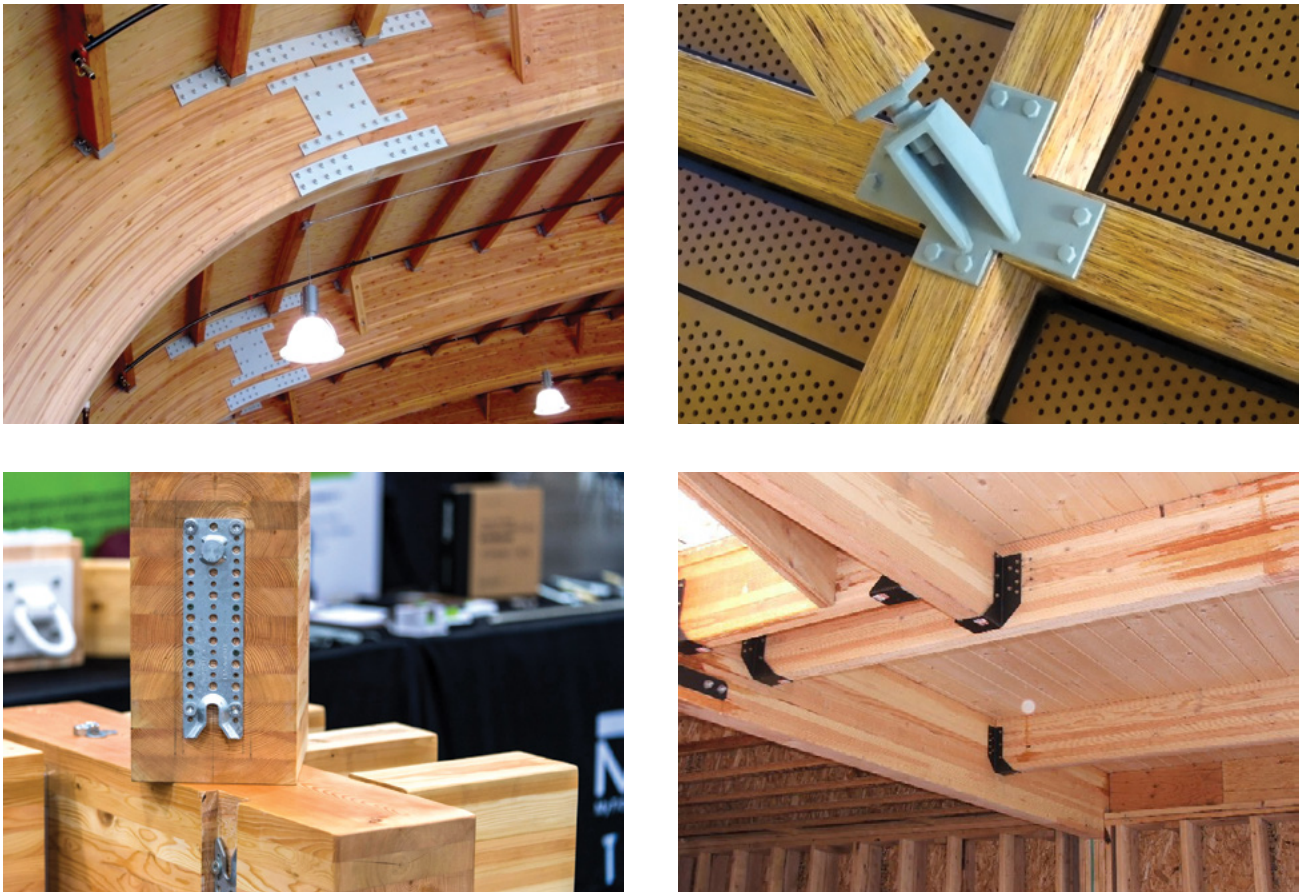


FIGURE 5.4: MASS TIMBER CONNECTOR EXAMPLES

Top Left — Plate Connector; Top Right — Custom Connection;
Bottom Left — Concealed Beam Hangers; Bottom Right — Exposed Beam Hangers

Sources: APA, The Engineered Wood Association, Structure Craft (top right); Oregon Department of Forestry (bottom left)

head patterns to one-off, custom-created connectors that weigh hundreds or thousands of pounds.

Connectors and fasteners must meet specific engineering requirements and be tested for performance. Two important requirements are shear strength and withdrawal strength. Shear strength is the ability of a material to resist forces that cause its internal structure to slide against itself (that is, fail) along a plane parallel with the direction of the force. Withdrawal strength, or withdrawal capacity, is the ability of the connector to resist forcible removal, or tear out, from its entry point.

The National Design Specification for Wood Construction (NDS) provides design values for most dowel connectors, as well as for shear plates and split rings. Design values for proprietary systems are found in code evaluation reports that the manufacturer can provide.

For all connectors, it is important to know where to find their applicable design values. The International Building Code (IBC) defines the structural property requirements for connectors and fasteners of wood components. Section 2302.1 lists the sections that cover the actual stress factors re-

ABOVE — FIGURE 5.5: CNC COLUMN AND BEAM JOINERY

Source: Shigeru Ban Architects
Credit: Didier Boy de la Tour

RIGHT — FIGURE 5.6: 2-HOUR-RATED WOOD-TO-WOOD CONNECTION

Source: Timberlab

quired for various building applications. Sections 2304.10.1 through 2304.10.7 define the requirements for connectors and fasteners: what types of fasteners are to be used in what situations, how many, and where they should be placed.

Joinery

Joinery uses specialized cutting techniques to form joints between wood components (mortise and tenon, dovetail, etc.). Joinery can create impressive results in both beauty and strength. Historically a time-consuming manual process requiring significant skill, joinery's possibilities have become more accessible to the building market through Computer Numerical Control (CNC) technologies (see **Figure 5.5** for an example). Designs translated into a computer model to be read by the CNC operator can be unusual and imaginative, and they can be optimized for fabrication efficiency and installation speed. Working with a fabricator early in the

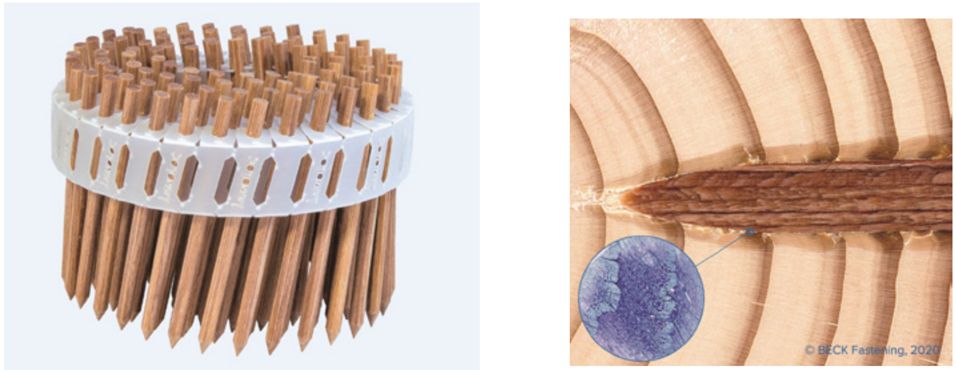


FIGURE 5.7: WOOD NAIL COIL AND LIGNIN WELDING
Source: LIGNOLOC®

design process can inform the cost-effectiveness of a joinery-based design approach.

In some cases, removing steel from a joint can increase the fire resistance of an assembly. For example, the first Type IV-C building in Seattle used joinery to create a 2-hour-rated assembly that required no steel connectors. As a result, additional fiber was not required to protect any hidden steel components (see **Figure 5.6**).

Dowels

Dowel connectors, the most common type of mechanical fastener, come in many forms and can be made from a variety of materials. They transfer loads well, are generally easy to install, and are cost-effective.

Metal dowel connectors are typically made of steel, and they include staples, nails, screws, and bolts. Wooden dowels are analogous to metal dowel connectors. The NDS allows designers and engineers to calculate the strength properties of dowel connectors. (See also Nail-Laminated Timber [NLT] and Dowel-Laminated Timber [DLT] in chapter 1.) The benefits of wood doweling in a mass timber connection or fabrication approach are twofold: a higher carbon sequestration potential, and a more readily reusable or recyclable product at end of life. “All-wood” timber products that do not contain added metal or adhesives generate an improved Life Cycle Analysis (LCA) profile.

In addition to the mechanical connection, lignin bonding is also possible with wooden dowels. Lignin is a polymer in wood’s cellular structure that, with enough friction, can create a fusing effect between 2 pieces of wood. Recent testing at the University of Hamburg identified the phenomenon of “lignin welding.” This has led to the development of wooden nails acceptable for structural applications. A proprietary wooden nail product (see **Figure 5.7**) made from beechwood was developed in Austria using the lignin welding effect.[3]

Splines

Spline connections combine joinery concepts and dowel connectors to structurally join large mass timber panels with smaller EWPs or steel components. A typical spline connection involves rout-

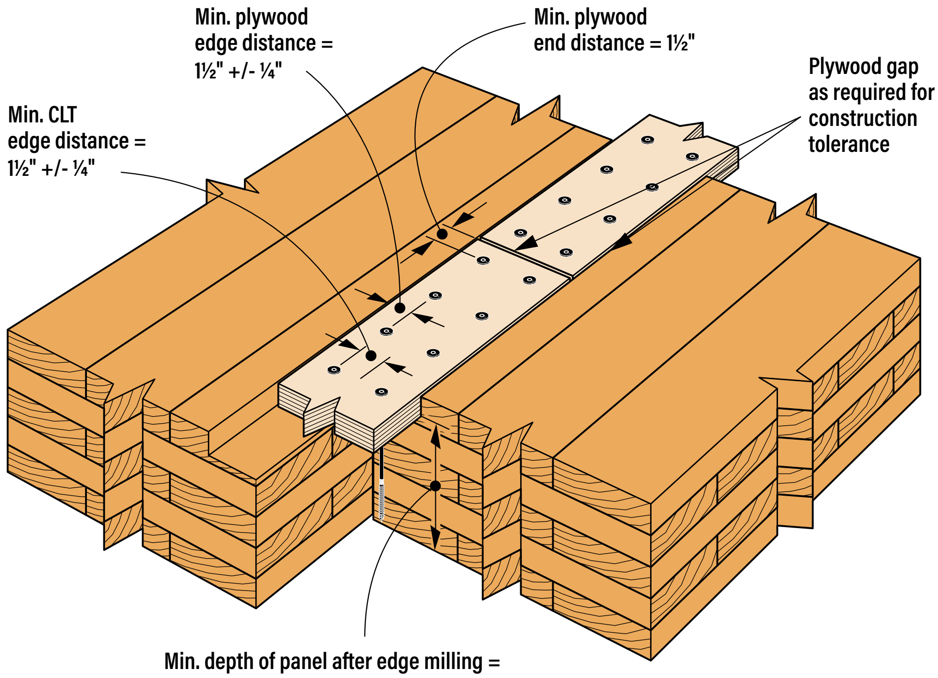


FIGURE 5.8: CLT SPLINE CONNECTION DIAGRAM WITH GAP AND FASTENER RECOMMENDATIONS

Source: Simpson Strong-Tie

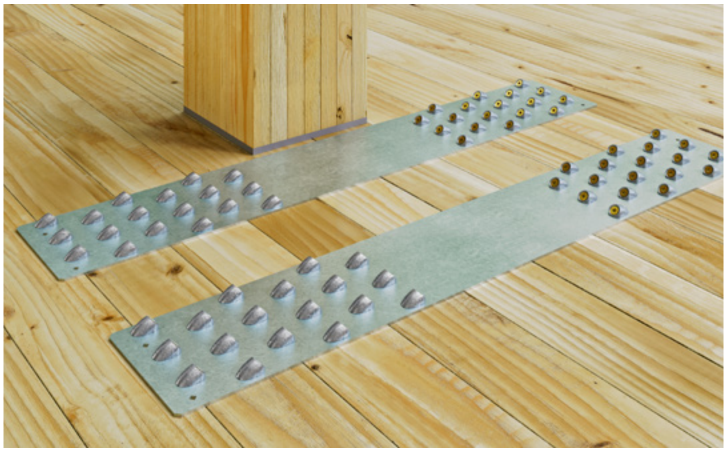
ing the connecting edges of 2 mass timber panels with a shallow groove, laying joinery boards in the groove, and fixing them in place with nails or screws (see **Figure 5.8**). This type of connection can also be achieved with plates connected on the panel surface.

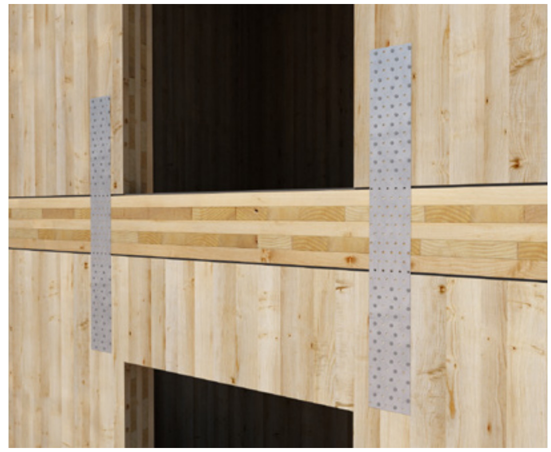
Plates and Straps

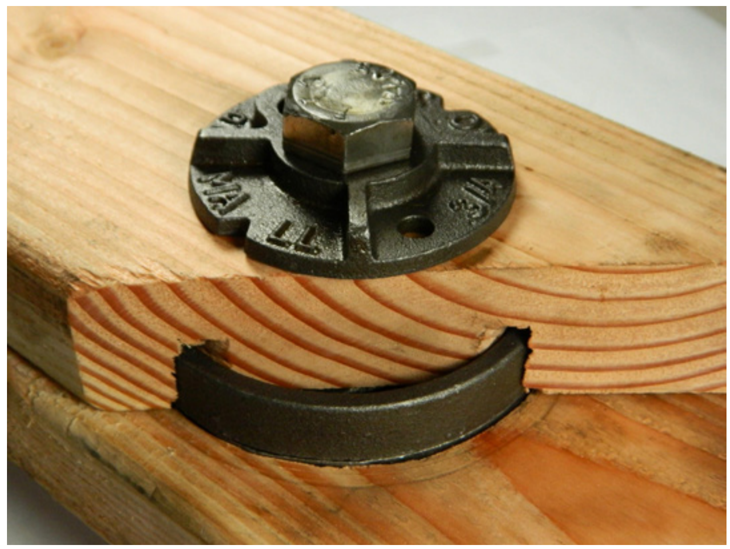
Custom and off-the-shelf metal plate and strap connectors can be combined with nails or screws, or through bolts, to connect multiple elements, as shown in **Figures 5.4, 5.9,** and **5.10**. Custom-welded connections can also be created from plate steel to manage a variety of loads in exposed or concealed conditions. Some metal connector plates were developed to help join trusses for floors and roofs without the use of additional fasteners. These plates are usually made from sheets of galvanized steel and are die-punched or scraped to create teeth that allow the connector to be applied with pressure. This type of toothed metal connector plate is not common for mass timber applications, but it can be an efficient way to achieve "design for disassembly" in some situations (see **Figure 5.11**).

Shear Connectors

Shear connectors, or bearing connectors, include shear plates, toothed shear plates, and split rings. These connectors are designed to help wooden components handle heavier loads. Shear plates, or timber washers, are iron discs with a shallow rim on one side and a flat surface on the other (see **Figure 5.12**). This connection disperses pressure from a load across the larger radius of the plate. By contrast, a bolt spreads pressure across







TOP LEFT — FIGURE 5.9: MASS TIMBER STRAP WITH ANGLED WASHERS, *Source: Simpson Strong-Tie*

TOP RIGHT — FIGURE 5.10: STRAP CONNECTIONS, *Source: Rothoblaas*

BOTTOM LEFT — FIGURE 5.11: HOOKED PLATE CONNECTIONS, *Source: Rothoblaas*

BOTTOM RIGHT —FIGURE 5.12: SHEAR PLATE CONNECTOR, *Source: Portland Bolt & Manufacturing Co.*

a smaller area. Shear plates, therefore, can handle heavier loads than bolts. Split rings are like shear plates in both form and function, but they are not as heavy-duty.

Structural Metal Castings

The free-form capability of the casting manufacturing process is ideally suited to addressing a variety of connection geometries with artistic creativity and structural integrity. Structural metal castings can transfer tension, compression, shear, and other loads, as well as offer increased ductility for structural systems meant to resist seismic motions. Preengineered, standardized castings are available off the shelf to suit an array of sizes. Custom-designed cast connections can satisfy specific project objectives and constraints for one-off and repetitive applications (see **Figure 5.13**).

FIGURE 5.13 OFF-THE-SHELF STRUCTURAL METAL CAST COLUMN CONNECTIONS TIMBER END CONNECTORS™, UMASS AMHERST INTEGRATED DESIGN BUILDING

Source: Cast Connex®; Credit: Alex Schreyer

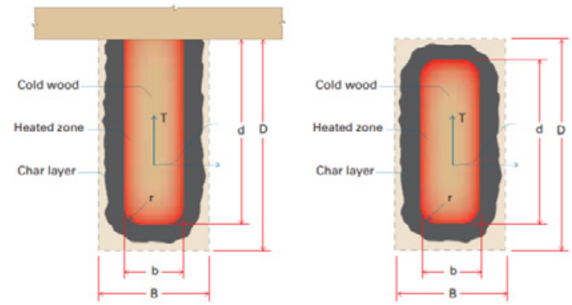
TOPIC	WOODWORKS RESOURCES
Detailing & Connections	Fire Design of Mass Timber Members: Code Applications, Construction Types and Fire Ratings:
	Inventory of Fire-Resistance Tested Mass Timber Assemblies and Penetrations
	Shaft Wall Solutions for Light-Frame and Mass Timber Buildings
	Shaft Wall Requirements in Tall Mass Timber Buildings
	Concealed Spaces in Mass Timber and Heavy Timber Structures
	Demonstrating Fire-Resistance Ratings for Mass Timber Elements in Tall Wood Structures:
	Standards and Testing: Ensuring Adhesive Performance in Mass Timber Buildings

TABLE 5.1: MASS TIMBER RESOURCES FOR DESIGNERS

Source: WoodWorks.org/resources/

Effective Char Rates and Char Layer Depths (for β_n = 1.5 inches/hour)

Required Fire Resistance (hr)	Effective Char Rate, β_{eff} (in/hr)	Effective Char Layer Depth, a_{char} (in)
1-Hour	1.8	1.8
1½-Hour	1.67	2.5
2-Hour	1.58	3.2



Reduction in member breadth and depth over time, t

FIGURE 5.14: CALCULATING THE FIRE RESISTANCE OF EXPOSED WOOD MEMBERS

Source: American Wood Council Technical Report, no. 10

5.3 FIRE RESISTANCE

Many mass timber products are large, thick, airtight masses of wood. These properties are inherently fire-resistant. This may seem counterintuitive because wood is regarded as a combustible material. However, tests have shown that large wooden components maintain their structural integrity during extended exposure to direct flame and intense heat. Fire ratings represent the length of time a given assembly can be exposed to high temperatures before losing crucial performance characteristics. Design teams will need to review and address flame and smoke spread classifications (as defined by the IBC) for exposed wood surfaces.

Charring

When exposed to fire, wood chars on its exterior, creating a barrier between the inner portion of the beam/panel and the flame. With continued heat, the char layer thickens at a very slow, predictable rate, and with each passing moment, it further insulates the wood at the core. The thickening char layer is removing oxygen from the inner depths of the wood and is thereby extinguishing the burning component. This enables the inner, uncharred core to remain structurally unaffected and allows the component to retain much of its original strength.

The IBC references the NDS, produced by the American Wood Council (AWC), to calculate the fire resistance of mass timber elements (see **Figure 5.14**). This standard establishes a nominal design char rate of 1.5 inches per hour. "Effective" char depth includes a 0.3-inch pyrolysis zone, where the wood is not yet burned but is heated to the point of losing all moisture and is no longer structurally viable. The effective char rate per hour gets slower the longer the wood burns, as the char layer insulates the remaining wood from further damage.

The NDS char rate value is necessarily a conservative one. Actual char rates depend on species. Generally, denser (heavier) woods char at lower rates, while less dense (lighter) species char more quickly. The char rates also depend on species-specific extractives (wood molecules that are nonstructural in nature), some of which can accelerate the burning process.

TOPIC	WOODWORKS RESOURCES
Fire Resistance	Fire Design of Mass Timber Members: Code Applications, Construction Types and Fire Ratings:
	Inventory of Fire-Resistance Tested Mass Timber Assemblies and Penetrations
	Shaft Wall Solutions for Light-Frame and Mass Timber Buildings
	Shaft Wall Requirements in Tall Mass Timber Buildings
	Concealed Spaces in Mass Timber and Heavy Timber Structures
	Demonstrating Fire-Resistance Ratings for Mass Timber Elements in Tall Wood Structures:
	Standards and Testing: Ensuring Adhesive Performance in Mass Timber Buildings

TABLE 5.2: MASS TIMBER RESOURCES FOR DESIGNERS

Source: WoodWorks.org/resources/

The design team for the Ascent tower in Milwaukee, Wisconsin, for example, demonstrated that the tall timber structure would have a slower char rating than the prescriptive code value. They tested their KLH -supplied panels at the Forest Products Laboratory (FPL) in Madison, Wisconsin, and measured a char rating of 1.29–1.31 inches per hour[3], saving the project the cost of almost ¼ inch of fiber from every exposed, rated wood component. This finding has excellent implications for reducing fiber and costs when design teams pursue a performance-based permitting process.

Flame and Smoke Classifications

Interior finish surfaces are classified based on a "flame spread" and "smoke-developed" index in the code with 3 levels of distinction: Class A is the most resistant; Class C, the least. Untreated wood falls into Classes B or C; designations are by species.[4] Flame spread ratings can be increased with treatments and coatings.

Encapsulation

If a design requires fire resistance in addition to the values provided by the wood itself, structural encapsulation is the most straightforward approach from a code perspective. Fire safety is attained by encapsulating mass timber elements with an approved and rated assembly. The encapsulation rating is defined as the time that charring of a structural mass timber element is delayed by the "encapsulation membrane," limiting the growth and spread of fire. Gypsum board, gypsum concrete, and intumescent coatings are among the most popular encapsulation materials.

3 https://timberlab.com/projects/3hr

4 American Wood Council, Design for Code Acceptance 1 (DCA1), "Flame Spread Performance of Wood Products Used for Interior Finish" (2019).

Coatings

Intumescent coatings and sealants fill gaps and protect the materials underneath by expanding when exposed to extremely high temperatures. These treatments decrease the immediate flammability of the wood, minimizing fuel for an active fire and slowing the spread of a flame. Intumescent coatings can be costly to install, but their thinness and transparency solve some dimensional and aesthetic issues, offsetting the cost for some projects.

New fire-resistant coatings are in development, including a very thin, transparent coating invented by scientists at Nanyang Technological University, Singapore (NTU Singapore).[5] Although they cannot always incorporate products that have not been tested under nationally recognized standards, by understanding the performance potential and current research, designers can imagine structures that would not previously have been possible.

5.4 STRUCTURAL PERFORMANCE

From foundations to overall systems strategies, structural engineering is key in the design of any building. Excellent mass timber engineering requires understanding the specific considerations of the material system and seeking opportunities for efficiency and elegance.

Foundations

Wooden structures are much lighter than buildings of a similar size made from steel, concrete, or masonry. Lighter-weight buildings transfer less load to their foundations, leading to smaller, less complex below-grade work and savings on excavation and concrete costs. This feature is particularly advantageous for building sites with poor soil-bearing pressures, and it also improves the ability to build over contaminated soils with minimum disruption. In one project that required deep foundation piles for an all-concrete building, DCI Engineers saved 30 percent in foundation costs by replacing the top 3 floors with mass timber.[6]

Using less concrete is desirable for lowering a building's embodied carbon footprint, and it often has significant schedule advantages as well.

Grid Layout/Structural Bay

Mass timber panel dimensions and thicknesses—and thus, their strength and stiffness—vary by manufacturer and product. Often, vibration, a subjective value in the US, will govern panel thickness over strength and fire resistance. A design team considering mass timber for floor panels should understand structural bay options and constraints when making early building layout decisions.

The manufacturing dimensions of various mass timber panel systems should be considered to optimize cost efficiency in plan layouts. It is advisable to bring a procurement or manufacturing partner on the team as early as possible to gain the benefits of efficient material use. Also see chapter 8 for what to consider when advising building owners on contract options.

5 https://techxplore.com/news/2022-08-invisible-coating-wood-fireproof.html
6 1 De Haro, San Francisco, Dean Lewis, DCI Engineers.

Seismic Performance

Some of the oldest wooden buildings in the world are in Japan, the most seismically active country on Earth. At over 122 feet tall, the Horyuji Temple near Osaka has survived at least 46 earthquakes of a magnitude 7.0 or greater on the Richter scale since the temple's construction in 607 AD. Japanese scholars describe the inherent flexibility in these wooden structures by a "snake dance" theory,[7] which enables the buildings to dissipate significant seismic energy without damage.

Building codes are the main tool for addressing seismic risks, establishing design requirements that vary by region and depend on the historical frequency and magnitude of earthquake activity. The main seismic criterion in building codes is a specification of the minimum lateral force a building must withstand to prioritize occupant safety during a seismic event. Building codes include an equation in which cyclic seismic forces are represented by a single static force, called *base shear*, that is applied to the base of a building. Designers adjust or design for variables in the base shear equation to achieve desired building performance. The variables include site seismicity, soil conditions, structural systems and building materials, building height, and building occupancy.

Wood, particularly mass timber, has characteristics that lead to favorable earthquake performance: weight, redundancy, and ductility.

Weight: A lighter building is advantageous in a seismic event because the inertial force exerted on a building is proportional to its weight, with higher inertial forces exerted on heavier buildings. Lateral systems for timber buildings are required to resist less force than heavier buildings, and as a result, can be smaller and less expensive.

Redundancy: Many fasteners and connectors are used in wooden buildings to join walls, roofs, floors, beams, and columns. Each of these connections is a load path through which seismic forces can travel. The numerous connections inherent in a component-based construction approach mitigate the chance of complete structural failure, if some connections fail.

Ductility is the extent to which a material or building can deform without failing. Buildings made from wood often use connection systems for joining walls, beams, and columns that further add to a building's ductility.

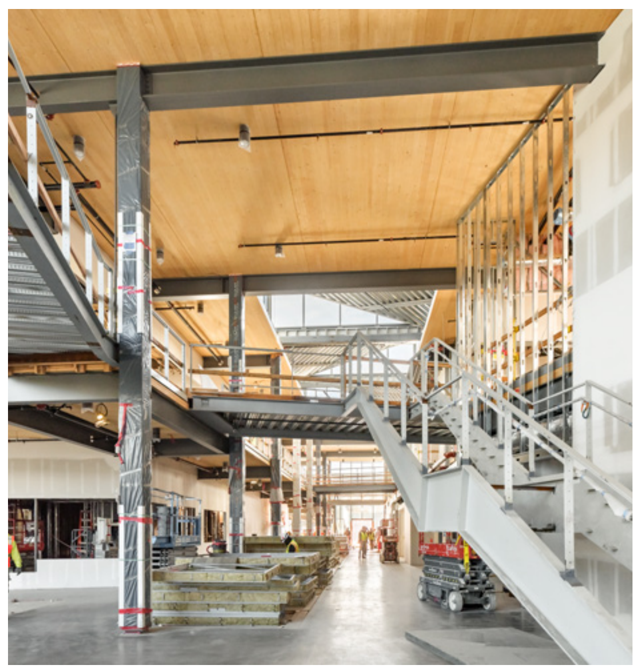
In high-seismic regions in the US, building codes limit the use of CLT to resist lateral forces from earthquakes, given the low ductility of CLT as a shear wall system (structural R-value of 2). The higher the structural R-value, the lower the lateral force required by the building code. Structural engineers, therefore, typically design with lateral systems having a higher R-value, such as light-frame timber plywood shear walls (up to R-7).

The design requirements of CLT shear walls and CLT diaphragms are defined in the AWC's *Special Design Provisions for Wind and Seismic (SDPWS), 2021 Edition* .[8] This reference guide can be used as a basis for alternative requests to jurisdictions that do not yet recognize IBC 2021. The CLT diaphragm requirements in SDPWS 2021 are engineering-based, with no specific prescribed details. It does include a low-seismic CLT shear wall option with a structural R-value of 1.5, as

7 https://web-japan.org/nipponia/nipponia33/en/topic/
8 https://awc.org/codes-standards/publications/sdpws-2021

well as design details for a platform-framed CLT shear wall system, including specific connectors and aspect ratio limits for individual CLT panels. WoodWorks offers a *CLT Diaphragm Technical Guide* that includes working examples using the new CLT diaphragm requirements.

Recent research and testing of CLT shear walls have resulted in proposals to use a structural R-value of 3.0 to 4.0, depending on the aspect ratio of the CLT wall. This, however, still means designing for lateral forces roughly twice those of light-frame plywood shear walls. The R-values of 3.0 and 4.0 for the platform-framed CLT shear wall system were published in *ASCE 7, 2022 Edition*. Research is ongoing on higher R-value, lower design force shear wall systems, including mass timber rocking wall testing.[9]



TOP — FIGURE 5.15: CONCRETE CORES AND PRECAST CONCRETE FRAME WITH TIMBER SLAB AND BEAMS

Adidas North American Headquarters, Portland, OR
Source: Lever Architecture

BOTTOM — FIGURE 5.16: HYBRID CLT AND STEEL STRUCTURE

Microsoft Campus, Mountain View, CA
Source: Holmes Structures
Credit: Blake Marvin Photography

9 Led by Shiling Pei of Colorado School of Mines.

RENDERING OF 55 FRANKLIN 4-BUILDING RESIDENTIAL HOUSING COMPLEX

Source: ABA Architects, Inc.

CASE STUDY: 55 FRANKLIN

FRANKLIN FLATS OPTIMIZES DELIVERY OF AFFORDABLE HOUSING

PROJECT OWNER: MAXWELL BUILDING CONSULTANTS

PROJECT LOCATION: 55 FRANKLIN ST, SOUTH KITCHENER, ON, CANADA N2C 1R5

COMPLETION DATE: DECEMBER 31, 2024

ARCHITECT/DESIGNER: ABA ARCHITECTS, INC.

MASS TIMBER ENGINEER/MANUFACTURER: ELEMENT5

OTHER CONTRACTORS: GSE GROUP (PLANNING), MTE CONSULTANTS, INC. (SITE SERVICES)

FRANKLIN FLATS, A 4-building, mid-rise residential housing complex, gave the project team opportunities to explore new and different strategies for optimizing the delivery of quality affordable housing in Ontario, and to test multiple design variations against their impacts on sustainability.

The developer, Maxwell Building Consultants, secured a 2-acre property for the specific purpose of constructing four 6-story buildings of the same size and placing them side by side. Based on the results, they would determine which design would be the most practical for building affordable housing. The project will create 240 residential units of various sizes, 60 in each of the mixed-use buildings.

ABOVE — RENDERING OF OVERHEAD VIEW OF 55 FRANKLIN RESIDENTIAL COMPLEX
Source: ABA Architects, Inc.

LEFT — FIRST BUILDING OF 55 FRANKLIN DURING CONSTRUCTION PHASE
Source: ABA Architects, Inc.

The first building, occupied in July 2023, is a hybrid structure made of conventional light wood-frame construction for exterior and interior wall panels, Cross-Laminated Timber (CLT) from Element5 for the floor and roof slabs, and concrete elevator cores and exit stairs on a cast-in-place foundation. CLT was chosen over conventional materials for speed of construction. Each of the CLT floors, about 7,700 square feet each, was installed in a day, cutting 8 weeks off the schedule.

The next 3 buildings will use different construction methodologies, but the structural approach for the second building (currently under construction) builds on the success of the original light wood-frame and mass timber design of the first building. It also takes advantage of a recent code update that permits the use of mass timber for elevator and stair shafts. Going with CLT shafts instead of poured concrete will save 8 days a floor, or about 48 working days ahead of the previous schedule.

Sustainable design features are also a focus of the development. These include photovoltaic solar panels, rainwater collection for graywater uses, and high-performance building envelopes and systems.

The developer is scheduled to break ground on the third and fourth buildings of the series in 2024.

TOP — FIGURE 5.17: COMPOSITE CONCRETE-TIMBER SLAB WITH ACOUSTIC MAT AND INCLINED SCREW REINFORCING

Peavy Hall, Oregon State University
Source: Evan Schmidt

BOTTOM — FIGURE 5.18: COMPOSITE CONCRETE-TIMBER SLAB WITH NAILPLATE REINFORCING

John W. Oliver Design Building at UMass Amherst
Source: Alex Schreyer/UMASS

Wind Loading

In regions with low seismic concerns, or in very tall buildings, wind loads may govern lateral design. Many of the seismic performance advantages of timber construction can be applied to wind loading design. However, lighter-weight buildings will require adapted shapes and/or more lateral strengthening forces than heavier buildings to deflect or resist wind.

Hybrid Systems

Most timber structures use steel-reinforced concrete for foundations and steel components for connections. But factors such as building height, grid layout, and seismic region may lead a design team to use a full-building hybrid approach. Such projects efficiently combine multiple primary structural materials. Although wood is very strong by weight in both tension and compression, selectively incorporating concrete or steel, or a combination, can mitigate vibration, increase span capacity, reduce structural member dimensions, and/or increase lateral capacity (see **Figures 5.15** and **5.16**). Component-based approaches, such as hybrid slabs, are also being developed in research and in practice.

TOP LEFT — FIGURE 5.19: POST-TENSIONED TIMBER BEAM

Source: 120 Clay Creative, Ankrom Moisan
Credit: Ethan Martin

TOP RIGHT — FIGURE 5.20: POST-TENSIONED CLT PANEL

Chibougamau terminal, Nordic Structures and EVOQ Architecture

Credit: EVOQ/Artcad

BOTTOM — FIGURE 5.21: TIMBER-TIMBER COMPOSITE FLOOR PANEL

Catalyst, Katerra
Credit: Andrew Giammarco

FIGURE 5.22: LIGHT FRAME AND MASS TIMBER HYBRID

The Canyons, Portland, OR

Source: Kaiser+Path; Credit: Marcus Kauffman, Oregon Department of Forestry

Hybrid Slabs

Some building programs require spans that are difficult to accomplish with mass timber panels alone. An efficient classroom building on a 30-foot grid, for example, might at first seem to call for solid timber floors with a thick section that would be cost-prohibitive. For such projects, designers may instead consider adding beams, tension cords, or composite slabs, or they could rethink standard grid approaches developed with other construction materials.

Some options for hybrid slabs have been established.

Composite concrete-timber slabs are composed of concrete and timber connected via steel components to create composite structural action; they take advantage of the properties of both materials simultaneously. A concrete diaphragm is poured over a timber slab and connected with reinforcing steel to tie the 2 materials together. Thickened concrete sections may act as beams. Reinforcing steel can take many inventive shapes, such as fasteners driven into the timber at an angle before the concrete is poured (see **Figure 5.17**), perforated steel flanges added during the timber manufacturing or glued in on-site (see **Figure 5.18**), or 2-way rebar. In Europe, special types of removable anchoring systems are being developed to facilitate the deconstruction of concrete-timber slabs at the building's end of life. Permanently integrated concrete-timber slabs may be very difficult and expensive to handle during deconstruction, weighing on the cradle-to-grave carbon balance of buildings that use them.

Post-tensioned timber can reduce overall beam depth and increase structural transparency by adding steel tension cords to timber beams or panels (see **Figures 5.19** and **5.20**).

TOP — FIGURE 5.23: CLT AND GLULAM STRUCTURE WITH BRB FRAME CORE AND MPP STAIR

Heartwood workforce housing, Seattle, Washington
Source: atelierjones
Credit: Susan Jones

BOTTOM — FIGURE 5.24: TIMBER BRB FRAME TEST

Source: Timberlabs

Timber-timber composite floor panels are timber slabs with thickened timber sections that increase the panel's span capacity. The designers of Catalyst, an office building in Spokane, Washington, conceived and developed a timber-timber composite floor panel to achieve a 30-foot span with CLT floors and shallow CLT beams integrated during panel fabrication (see **Figure 5.21**). Other manufacturers have produced mass timber hollow core panels that combine thinner (3-ply) CLT panels for top and bottom layers, connected with internal glulam ribs. The hollow spaces are filled with insulation materials. Mass timber ribbed panel assemblies are another relatively new mass timber product; they combine CLT decks with integrated glulam ribs connected to the bottom by screws, glue, or a combination.

Hybrid Lateral Systems

Because of the stiffness of mass timber panels, hybrid approaches for lateral systems are often the most cost-effective choice.

For mid-rise structures, light-framed wood shear walls are a straightforward and cost-effective approach (as shown in **Figure 5.22**).

For taller buildings, concrete cores can be advantageous from permitting and constructability perspectives. Concrete cure times should be considered and construction sequencing optimized so building the cores does not offset the time-saving advantages of timber framing.

Buckling Restrained Braced (BRB) frame cores and walls, which can be prefabricated with steel (as seen in **Figure 5.23**) or glulam (as seen in **Figure 5.24**) cross bracing, have time-saving advantages over concrete. BRB frames can be

FIGURE 5.25: POST-TENSIONED CLT 'ROCKING' SHEAR WALL INSTALLATION
Peavy Hall, Oregon State University; Credit: Hannah O'Leary

designed with bolted rather than welded connections, working with the mass timber components as a kit-of-parts for rapid on-site assembly in any weather. An all-timber BRB frame lateral system that works in high seismic zones is under development at the University of Utah.[10]

Post-tensioned CLT shear walls combine strong, rigid wood panels with steel tendons and fuses for added ductility and seismic force dissipation (see also chapter 8's section on resiliency). The technology was developed in New Zealand and has been in use there for nearly a decade. Peavy Hall at Oregon State University is the first installation of its kind in North America (see **Figure 5.25**).

Ballistic/Blast Performance

The US military is interested in using mass timber in construction projects, with one estimate finding that military construction using CLT instead of concrete and steel could create a market of $1.9 billion annually for buildings, housing, and facilities requiring low levels of blast resistance.[11] When designing military buildings, architects

10 University of Utah et al., Wood Innovations Grant, "BRB Braced Frames for Seismically Resilient Mass Timber Buildings" (USDA Forest Service, 2021).
11 https://www.woodworks.org/learn/mass-timber-clt/protective-design/

TOPIC	WOODWORKS RESOURCES
Structural Design	CLT Layups and Basis of Design for Gravity Load Applications
	CLT Diaphragm Design for Wind and Seismic Resistance
	U.S. Mass Timber Floor Vibration Design Guide
	Differential Material Movement in Tall Mass Timber Structure
	CLT Structural Floor and Roof Design:
	Holes and Penetrations in Mass Timber Floor and Roof Panels
	Analysis Guidance for Cross-Laminated Timber Construction Exposed to Airblast Loading
	An Approach to CLT Diaphragm Modeling for Seismic Design with Application to a U.S. High-Rise Project:
	Creating Efficient Structural Grids in Mass Timber Buildings

TABLE 5.3: MASS TIMBER RESOURCES FOR DESIGNERS
Source: WoodWorks.org/resources/

are often required to integrate blast- and projectile-resistant materials.

Initial blast-resistance tests conducted at Tyndall Air Force Base in Florida validated acceptable levels of blast resistance for structures built with NLT and CLT. All structures remained intact and matched modeling predictions for acceptable levels of damage.

In addition, efforts are underway to understand how mass timber structures perform when struck by projectiles. Georgia Institute of Technology (Georgia Tech) completed studies in which CLT panels made of spruce, pine, fir (SPF) and Southern Yellow Pine (SYP) were subjected to ballistic testing. The results showed that both types of conventional CLT materials' inherent penetration resistances are significantly greater than those of the dimension lumber and plywood now used for temporary military structures. Additionally, the testing showed that US military guidelines (UFC 4-023-07) for determining required wood thickness based on ballistic threat underestimated the performance of CLT. The tests resulted in new equations for predicting the required thickness of CLT for ballistic protection.[12]

5.5 ACOUSTIC PROPERTIES

Mass timber has advantages as an acoustic solution. The massive arrangement helps mitigate the transfer of low-frequency sound vibrations. Combining mass timber with other building materials can create relatively thin assemblies with high—above 50—Sound Transmission Class (STC) and Impact Insulation Class (IIC) values.

12 Kathryn P. Sanborn, PhD, "Exploring Cross-Laminated Timber Use for Temporary Military Structures" (thesis, Georgia Institute of Technology, 2018).

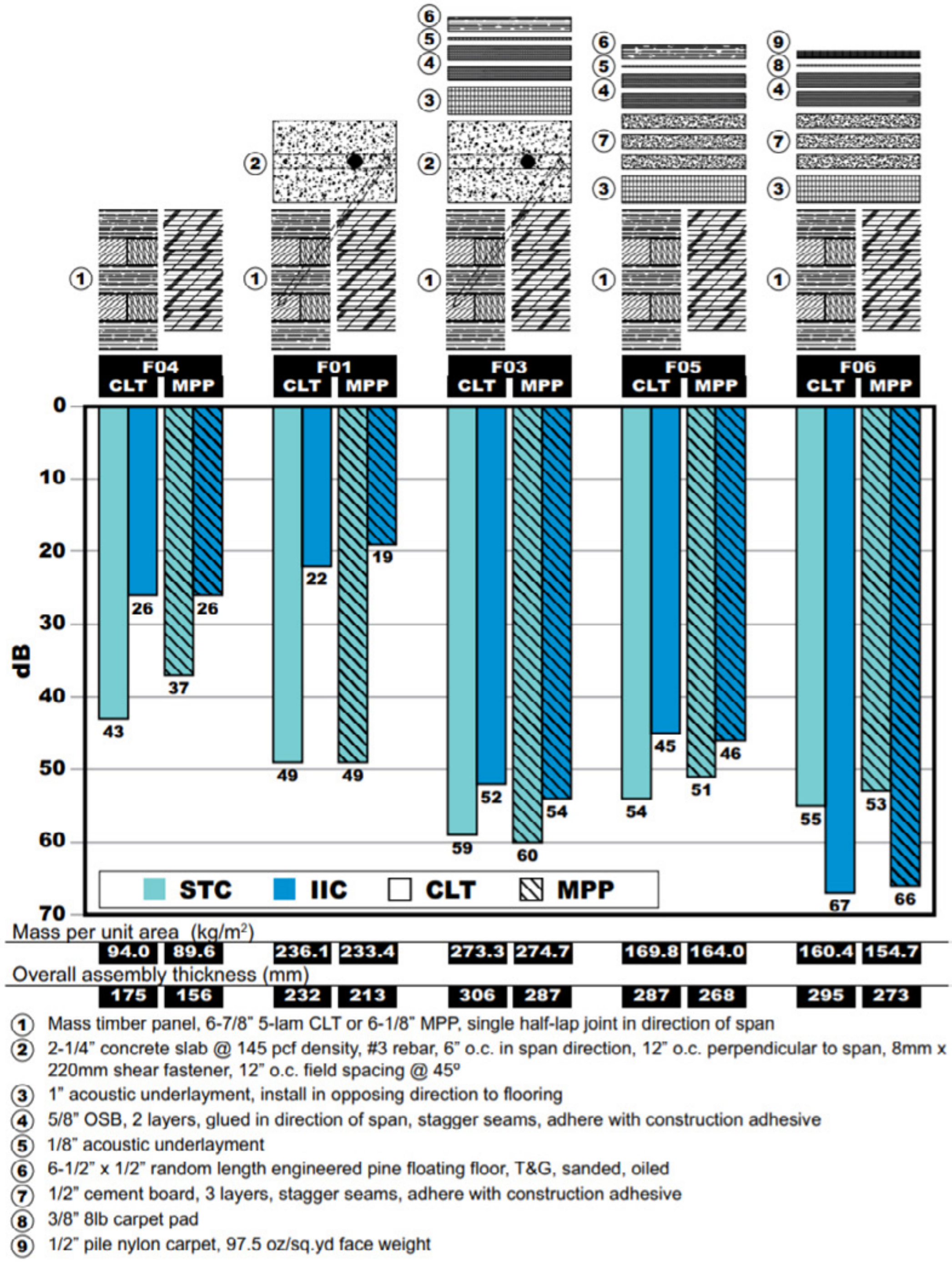


FIGURE 5.26: CLT + MPP FLOOR ASSEMBLY ACOUSTIC TESTING

Source: University of Oregon, Acoustic Lab Testing (ASTM E492-2016, ASTM E90-2016) of CLT and MPP Wall and Floor Assemblies for Multifamily Residential

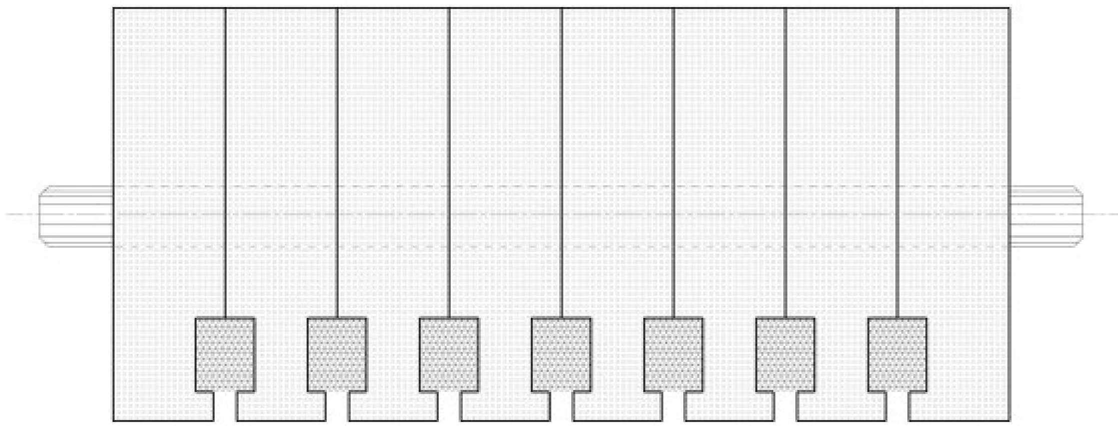


FIGURE 5.27: SIDE VIEW OF ACOUSTICALLY DESIGNED DLT PANEL
Source: StructureCraft

Standard assemblies that improve acoustical performance in mass timber buildings have been developed, in addition to an array of proprietary solutions. WoodWorks has an online inventory of hundreds of mass timber assemblies that have been acoustically tested.[13] Additionally, some guidelines have been developed for floor assemblies, including raised access floors, "dry" build-ups (which eliminate installation challenges and drying times associated with "wet" materials like gypcrete or concrete slabs), and numerous assemblies specific to the 2021 IBC tall mass timber construction types. In Europe, where noise and vibration transmission standards for various classes of buildings are more stringent than in North America, many panelized mass timber projects use special durable polymer dampening seals in pedestal-type, floor-to-wall connections to further reduce vibration and sound transmission.

A 2019 research project[14] at TallWood Design Institute (TDI) showed promising outcomes for 5 common floor assemblies, each with a CLT and MPP iteration (see **Figure 5.26**). STC and IIC values were above 50 for all floor assemblies with acoustic underlayment and floating floors, except for IIC values on a dry assembly with tongue-and-groove engineered pine flooring. STC and IIC values for bare timber assemblies and bare timber-composite assemblies fell below 50, but STC values were 49 for bare concrete-timber composite floors.

As with other code-required assemblies, permitting authorities may allow a performance-based approach for acoustic ratings. An acoustic engineer can review floor and wall assemblies, make performance recommendations, and provide project-specific STC and IIC values.

13 https://www.woodworks.org/wp-content/uploads/Acoustically-Tested-Mass-Timber-Assemblies-WoodWorks.pdf
14 Kevin Van Den Wymelenberg, *Acoustic Lab Testing of Typical Multi-Family Residential CLT and MPP Dry and Concrete-Composite Wall and Floor Assemblies*, https://tallwoodinstitute.org/acoustic-lab-testing-of-typical-multi-family-residential-clt-and-mpp-dry-and-concrete-composite-wall-and-floor-assemblies/.

MASS TIMBER IN THE FOREST
Source: ReArch Company, Inc.

CASE STUDY: ADIMAB EXPANSION

LIFE SCIENCES LEVERAGE TIMBER'S STRENGTHS

PROJECT OWNER: ADIMAB, LLC

PROJECT LOCATION: 7 LUCENT DR, LEBANON, NH 03766

COMPLETION DATE: DECEMBER 31, 2023

ARCHITECT/DESIGNER: CHRISTOPHER SMITH & SYLVIA RICHARDS

MASS TIMBER ENGINEER/MANUFACTURER: ODEH ENGINEERS (ENGINEER)/BENSONWOOD (FABRICATOR/INSTALLER)/NORDIC (SUPPLIER)

GENERAL CONTRACTOR: REARCH COMPANY, INC.

STRUCTURAL ENGINEER: ODEH ENGINEERS

OTHER CONTRACTORS:
BENSONWOOD (MASS TIMBER CONTRACTOR)

WHEN ADIMAB, A biotech company in New Hampshire, decided to expand their facilities, they looked to create a multistory timber structure to house new office, meeting, and lab spaces in as

THE TIMBER FRAME
Source: Odeh Engineers; Credit: Kelly Price

sustainable a fashion as possible. In addition to using sustainable building materials, the project was also designed with a robust thermal envelope.

SELECTING THE RIGHT STRUCTURAL SYSTEM

The primary floor area is made up of column and beam glulam construction that supports 1-way spanning Cross-Laminated Timber (CLT) floor and roof panels. Although the project was afforded modest floor-to-floor heights, the high demand for systems distribution associated with a lab facility would have conflicted with the architectural goals of clean ceiling lines if a traditional construction approach had been used throughout. Instead, the 2-way spanning capabilities of CLT are leveraged to create a pathway of beam-free mechanical, electrical, and plumbing (MEP) distribution corridors throughout the building. With the selected framing layouts, most elements of the MEP system have an unobstructed pathway through the building, reducing the need for coordinated beam and wall penetrations, freeing up more head height, and creating more visually appealing spaces.

Interior CLT bearing and shear walls are used selectively, in conjunction with the post and beam construction, to help support the structural approach while creating unusual architectural moments in the space. These interior CLT walls are also used to supplement non-load-bearing exterior light-frame wood shear walls detailed to resist lateral forces only. Although CLT walls can provide unusual advantages for exterior wall construction, light-frame wood was selected to create well-insulated exterior walls with traditional detailing methods. To maintain a fast erection schedule, however, the contractor preferred not to use the exterior as bearing walls. Special care was provided in detailing to ensure that these exterior walls are compatible with the anticipated shrinkage of the timber structure.

ACHIEVING LABORATORY VIBRATION PERFORMANCE

A concrete topping was selected to help meet acoustic and vibration goals of the project, but the CLT panels and plywood splines were used as the structural diaphragm to avoid the need for a thicker, structural concrete topping slab. With the effect of the noncomposite and nonstructural topping included, vibration analysis confirmed that the timber structure was adequate to create a high-frequency floor that met the needs of the client's laboratory equipment without significant enhancements to the primary structure. This performance was attributed to multiple design decisions, including a structural layout that respected timber's naturally tighter grid and isolating framing for corridors with higher walking speeds from the lab bench areas.

TOPIC	WOODWORKS RESOURCES
Acoustics	Acoustics and Mass Timber: Room-to-Room Noise Control
	Inventory of Acoustically Tested Mass Timber Assemblies

TABLE 5.4: MASS TIMBER RESOURCES FOR DESIGNERS

Source: WoodWorks.org/resources/

Some mass timber panels are designed for acoustic performance. For example, StructureCraft produces a sound-dampening DLT panel with insulation-filled grooves that are engineered to absorb sound waves (see **Figure 5.27**).

5.6 THERMAL PERFORMANCE

A building's thermal performance directly influences not only its energy efficiency, but also its occupants' comfort and the life span of some building components. Mass timber is an excellent material selection for thermal performance. Wood is a good insulator and is universally appealing, with exposed wood surfaces giving occupants a "warm" feeling (see chapter 7 for more on occupant comfort).

The thermal performance of a building is dependent on many factors, including climate, building shape, building orientation, architecture, and building and insulating materials. The R-values and k-values of various building materials help determine the overall thermal performance of a structure. The k-value, known as "thermal conductivity," is a measure of the rate of heat transfer through a material. The unit of measure for this rate is watts per meter kelvin (W/[m-K]); the measure is independent of the material's thickness. Materials with high thermal conductivity transfer heat more quickly and thus are generally not useful insulators. Materials with low thermal conductivity transfer heat more slowly and are more likely to be found in insulating applications. **Table 5.5** shows common building materials (and other materials for comparison) and their thermal conductivity values.

MATERIAL	THERMAL CONDUCTIVITY K-VALUE(W/(M K))
Sheep wool	0.04
Insulation, average quality	0.04
Sawdust	0.08
Douglas-fir	0.12
Hemlock	0.12
Plywood	0.13
Southern Yellow Pine	0.15
Gypsum board	0.17
Plaster and wood lath	0.28
Concrete, medium	0.4 – 0.7
Concrete, dense	1.0 – 1.8
Steel, 1% carbon	43.00

TABLE 5.5: THERMAL CONDUCTIVITY OF BUILDING MATERIALS

Source: Engineering Toolbox, Thermal Conductivity of Common Materials and Gases (2003)

FIGURE 5.28: MPP WALL ASSEMBLY FOR IMPROVED THERMAL RESISTANCE

Source: SRG Partnership

The thermal R-value, known as “thermal resistance” (not to be confused with the structural R-value discussed in an earlier section), can be measured for an individual layer of material. It quantifies the effectiveness of that layer as an insulator, given its thickness. Thermal R-value is calculated by taking the thickness of a layer and dividing it by the thermal conductivity of the material. The thermal conductivity of solid wood is relatively low; it can be used as an insulator. The thermal conductivity of solid wood is up to 15 times lower than concrete and over 350 times lower than steel. Mass timber buildings can be designed and built with superior thermal performance, leading to reduced energy requirements over their life span, cost savings for building owners and occupants, and reductions in the operational carbon footprint. A higher education lab building in Vancouver, Washington (see **Figure 5.28**), will save a projected 5 percent on energy annually by using a cost-neutral MPP wall assembly that improved the building envelope’s R-value from R-16 to R-22.[15]

Air infiltration rates of exterior envelopes contribute significantly to the energy performance of a building. CLT has an exceptionally low air infiltration rate, making it a good choice for the high-performing exterior walls required for very low-energy building design.

5.7 MOISTURE

A mass timber designer will need to consider moisture concerns similar to those associated with light-frame construction and finished wood products, but they must also be aware of a few key differences. Understanding wood’s behavior as an organic material is essential to establishing best

15 Washington State University-Vancouver Life Sciences Building, 2024. Architect: SRG Partnership, Contractor: Andersen Construction

practices. Designers will find additional relevant information on weather protection and moisture management during construction in section 6.7 .

Wood has a cellular structure ideal for holding and distributing moisture within a live tree. Once harvested, wood fibers continue to be hygroscopic, readily expanding and contracting as the environmental moisture content (MC) increases or decreases. Controlling the moisture exposure of wood building products is important along the entire supply chain, from lumber processing to fabrication, delivery, construction, and occupancy. Maintaining a relatively stable MC at each stage avoids the performance and aesthetic concerns that arise from dimensional changes, cracking or checking, staining, and decay. Factors most commonly contributing to these issues are exposure to weather before or after occupancy, trapped (unventilated) moisture, and roof or plumbing leaks.

The MC of logs at harvest may exceed 100 percent (i.e., there may be more water than dry woody substance) by "oven dry base," the metric used by the lumber industry. Of the total weight of the water in a log, about 60 percent is "bound" within the anatomical structure of individual cells. The balance is "free" water in cavities between the wood cells. Industry expectations are that the types of lumber used to make mass timber will be dried to 12 percent moisture (+ or – 3 percent, i.e., 12 percent is the target; 9 to 15 percent is the acceptable range). Drying lumber to this level helps ensure dimensional stability during mass timber manufacturing and in situ, and it prevents decay. In wet climates, wood structures might absorb moisture during the construction phase; in which case, a building must go through a "dry-out" phase before the wood is enclosed—or risk compromise.

A building with properly ventilated and dried wood will stabilize during the first 2 or 3 years of occupancy to match the ambient moisture content. MC, for example, will typically stabilize at around 6 to 8 percent for wood in interior use applications in the Pacific Northwest. The greater the MC differential within a wood member, or between the installed wood and the future occupied building, the greater the impact of shrinkage and checking. Fungus is most likely to grow if the MC reaches a range of 26 percent to 60 percent. Factors contributing to the variances include wood species, fungus species, temperature, and time (rate of dry out).

Ongoing research in academia and in the industry will continue to inform the best practices for protection and detailing. Although industry standards are nascent for many of the issues specific to mass timber and moisture mitigation, resources for designers are developing. RDH Building Science Inc. has published advice to designers on some aspects of detailing mass timber buildings to protect and recover from moisture exposure.[16]

A project studying water in mass timber[17] is ongoing at TDI via grants from the US Department of Agriculture (USDA) and the Agricultural Research Service (ARS). One aspect of this project is exploring the effects of a variety of moisture exposure types—like ambient exposure and sustained flooding—on the performance of timber connections; another aspect of the project is providing benchmark data for engineering models. In early 2020,

16 RDH Building Science, *Mass Timber Building Enclosure Best Practice Design Guide, V2* (2021).
17 Arijit Sinha, *Water and Mass Timber*, Oregon State University (OSU), https://tallwoodinstitute.org/water-and-mass-timber/.

FIGURE 5.29: MOISTURE MONITORING CLT FLOORS WITH A HAMMER-IN PROBE

Source: Kaiser+Path; Credit: Kevin Lee

hundreds of connection samples were prepared and inoculated with 2 wood-decay fungi. Some testing of water-exposed connections as well as biological degradation has been completed. Some results are available, while additional results and data were expected to be available by fall 2023.

Moisture Management and Monitoring

Design specifications should include expectations about weather protection for stored and in situ materials during construction. A moisture management plan should be in place before construction starts, and a clear strategy should be proposed before building costs are finalized (see also chapter 6). Monitoring moisture before and during dry out with an instrument designed to measure wood MC (see **Figure 5.29**) will determine if panels are ready to be enclosed or encapsulated with other materials.

Massive panels dry at different rates than stick framing (see chapter 6 on weather and weather protection for more information); the dry-out period should also be considered in terms of both schedule and technique. Allowing wood to slowly reach moisture equilibrium mitigates potential shrinkage and checking issues, of special concern where structural wood doubles as a finished surface.

The smooth, precise look of a freshly pressed CLT panel is more likely to be preserved if MC is stable from manufacture through installation. A CLT panel is manufactured with little to no gap between the boards in a lamination. If a CLT panel becomes saturated, the added moisture can cause each laminated board to swell and push against the others, although the overall panel width and length dimensions remain stable. The more the MC of a panel drops, the larger the gap between boards will be—or the cracks in the case of edge-glued boards. Some European-sourced panels have edge-

TOPIC	WOODWORKS RESOURCES
Durability & Appearance	Design of Mass Timber Exposed to Weather and Wetting Cycles
	Exposed Wood Structure in Aquatic Centers and Pools
	Specifying Appearance Grades for CLT, NLT and Glulam

TABLE 5.6: MASS TIMBER RESOURCES FOR DESIGNERS

Source: WoodWorks.org/resources/

glued boards to eliminate shrinkage gaps at each board seam. Because CLT adhesives are stronger than wood fiber bonds, shrinkage cracks then occur within boards, rather than between them, as a panel takes on and releases moisture.

Mitigation

The most effective and low-cost way for a designer to protect a wood building from moisture is through architectural detailing. Treatments or coatings add to the cost and environmental footprint of a project, so they should be used sparingly, but they may be warranted in various exposure conditions.

Proper architectural detailing, with little to no additional cost, incorporates expansion joints to allow for shrinkage, considers protection from direct moisture contact, and allows wood in place to breathe (release moisture). These details should also be designed to protect wood from exposure and contact with materials like concrete that can transfer moisture. Designers should consider that moisture is absorbed and expelled most rapidly through the wood's end-grain, and that most shrinkage happens tangentially or radially (see **Figure 5.1**).

Wood coatings can add protection against moisture and ultraviolet (UV) radiation to the completed building or during construction exposure—or both. Mass timber manufacturers often have standard temporary coatings to protect wood during transport, storage, and installation. These products should be included in the specifications for clarity and for coordination with other specified coatings. Coatings applied to encapsulate dry wood and keep it from gaining moisture from the external environment work if the coating is not compromised. Any cuts or scratches in a coated element create breaches that allow moisture in, while the remaining intact coat prevents drying.

Treated wood is common for exterior wood structures such as bridges, decks, railroad ties, and telephone poles. Not all treatments are appropriate for occupied structures, as many formulas come with human health risks. Treatments come at a higher cost than coatings, but they are highly effective. Chemical changes at the cellular level may alter the composition of the wood, and in some cases, can diminish its strength. The mass timber market has few options for treated wood, owing in part to the large dimensions of mass timber components, but several testing efforts are in progress to analyze the structural performance of treated mass timber and its interactions

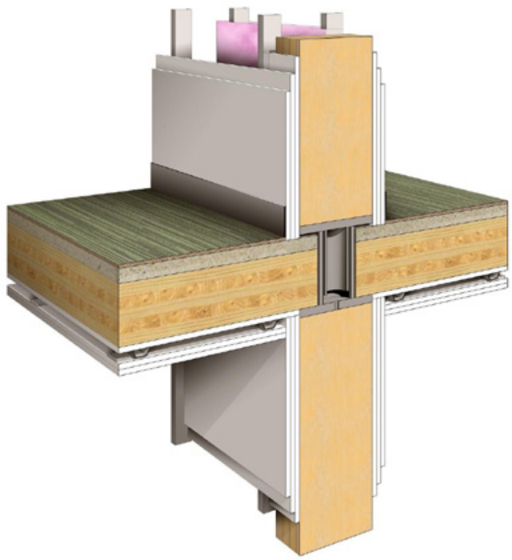


FIGURE 5.30: END-GRAIN TO END-GRAIN COLUMN CONNECTIONS MINIMIZE SHRINKAGE

Brock Commons, University of British Columbia
Source: Acton Ostry Architects

with adhesives. Treated mass timber panels could also have insect-repellent capabilities, expanding geographic acceptance into regions with termites. But, with the available treatment processes, the large sizes of the panels make post-fabrication treatment impractical.

Dimensional Stability

Engineered wood elements like CLT are less susceptible to in-plane moisture- and temperature-related dimensional changes than lumber or sawn timber because adhesives and multiple fiber directions hold their overall dimensions (except panel thickness) stable. CLT and MPP therefore have an advantage over NLT or DLT if a building is constructed during wet weather. Potential dimensional changes during construction in wet climates should always be factored into architectural and structural detailing.

Building Shrinkage

Cut wood contracts and expands differently depending on its relationship to the growth rings and the direction the fiber runs. Radial and tangential dimensions change more significantly than those in the direction of the grain. In light-wood framing, shrinkage is calculated mostly within the top and sill plates. Vertical wall studs have little effect on potential building shrinkage.

Mass timber elements can help prevent shrinkage, depending on the detailing and the products used. CLT will contribute to shrinkage in a platform-framed building, but this effect could be avoided with a balloon-frame approach. Because shrinkage in the direction of the grain is almost negligible, shrinkage can be largely avoided with details that use end-grain-to-end-grain connections. For example, both the 18-story Brock Commons at the University of British Columbia (UBC), shown in **Figure 5.30**, and the 8-story Carbon12 in Portland were designed with stacked glulam columns with steel connections in between. This design has more impact in taller buildings, where the accumulation of floor-to-floor shrinkage becomes a greater concern.

5.8 PROJECT MANAGEMENT AND COORDINATION

In these early stages of the introduction of mass timber to North America, design teams need to be well educated about how to best integrate the many benefits of these products into their projects. Development teams must include architects and engineers who understand the advantages and disadvantages of these products. CLT is not simply a replacement for concrete. The two materials have very different characteristics and design considerations. With rapidly evolving standards, best practices, and codes, teams should also be aware of the many resources available to support designers, builders, and building owners. See **Table 5.8** for WoodWorks' comprehensive list of resources for mass timber designers.

Planning Ahead

Design-phase forward planning can result in significant improvements to construction schedules, but it also requires more coordination and investment in the design process. Project managers should account for this when advising owners, determining fees, scheduling staff, and choosing consultants and software tools. More coordination time before construction starts can reduce costly field labor and project overhead, and it can deliver a superior product.

Design Partners

Early mechanical, electrical, and plumbing (MEP) coordination, for example, can have positive aesthetic, cost, and maintenance implications in the final building. Many traditional MEP consultants provide a diagrammatic design, intending the final layouts to be largely field-coordinated. In a mass timber building, however, the structure is often substantially exposed. Thoughtfully exposing utilities where necessary or desired requires working with consultants early on to consolidate the utilities in carefully planned zones and to arrange for higher-quality materials in exposed areas. If penetration locations are determined before timber components are fabricated, on-site trade conflicts and installation time can be reduced. Planning for more off-site fabricated components can also improve scheduling and craftsmanship while reducing risks.

The benefits to a building owner go beyond aesthetics and construction. In the completed building, as-built reference documents will be more accurate and will require fewer modifications from the original design documents. Building operations and management teams working with logical, accurate reference materials will also be more efficient and successful.

Procurement and Construction Partners

One of the unusual opportunities inherent in designing with mass timber is how it makes clear the stark advantages of an integrated design-and-build team. To produce an efficient and cost-effective mass timber design, the design team ideally works with the procurement team early in the design process to track and advise on market and supply trends as the design evolves. A building owner should be advised to use collaborative contract models that support effective prebid coordination (see also chapter 8). Working with design-build trade partners can also provide valuable continuity from early design through closeout.

Site coordination and installation approaches can significantly impact estimated costs. A general contractor who can quantify the efficiencies achieved by a modular mass timber structure will be able to advise on overall construction schedule reductions when compared with other construction techniques. Choosing a construction partner familiar with the unusual time and cost savings mass timber can offer is key to realizing these savings in early cost models or bids. Structural mass timber panel manufacturing companies often offer architectural and engineering design, modeling, project management, and construction as an integrated package. They may also offer assistance in all these functions to clients selecting external designers and/or contractors.

FIGURE 5.31: INDUSTRY-COLLABORATIVE WOOD RESEARCH INSTITUTIONS IN NORTH AMERICA

Research Partners

For novel and performance-based design approaches, design teams can seek testing and research resources available through collaborative research institutions throughout North America. **Figure 5.31** and the list below identify nonprofit, building-industry supportive institutions with physical laboratory facilities and expertise in areas specific to mass timber.

Northwest

1. FPInnovations (Vancouver, British Columbia)
2. University of British Columbia Timber Engineering and Applied Mechanics Laboratory (Vancouver, British Columbia)
3. University of Northern British Columbia, The Wood Innovation Research Lab (Prince George, British Columbia)
4. University of Alberta Advanced Research in Timber Systems (Edmonton, Alberta)
5. Washington State University Wood Materials and Engineering Laboratory (Spokane, Washington)
6. University of Washington Construction Materials Lab (Seattle, Washington)
7. APA Research Center (Tacoma, Washington)
8. TallWood Design Institute, Oregon State University (Corvallis, Oregon), and University of Oregon (Eugene, Oregon)

Southwest

9. NHERI Shake Table (San Diego, California)
10. Colorado School of Mines (Golden, Colorado)
11. Colorado State University (Fort Collins, Colorado)

Northeast

12. FPInnovations (Pointe-Claire, Québec)
13. Université Laval CRMR Lab (Québec, Québec)
14. Forest Products Laboratory, USDA Forest Service (Madison, Wisconsin)
15. University of Maine Advanced Structures and Composites Center (Orono, Maine)
16. UMass Amherst Wood Mechanics Lab (Amherst, Massachusetts)
17. Lehigh University (has done some testing) (Bethlehem, Pennsylvania)

Southeast

18. Clemson Wood Utilization and Design Institute (Clemson, South Carolina)
19. Virginia Tech Sustainable Biomaterials Lab (Blacksburg, Virginia)
20. Mississippi State University Department of Sustainable Bioproducts (Starkville, Mississippi)

Building Information Modeling

Building Information Modeling (BIM) is the process of creating virtual models in 3 (and sometimes 4) dimensions, including detailed or approximated components. BIM models are used for coordination and collaboration across architecture, engineering, manufacturing, and construction fields. In the last decade or so, BIM programs have become standard tools for design documentation, and they have revolutionized construction coordination and “clash detection” as well. These developments are auspiciously synchronized with the development of modular timber construction techniques. Design and construction models can often be adapted into shop drawings, facilitating communication around complex 3D-material intersections. BIM models can be highly detailed, so it is possible to have the quantities and dimensions of any building component, from conduits to fasteners to mass timber panels, determined well before it arrives on-site.

Precision and Prefabrication

The precision and design control of prefabricated building components (see **Figure 5.32**) appeal to designers around the world. Prefabrication has many benefits for the construction schedule, as discussed in more detail in chapters 6 and 8. Because mass timber is inherently prefabricated, designing with it may lead to further discussions of off-site fabrication, allowing it to grow from a focus on structure into more complex systems components, full wall assemblies, or even volumetric modular spaces. A build partner familiar with these techniques will be able to quantify the benefits of working with more complex prefabricated components. A project’s location and the availability of prefabrication facilities will also play a role in cost and viability.

Implications for the design team include planning for more up-front coordination and understanding connections among prefabricated elements. They must consider the extent of prefabricated

FIGURE 5.32: PRECISE PREFABRICATED MATERIAL INTERSECTIONS

IZM Building, CREE and Hermann Kaufmann
Source: Emily Dawson

components—and how they are sourced, manufactured, and procured—to estimate the amount of extra coordination required.

5.9 BUILDING CODES

When a building project team desires to use a material or construction method that is not included in applicable building codes, they must have the building permitted using an "alternate means" or "performance" approach to demonstrate to the permitting body that the project is equivalent to the adopted codes for the specified use. Although common for unusual building designs of all kinds, this process can be costly, time-consuming, and difficult—and its outcome is not guaranteed. This is why, for new structural materials, adoption into building codes is so important. Historically, common wood structural building materials and methods have been included in building codes across North America using Type IV construction. Type IV allows for the use of heavy, solid-sawn timbers (6 inches and larger in vertical framing components and 8 inches and larger in horizontal components), as well as commonly available wood composites, such as glulam beams. Other construction types (I, II, III, and V) allow for the use of wood elements, though some will require additional protections to increase fire resistance. Many multifamily housing project

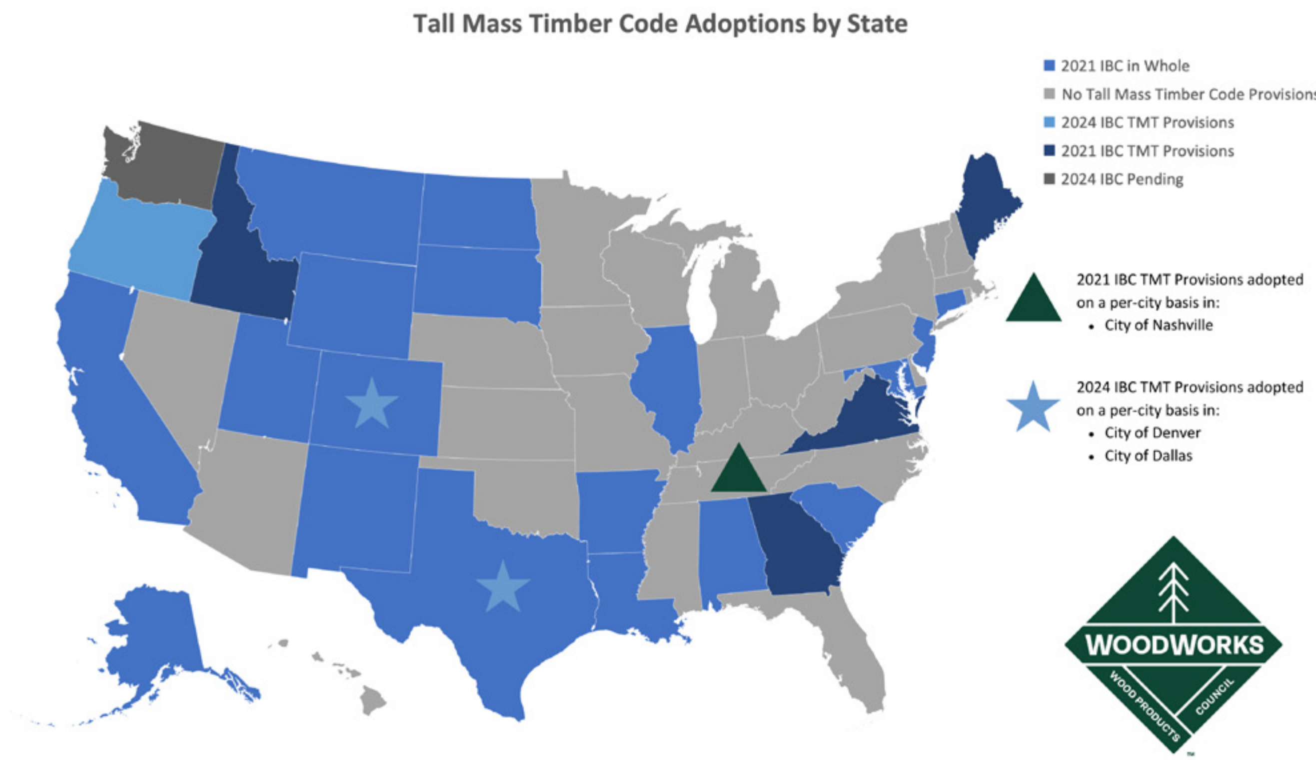


FIGURE 5.33: TALL MASS TIMBER CODE ADOPTIONS BY STATE

Source: WoodWorks

teams have found success using mass timber under Type III construction, and Type V can be an excellent choice for industrial buildings.

Organizations in the US and Canada develop building codes at the national level and revise them on 3- and 5-year cycles, respectively. Both countries have made several building code changes in recent years specific to the use of wood structural components; state/provincial and local authorities have adopted the changes on different timelines, creating a patchwork effect. **Figure 5.33** shows code adoption by US state, and in some cases, by city jurisdictions.

Canada

The 2015 National Building Code of Canada (NBC) allows wood to be used as the structural frame of buildings as tall as 6 stories for residential, office, and mixed-use occupancies. The previous version of the code allowed wood only in residential buildings, and they were limited to 4 stories. This update also recognizes mass timber for use in podium levels, considered noncombustible (NC). Two construction types are recognized in this version of the code: (1) combustible, including heavy timber, but recognized as having NC properties; and (2) NC.

Updates to the NBC, developed by the Canadian Commission of Building and Fire Codes (CCBFC), come out every 5 years and are adopted on

FIGURE 5.34: NATIONAL BUILDING CODE OF CANADA ADOPTION BY PROVINCE

a province-by-province basis. Most regions in Canada have adopted the 2015 code. The 2020 update of the NBC was released in early 2022 and added a new construction type: Encapsulated Mass Timber Construction (EMTC), commonly referred to as the EMTC provisions. The new code increases the maximum allowable height of mass timber structures from 6 to 12 stories. Requirements include encapsulation of structural timber with NC materials, and limited permissions for exposed structures.

The City of Vancouver, British Columbia, recognizes its own code authority autonomously from the province, and it has adopted the Tall Wood aspects of the 2020 NBC code. British Columbia and Alberta have allowed jurisdictions to apply for early adoption, and dozens have. Ontario has been supportive of alternative equivalent solutions for mass timber projects.

FIGURE 5.35: TYPE VB CONSTRUCTION

Janicki Industries Building 10, Hamilton, WA
Source: Vaagen Media, Credit: Structural design by DCG Watershed

United States

Keeping in mind that timber can be used structurally in any construction type that allows its use (see **Figure 5.35**), progressive improvements to building codes that address the use of timber as a fire-resistant material have been critical to increasing adoption across the country. In early 2015, the International Code Council (ICC) adopted new codes allowing the use of CLT in buildings up to 6 stories for offices and up to 5 stories for residential buildings. However, CLT use in taller buildings was not addressed. Because CLT is speculated to have competitive advantages in terms of cost and appropriateness of application in buildings that are 6 to 16 stories tall, the 2015 IBC adoption was considered only a partial improvement. The 2021 edition of the IBC included major changes to Type IV construction specific to mass timber, including provisions for the use of mass timber as a primary structural material in buildings up to 18 stories. These changes are often referred to as the Tall Wood Provisions.

Construction Type IV was revised to IV-HT and includes 3 additional types, distinguished by fire resistance, height, and area restrictions (see **Figure 5.36**).

Type IV-HT: Maximum 6 stories, 85 feet in height, and 108,000 square feet in area. Concealed spaces are allowed with exceptions for sprinklers, filled cavities, and protection with NC construction, such as gypsum.

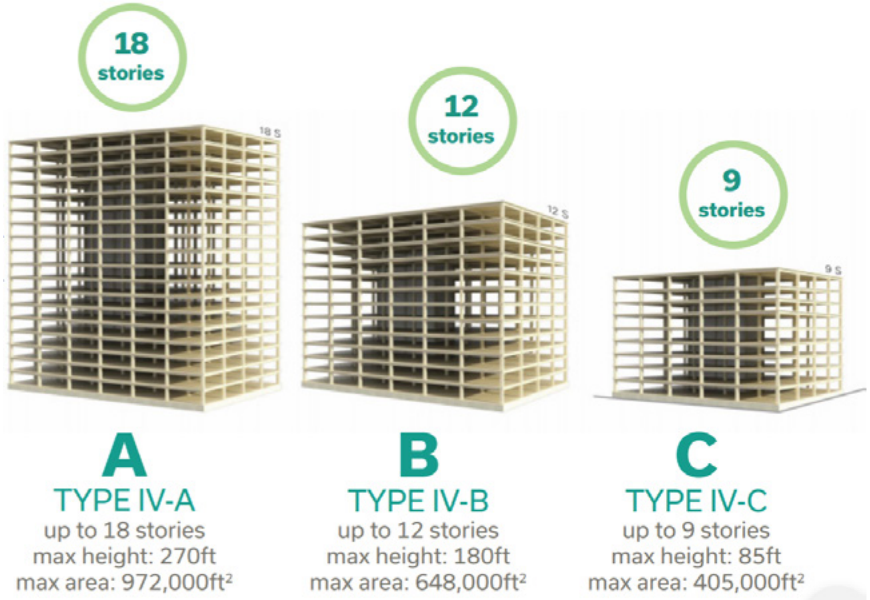


FIGURE 5.36: TALL WOOD CONSTRUCTION TYPES ADDED TO THE 2021 IBC

Think Wood Research Brief Mass Timber 2021 Code

Type IV-C: Maximum 9 stories, 85 feet in height, and 405,000 square feet in area, and all mass timber designed for a 2-hour fire resistance may be exposed. Concealed spaces are allowed if protected with NC construction.

Type IV-B: Maximum 12 stories, 180 feet in height, and 648,000 square feet in area. Exposed mass timber walls and ceilings are allowed with limitations, and concealed spaces are allowed if protected with NC construction.

Type IV-A: Maximum 18 stories, 270 feet in height, and 972,000 square feet in area. NC fire protection is required on all mass timber elements, and concealed spaces are allowed if protected with NC construction.

Following a successful fire compartment testing study performed in Sweden in 2020[18] that included technical advisory partners from around the world, the ICC 2024 Group A Code Committee voted to increase the allowed area for exposed ceilings in Type IV-B construction from 20 percent to 100 percent. This decision was made public in January 2022, and it will be included in the 2024 IBC.

The Woodworks Innovation Network (WIN) is a database of built and in-design US timber projects. As of winter 2023, 13 projects have been reported under the IV-C designation (see **Figure 5.37**), 65 projects have used IV-HT (see **Figure 5.38**), and, to date, no completed projects have reported using the IV-A (see **Figure 5.39**, 2024 completion date) and IV-B construction types.

Oregon and Washington have been leaders in the adoption of mass timber construction, proactively adopting the Tall Wood Provisions in 2018, and again with the upcoming 2024 provisions , this

18 https://www.ri.se/en/what-we-do/projects/fire-safe-implementation-of-mass-timber-in-tall-buildings

FIGURE 5.37: TYPE IV-C CONSTRUCTION

Heartwood, Seattle, WA

Source: atelierjones; Credit: Lara Swimmer

time joined by the cities of Denver and Dallas. Nineteen states have fully adopted the 2021 code, and 4 have adopted only the Tall Wood Provisions in advance of the full code. New York City has not adopted the Tall Wood Provisions; but in 2021, the City Council approved the use of mass timber for buildings up to 85 feet tall.

The 2024 Tall Wood Provision updates are a huge step for the uptake of mass timber in the US, helping project teams bring more mass timber buildings of up to 12 stories to market. Because encapsulation adds costs and diminishes many of the occupant and market benefits, cost-effectiveness will remain a challenge for Type IV-A structures.

Expanded Provisions for the Fire Design of Wood Members

The American Wood Council Wood Design Standards Committee has recently completed over 5 years of design standards development for the 2024 editions of the National Design Specification for Wood Construction (ANSI/AWC NDS-2024) and the Fire Design Specification of Wood Construction (ANSI/AWC NDS-2024)[19] (see **Figure 5.40**). Engineers and architects who design mass timber buildings that have fire resistance rating requirements will benefit from the expanded code language in these standards. Most of the changes to the NDS Chapter 16 were made to bring its provisions into alignment

19 https://awc.org/resource-hub/?gcat=codes-and-standards

FIGURE 5.38: 19 STORIES TYPE IV-HT OVER A 6-STORY CONCRETE PODIUM

Ascent, Milwaukee, WI
Source: New Land Enterprises; Credit: Nate Vomhof

FIGURE 5.39: ONE STORY OF STEEL OVER 16 STORES OF TYPE IV-A OVER

1510 Webster, Oakland, CA
Source: oWow; Credit: Andrew Nelson

with provisions within the FDS. The scope of NDS Chapter 16 has been updated to delineate where the NDS applies and where the FDS should be used.

Here are some of the highlights to changes in the NDS Chapter 16:

- NDS 16.2.2.4 has been added to permit the use of an approved char model for CLT that uses provisions of the FDS which addresses char penetration at lamination intersections.

- NDS 16.2.3 has been added to reference the FDS for design of char penetration at intersections and abutting edges of wood member.

- NDS Table 16.3.1: Provisions for determining effective char depths remain unchanged. However, provisions have been added in 16.3.1.4 to allow the use of a more detailed analysis for determining effective char depth of CLT, where more rigorous char models from NDS 16.2.2.4 are approved.

- NDS 16.3.1.5 provides new provisions for determining effective char depth specific to calculation of wood member bearing capacities.

- NDS Table 16.3.3: Adjustment factors for fire design of shear strength and bearing strength have been added.

FIGURE 5.40: 2024 NDS AND 2024 FDS

American Wood Council Design Standard
Source: American Wood Council

- NDS 16.4 has been added to reference the FDS for determining the structural fire resistance of wood members that are protected by materials such as additional layers of wood, gypsum wallboard, and/or insulation.

- NDS 16.5 has been modified to reference the FDS for the design of protection for fire-resistance-rated wood connections. This includes provisions for calculating adequate thermal separation and how to account for char penetration at gaps occurring at intersections and abutting edges of connections.

The 2024 NDS has been updated in time to be referenced in the 2024 edition of the IBC.

Future Code Updates

In the spring of 2023, at the University of California San Diego's Natural Hazards Engineering Research Infrastructure (NHERI)[20] Shake Table, a 10-story mass timber structure withstood tests designed to simulate the most destructive earthquakes ever recorded. The 10-story structure, featuring 4 mass timber floor types (CLT, GLT , N/DLT, and Veneer Laminated Timber [VLT]), and full-height rocking CLT and MPP shear walls, is the tallest structure ever tested (see **Figure 5.41** and **5.42**). The structure also includes various nonstructural assemblies for interior walls, the exterior envelope, and a prefab drift-ready stair detailed with the intent of limiting or avoiding

20 The shake table is located at the Englekirk Structural Engineering Center, and part of NSF's Natural Hazards Engineering Research Infrastructure network (NHERI), https://nheri.ucsd.edu/

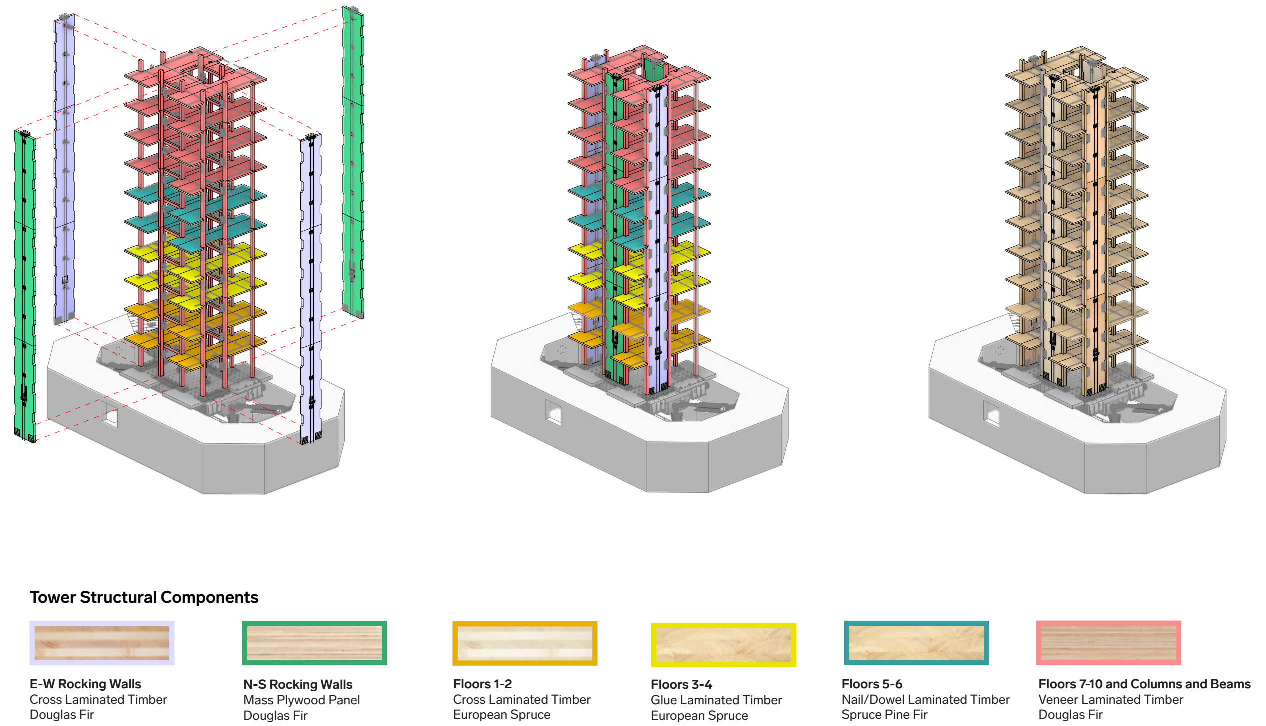


FIGURE 5.41: NHERI TEST CONSTRUCTION DIAGRAM

Source: LEVER

damage from the simulated earthquakes. Researchers determined that the building sustained no damage from the back-to-back tests. This has excellent implications for future inclusion in the building code for rocking shear walls as a prescriptive seismic force-resisting system for high-rise structures. A code change proposal to a future version of *ASCE 7* would follow a full review of the data and further testing and simulations.

Mass timber components are allowed in exterior wall assemblies, though only up to 40 feet (60 feet if using fire retardant-treated wood). The Tall Wood Provisions of the 2021 IBC indicate the potential to go higher, with language allowing timber in exterior wall assemblies for taller buildings, but these provisions are not reconciled with limitations in other sections of the code. Testing completed in spring 2022[21] demonstrated that "it is safe to utilize CLT in an exterior wall application above 40 feet in height." The tests were performed with 3-ply CLT exposed on the interior side, the first time a mass timber exterior wall assembly had been tested to the National Fire Protection Association (NFPA) 285 standard. The published test reports will help project teams use the material in this application before incorporation into building codes.

The USDA Forest Products Laboratory (FPL) hosted the third Mass Timber Research Needs Workshop in early 2023. Topics related to fire performance, durability, structural systems, and repair methodologies point to the need for new

21 Timberlab et al., Wood Innovations Grant, "Cross Laminated Timber Exterior Wall Testing to NFPA 285 Test Standard" (USDA Forest Service, 2021), and https://www.fs.usda.gov/sites/default/files/TimberLab-FireSafe.pdf.

research and eventually for code improvements, evaluated for relative industry impact and effort by mass timber professionals across sectors.

Embodied Carbon

A new frontier in construction-related legislation is embodied carbon. Energy codes have long helped guide the construction industry to greater energy efficiency and reduced operational impacts on carbon emissions. The year 2023 brought about the first steps toward addressing emissions related to the materials and construction of buildings. As of October 2023, under a Zero Emissions Building (ZEB) plan, the city of Vancouver, British Columbia, requires large buildings to report on embodied carbon and meet progressive reduction targets over the next decade, up to 40 percent below established baselines. In July 2024, California will incorporate new requirements into the state building code to limit embodied carbon emissions in commercial projects over 100,000 square feet and school projects over

FIGURE 5.42: 10-STORY TIMBER TOWER EARTHQUAKE TEST
NHERI Shake Table, 2023
Source: Timberlab/FLOR

TOPIC	WOODWORKS RESOURCES
Construction Type, Occupancy, & Use Resources	Tall Wood Buildings in the 2021 IBC – Up to 18 Stories of Mass Timber
	Mass Timber Cost and Design Optimization Checklists
	Accommodating MEP in Mass Timber Buildings
	Tall Mass Timber Trends and Exposed Timber Allowances
	Taking the Guesswork out of Mixed-Use Building Requirements
	Status of Building Code Allowances for Tall Mass Timber in the IBC
	Using Podiums in Tall Wood Buildings
	Key Design Considerations for Mass Timber Projects
	Heights and Areas Calculator

TABLE 5.7: MASS TIMBER RESOURCES FOR DESIGNERS
Source: WoodWorks.org/resources/

50,000 square feet. Using more bio-based materials is one way project teams can reduce the embodied carbon impact of buildings, and mass timber structures can help achieve significant reductions.

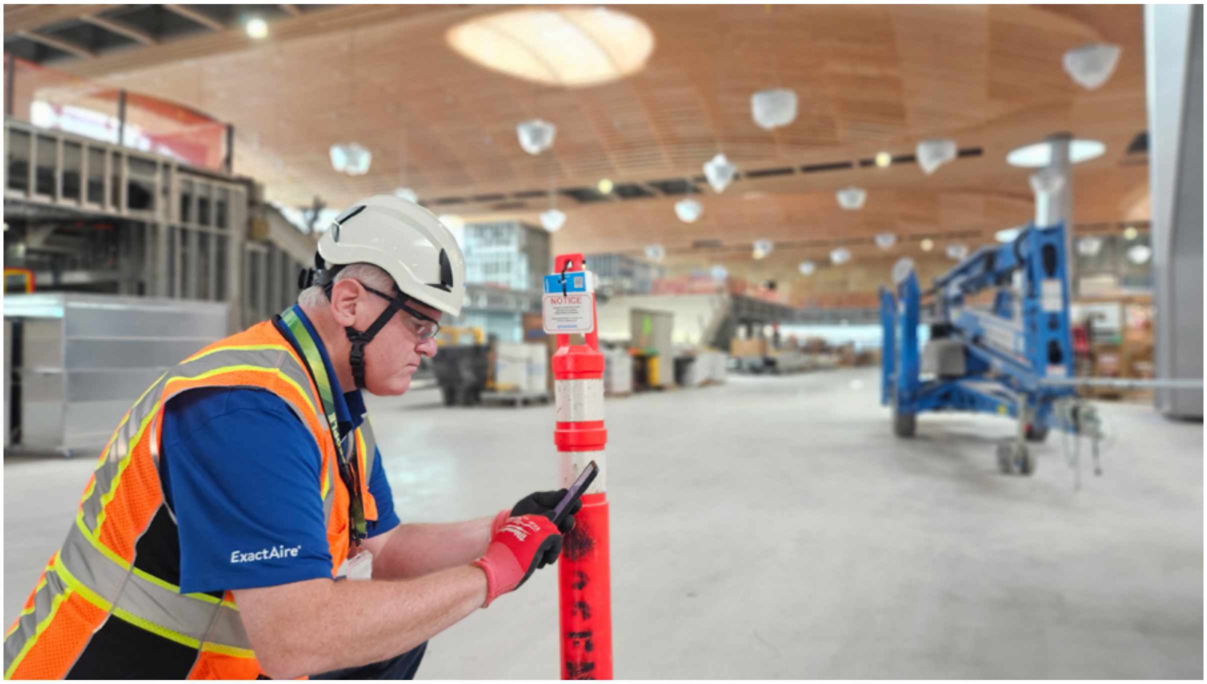
The topic of embodied carbon and its importance to designers is covered extensively in chapter 9.

5.10 AUTHORITATIVE SOURCES

Table 5.8 lists various authoritative sources referenced throughout chapter 5, and where they can be found for further research. Many must be purchased. However, acquiring up-to-date versions of these guides and standards will ensure that the user has access to complete and current information.

STANDARD	WEBSITE
International Building Code	https://www.iccsafe.org
National Building Code of Canada Fire Safety Design in Buildings	http://cwc.ca/design-with-wood/building-code/
AIBC Encapsulated Mass Timber Construction up to 12 Stories	https://aibc.ca/
NDS for Wood Construction; NDS Supplement; Special Design Provisions for Wind; and Seismic Manual for Engineered Wood Construction	https://awc.org/codes-standards/publications/nds-2018
Nail-Laminated Timber Design and Construction Guide	https://www.thinkwood.com/products-and-systems/nail-laminated-timber
CLT Handbook-US Edition Design and Cost Optimization Checklists and Downloads	https://info.thinkwood.com/clt-handbook https://info.thinkwood.com/mass-timber-direct-2
Technical Guide for the Design and Construction of Tall Wood Buildings in Canada	https://web.fpinnovations.ca/tallwood/
ANSI/APA PRG 320: Standard for Performance-Rated Cross-Laminated Timber; Glulam Product Guide; Glued-Laminated Beam Design Tables; ANSI/APA A190.1: Standard for Wood Products-Structural Glued-Laminated Timber; ANSI 405: Standard for Adhesives for Use in Structural Glued-Laminated Timber; Many more	https://www.apawood.org/resource-library
American Institute of Timber Construction: Test Methods for Structural Glued-Laminated Timber	https://www.aitc-glulam.org
CSA Standard O177-06: Qualification Code for Manufacturers of Structural Glued-Laminated Timber	https://www.csagroup.org

TABLE 5.8: AUTHORITATIVE SOURCES



A POLYGON EMPLOYEE CHECKS REAL-TIME T/RH LEVELS, USING THE EXACTAIRE REMOTE MONITORING MOBILE APP

Source: Polygon; Credit: Kevin Lockard

CASE STUDY: PDX NEXT — PORTLAND AIRPORT EXPANSION PROJECT

PROTECTING MASS TIMBER AND CONSTRUCTION AT PORTLAND AIRPORT

PROJECT OWNER: PORT OF PORTLAND (AIRPORT)

PROJECT LOCATION: 7000 NE AIRPORT WAY, PORTLAND, OR 97218

COMPLETION DATE: MAY 1, 2024

ARCHITECT/DESIGNER: ZGF

MASS TIMBER ENGINEER/MANUFACTURER: TIMBERLAB / ZIP-O-LAMINATORS

GENERAL CONTRACTOR: HOFFMAN SKANSKA JV

STRUCTURAL ENGINEER: KPFF CONSULTING ENGINEERS

OTHER CONTRACTORS: POLYGON US

POLYGON PARTNERED WITH Hoffman Skanska JV to monitor and manage indoor environmental conditions for protecting mass timber and materials on PDX Next, the Portland Airport expansion project. Stakeholders wanted visibility and control of temperature and humidity for creature comfort and drying of construction materials, and continuous wood moisture content monitoring for mass timber. Polygon designed a comprehensive climate-control solution with temporary heat and ExactAire remote monitoring.

PROBLEM

Polygon needed to heat about 10 million cubic feet with 50-foot ceilings. They saw 3 problems with using direct-fired heat:

1. Finding and occupying outside space would be difficult.
2. Direct-fired heat uses outside air, which can lead to high fuel consumption and additional humidity.
3. Direct-fired heat produces fuel-hazardous by-products, like carbon dioxide, that can negatively impact people and the environment. This didn't align with what Polygon knew about the environmental, social, and governance philosophy of the project.

As for the mass timber, the roof was being built in 20 sections outdoors. Although the beams were sealed, it was possible that moisture might get trapped, leading to mold. Conversely, heating equipment might cause overdryness, leading to checking or splitting. Polygon offered a more proactive approach to help avoid any potential problems.

SOLUTION

The first step was to deploy remote monitoring. Twenty-two ExactAire multisensors were installed to continuously record ambient conditions. Six were equipped with wood moisture equivalent (WME) probes and connected to beams.

A few months later, Polygon installed 5 fuel-efficient, 1 million-BTU heaters indoors. These produced and recirculated clean, warm air to over 60 degrees Fahrenheit.

"Polygon set up a custom ExactAire system, online dashboard, and reporting process," said Joel Bennett, project manager for Hoffman Skanska JV. "We can see if there's an issue right away and, based on the location of the sensor, we can quickly hone in on the cause and get right to work on the solution. We also have the history and trendlines, which provide assurance that conditions are kept within the necessary ranges for our mass timber and finish elements. It's great to be able to show, without any question, that conditions are right. It removes any doubt and helps us keep things on track and moving forward."

BENEFITS

The combination of ExactAire and the right climate control gave stakeholders reassurance that the proper conditions were being produced, and they were able to communicate that information. This helped with managing schedule slips and helped to protect materials from poor conditions.

The trend logging from ExactAire serves as documentation and verification for future reporting. Should anyone question what conditions were at a given point in time, the project team will be able to share temperature, relative humidity (RH), and WME data.

A superior, efficient heating solution was provided because Polygon understood the trade-offs among the options, the requirements and limitations of the job and site, and the overall project goals.

Full case study:

https://www.polygongroup.us/PDX

YWKW SUPPORTIVE HOUSING
Source: Edge Architects

CASE STUDY: YWCA SUPPORTIVE HOUSING

CELEBRATING R&D IN MASS TIMBER ACOUSTICS

PROJECT OWNER: YWKW

PROJECT LOCATION: 1470 BLOCK LINE RD. KITCHENER, ON, CANADA N2C 2S2

COMPLETION DATE: OCTOBER 1, 2022

ARCHITECT/DESIGNER: EDGE ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: ELEMENT5

GENERAL CONTRACTOR: MELLOUL-BLAMEY CONSTRUCTION

STRUCTURAL ENGINEER: MTE CONSULTANTS (MECHANICAL, ELECTRICAL, AND PLUMBING), DEI CONSULTING (ENGINEERS), HGC ENGINEERING (OTHER CONTRACTORS)

THE YW BLOCK Line Supportive Housing complex is a 22,819-square-foot, 4-story mass timber residential building at 1470 Block Line Road in Kitchener, Ontario. The building includes 41 affordable 1-bedroom housing units for single women experiencing or at risk of homelessness. These homes come with built-in support services, including case and crisis management, help with daily life skills, and access to food bank services. The housing project was built on land provided by the City of Kitchener with support from YW Kitchener-Waterloo (YWKW), and from the federal government's Rapid Housing Initiative (RHI).

LEFT — SOUND TRANSMISSION MEASUREMENTS

RIGHT — A WORKER MEASURES VIBRATION TRANSMISSION ACROSS A JUNCTION.

Source: HGC Engineering; Credit: Simon Edwards

This project won the 2023 Ontario Wood WORKS! Design award for design excellence, advocacy, and innovation, as well as the 2023 Sustainable Kitchener Award for demonstrating innovation and exceptional design with respect to sustainable development.

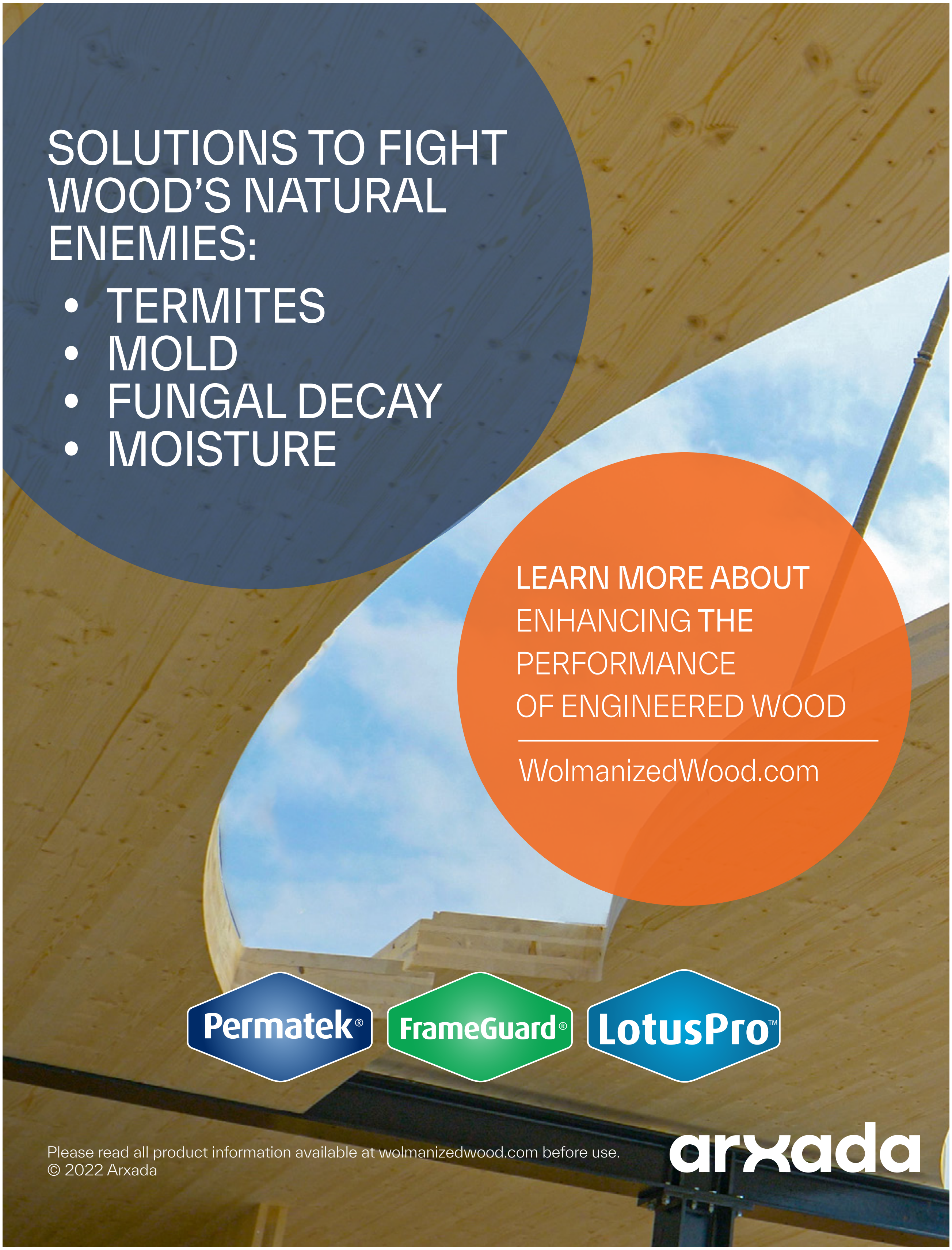
A core requirement of the RHI funding is that the development be built within 12 months of the contract award. The use of prefabricated, modular mass timber components that were factory-built and then assembled on-site helped reduce the length of the construction schedule while also delivering cost savings over a traditional site-built project.

HGC Engineering provided comprehensive acoustical services for this project. It was a challenge at first, given the lack of testing data available for the proposed exposed, modular mass timber assemblies. In 2015, Canada amended the National Building Code (Sections 5.9 and 9.11) to consider airborne sound transmission concerns through flanking (indirect) transmission paths, introducing added complexity to designing mass timber buildings with exposed wood walls or ceilings. HGC designed acoustical isolations for the Cross-Laminated Timber (CLT) structure at the junctions, and it provided ASTC testing of the suite-demising assemblies during construction.

Continuous mass timber panels across suite-demising boundaries could not be exposed in adjacent suites to maintain code compliance, based on research from the National Research Council (NRC) regarding sound transmission through these continuous panels. This led to a design with dropped ceilings in every other suite in a checkerboard pattern.

However, field testing and additional testing since this project suggested that, with an isolated concrete topping above the mass timber (not present in the NRC testing), this flanking transmission path may not limit compliance with code requirements. This is a significant acoustical development toward allowing developers to maintain exposed CLT ceilings in adjacent suites even when CLT panels are continuous. This research has further expanded into discussions regarding the possibility of "dry" buildups (e.g., isolated plywood toppings) or different roof assemblies such as green roofs to create a similar effect.

In addition, YWCA Supportive Housing included mass timber suite-demising walls and exterior walls; indirect sound transmission vertically or laterally through the exterior wall or from the exterior wall through other structural elements above and below was also of concern. Isolated junction details were developed to reduce this transmission, but the need to maintain full building-height exterior wall CLT panels lined horizontally along the facade resulted in the protection of the majority of exterior walls with insulated drywall partitions.


SOLUTIONS TO FIGHT WOOD'S NATURAL ENEMIES:
• TERMITES
• MOLD
• FUNGAL DECAY
• MOISTURE
LEARN MORE ABOUT ENHANCING THE PERFORMANCE OF ENGINEERED WOOD
WolmanizedWood.com
Permatek®
FrameGuard®
LotusPro™
Please read all product information available at wolmanizedwood.com before use.
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CHAPTER 6: BUILDERS

EMILY DAWSON
OWNER, SINGLE WIDGET

Mass timber is a disruptive technology with respect to building construction, with increased off-site fabrication and highly collaborative construction approaches. The necessity of these approaches is a result of the size and weight of the structural components, precluding significant modifications at the construction site. Many contractors will find the information in chapter 5 relevant as teams become more integrated, optimizing the design, schedule, and costs together in real time.

FIGURE 6.1: TALL TIMBER RISING
Heartwood, Seattle, Washington
Source: APA – Timberlab Inc.

Prefabricated mass timber panels are typically made to order once the project's architectural and engineering design is complete, and construction site logistics are understood and integrated. This naturally puts a high premium on integration of the design, manufacturing, and construction aspects of the project, relying on tight collaboration among all parties from the start and creating an incentive for vertical integration of companies along the supply chain.

6.1 WOOD AS A CONSTRUCTION MATERIAL

Despite being a common building material for many construction types, in the global construction materials market, timber's share is tiny compared with concrete and metal products. In a 2023 Allied Market Research Study,[1] aggregates, cement, and bricks and blocks overwhelmingly dominated the market in terms of revenue. The study notes, however, that "with increasing urban populations, there is a need for environmentally friendly construction materials and sustainable building practices to reduce the impact on resources," and it acknowledges an increasing "demand for materials made from renewable resources." The report goes on to state that "the growing demand for green construction materials is anticipated to offer many opportunities for market growth in the coming years."

See chapter 8 for data on the US construction market, as well as mass timber market data by project and material type.

Compared with steel and concrete, the other 2 primary construction materials, wood is unusually strong in both tension and compression for its weight, and it is the only innately renewable structural material with a significant market presence. The structural properties of timber result from trees evolving to carry substantial crown loads and

1 *Construction Materials Market Research*, 2032, https://www.alliedmarketresearch.com/construction-materials-market-A68813.

FIGURE 6.2: LIGHT WOOD-FRAME BUILDING

Source: APA – The Engineered Wood Association

resist swaying in the wind. These properties make wood highly effective for dynamic loading and fatigue as well. As such, wood has a high potential for resilience—uncompromised recovery—as a structural material under strong gravity loads, as well as seismic and wind loads (see **Figure 6.1**).

Three types of wood construction are reviewed here: light frame, traditional heavy timber, and mass timber.

Light Frame

This type of construction, also known as "stick frame," is the most common construction method for residential buildings in North America. Light wood-frame construction can be panelized for a prefabricated construction approach, or combined with mass timber in a hybrid structural system. It is widely used in low- and mid-rise commercial buildings. For lateral resistance and spanning between "sticks," Engineered Wood Products (EWPs) such as plywood or Oriented Strand Board (OSB) sheathing are commonly used (see **Figure 6.2**).

The advantages of this building system are low cost, material availability, and ease and speed of assembly. The smaller format of the building materials means workers can move them around a jobsite more easily than larger and bulkier materials such as steel beams. They can also use relatively common, inexpensive, lightweight tools. Lumber and sheathing typically arrive on the construction site in bulk, and are then cut to fit the design at the site, meaning that the design may continue to be adjusted until the framing is complete. All these factors contribute to the widespread use of this construction type for buildings that have lower fire-resistance requirements.

A disadvantage of light wood-frame construction is the amount of waste generated on-site, increas-

FIGURE 6.3: POST AND BEAM BUILDING

Source: Nordic Structures

ing the cost of in-place materials. And of all the building styles discussed here, light wood-frame carries the lowest resistance to fire damage.

Heavy Timber

Heavy timber is another traditional method of wood construction, often referred to as "post and beam." The mass and size of these timbers provides fire resistance. In this construction style, large timbers form vertical columns, and horizontal beams are connected either with wooden joinery or metal connectors (see **Figure 6.3**). A key implication of this design is that the columns bear the building's weight, meaning the walls are not load-bearing.

Because the timber columns and beams bear the weight, post and beam construction offers greater design flexibility and allows customized and open floor plans. Another advantage is quick completion of the structure. Many consumers also find the natural warmth and elegance of exposed wood surfaces appealing.

Mass Timber

Mass timber (see **Figure 6.4**) refers to engineered wood members that offer a high level of fire resistance because of their size. (See chapter 1 for definitions of the many types of components that fall into this category.) Up to this point, most mass timber buildings in North America have been low- to mid-rise. However, the 2021 US building code allows timber buildings up to 18 stories (270 feet), with reduced encapsulation requirements arriving in the 2024 version of the code. Canada has also developed the Tall Wood Provisions.

FIGURE 6.4: A CLT AND GLULAM MASS TIMBER OFFICE BUILDING
First Tech Federal Credit Union, Hillsboro, Oregon
Source: Swinerton Builders

For more details, and for information on regional adoptions of these codes, see chapter 5.

6.2 PRECONSTRUCTION

When mass timber started making headway as a building material in North America, few building contractors were experienced in expanding what had been the post and beam, heavy timber paradigm. New mass timber technologies necessitated a fresh approach.

Mass timber introduces a paradigm shift in construction that enforces integration of the design, manufacturing, and construction processes. This integration challenges the traditional procurement processes and standard allocation of risks and responsibilities. Integrated approaches offering solutions akin to a turnkey package from design through construction also may create conflicts with parties bidding for individual parts and design-bid-build contract models.

Recognizing the urgent need to train construction teams and trades in the US in mass timber, WoodWorks has published resources (see **Table 6.1**) to help guide contractors on the particularities of bidding, planning, and constructing with mass timber.[2] With partners nationwide, WoodWorks also offers workshops on mass timber project management and training in installation.

To bid and plan mass timber projects successfully, build team members should familiarize themselves with project optimization during de-

2 WoodWorks, *Mass Timber Construction Manual* (October 2021).

TOPIC	WOODWORKS RESOURCE
Contracting & Installation	U.S. Mass Timber Construction Manual
	Mass Timber Installation Training Curriculum
	Mass Timber: Shifting Labor from Jobsite to Shop
	Insurance for Mass Timber Construction: Assessing Risk and Providing Answers

TABLE 6.1: MASS TIMBER RESOURCES FOR DESIGNERS

Source: WoodWorks.org/resources/

sign and procurement, digital tools like Building Information Modeling (BIM) and Computer Numerical Control (CNC) technology, and the use of prefabricated components.

Optimize during Design

A custom mass timber package can save significant field costs, but only if the design and procurement/build teams work together as early as possible in the design process. Often, traditional procurement processes are a barrier to early collaboration among designers, builders, and manufacturers. A property owner considering a mass timber building should choose a procurement process that supports the close collaboration required for the best value outcome (also see chapter 8). Some build teams recognize the advantages of "vertically integrated" building production processes and integrate traditionally separate functions within one company. Others offer an alliance of partners with know-how and a history of collaboration.

Each mass timber manufacturer has specific efficiencies and limitations that should be worked into the design and logistics plans. Optimizing the design and erection process balances the premium costs of early planning, the use of high-value materials, and prefabrication. Early communication among the design, manufacturing, and construction teams can also lead to efficiencies offered by using available component sizes, prefabrication, and high-precision CNC finishing. If layout and detail optimization begins later in the process, such as during bidding, that introduces the risk that a significant redesign may be required to achieve an on-budget package. Design work done during the construction phase creates cost and schedule risks; one of the cost advantages of the mass timber construction approach is a reduction of these risks.

The schedule benefits of early coordination also occur in the field. A savvy contractor will amplify the structural coordination benefits into other trades as well. A high level of coordination during design, for example, was an essential part of the construction-phase success of Carbon12, an 8-story mass timber building in Portland, Oregon. The project team chose a design-build approach, allowing significant time for mechanical, electrical, plumbing, and fire (MEPF) system coordination with the Cross-Laminated Timber (CLT) package. Along with optimizing the structure, the MEPF penetrations were reduced by careful consideration from an installation-sequencing standpoint. The sequencing plan ensured trades were not in conflict

LOCATED IN OAKLAND, CALIFORNIA, 1510 WEBSTER STREET IS THE FIRST POINT-SUPPORTED (BEAMLESS) MPP HIGH-RISE IN THE WORLD.

Source: DCI Engineers; Credit: Erin Spaulding, DCI Engineers

CASE STUDY: 1510 WEBSTER STREET

1510 WEBSTER: A WORLD AND WEST COAST FIRST

PROJECT OWNER: oWOW

PROJECT LOCATION: 1510 WEBSTER ST, OAKLAND CA, 94612

COMPLETION DATE: FEBRUARY 1, 2024

ARCHITECT/DESIGNER: oWOW

MASS TIMBER ENGINEER/MANUFACTURER: WEBCOR TIMBER & FRERES ENGINEERED WOOD

GENERAL CONTRACTOR: oWOW

STRUCTURAL ENGINEER: DCI ENGINEERS

MECHANICAL, ELECTRICAL, AND PLUMBING: FARD & MELGAR (MECHANICAL); EMERALD CITY AND CES (ELECTRICAL); AND MK ENGINEERS AND LOWERY PENA (PLUMBING)

WHEN IT WAS topped out in early August 2023, 1510 Webster Street, a 19-story residential tower with 17 stories of mass timber in Oakland,

LEFT — AFTER DEVELOPING A FINITE ELEMENT MODEL, PERFORMING AN ANALYSIS ON 2-WAY BENDING FOR PANELS, AND CONDUCTING TESTING AT WOOD RESEARCH AND DEVELOPMENT, DCI ENGINEERS DETERMINED THE PROJECT COULD USE 5-INCH MPP PANELS INSTEAD OF 6-INCH PANELS, WHICH SAVED 16 PERCENT ON WOOD FIBER.

RIGHT — 1510 WEBSTER'S MPP FLOORS AND COLUMNS PRODUCED A 40 PERCENT LIGHTER STRUCTURE THAN A COMPARABLE CAST-IN-PLACE CONCRETE SYSTEM.

Source: DCI Engineers; Credit: Erin Spaulding, DCI Engineers

California, became the first Type IV-A high-rise mass timber tower in the United States. In addition, 1510 Webster also became the first point-supported (beamless) Mass Plywood Panel (MPP) high-rise in the world.

DCI Engineers, the structural engineer of record, collaborated with oWOW, a vertically integrated Oakland-based developer, architect, and general contractor, to capitalize on mass timber's construction speed to deliver market-rate and affordable units.

Performing additional strength and deflection testing of the MPP, DCI confirmed that thinner panels than originally calculated could satisfy all code and performance requirements. Although MPP provides higher flexural and shear strength, and greater stiffness for the floors, the 1510 Webster Street project also used Mass Ply Lam (MPL) for the columns. MPL is very similar to MPP in that it is fabricated from a thick buildup of plywood.

Given that the project is 3 miles from the Hayward Fault and 14 miles from the San Andreas Fault, the substantial reduction in weight provided by using mass timber was key. The MPP floors and columns resulted in a 40 percent lighter structure than a comparable cast-in-place concrete system. The lighter floor system reduces demands on the lateral system and, therefore, the foundations, equating to an overall reduction in materials and embodied carbon. DCI is performing a comparative Whole Building Life Cycle Assessment (WBLCA) case study in collaboration with WoodWorks to confirm and quantify the embodied carbon reduction of mass timber versus a conventional concrete structure.

The project is expected to reach occupancy by early 2024, adding 200 units to the Bay Area.

Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Expanding Mass Timber Market Opportunities

Talk to us about getting your mass timber project from the drawing board to market. Our Wood Innovations team manages grants and provides technical expertise to assist in realizing the full potential of the growing demand for mass timber construction. Our Forest Products Lab provides wood product research. The USDA Forest Service is here for you.

USDA Forest Service Wood Innovations Program and Forest Products Lab

- Innovation Grants support design and engineering, development of U.S.-sourced timber, and U.S. manufacturing of mass timber and other wood products
- Research on Building and Fire Science, Sustainability and Life Cycle Assessments

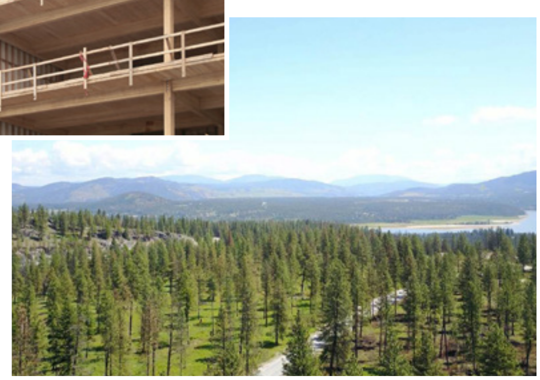


Photo Credits (from top to bottom)
Vaagen Timbers
Albina Yard: Jeremy Bittermann courtesy LEVER Architecture
CLT Fire Testing: USFS
Building construction: LEVER Architecture
After harvest: Vaagen Timbers

during installation, leading to the subcontractors "working together like a well-oiled machine."[3]

This high level of coordination and early involvement of integrated design, fabrication, and construction teams are often offered as part of a package by seasoned mass timber panel companies, and/or by contracting companies specializing in mass timber panel construction.

For best practices for early coordination, WoodWorks has created mass timber cost and design optimization checklists to assist project teams (see **Table 5.3**).[4]

Quantifying Cost Savings

For many reasons, mass timber buildings can be less costly than other construction types. Cost estimating, however, is traditionally based on a wealth of data from past projects, and few contractors in North America have a portfolio of mass timber data to draw from yet. Regardless of experience level, estimates that are not holistically coordinated with the design, procurement, and logistics teams will be less accurate.

One of the most quantifiable ways to estimate the difference between one construction approach and another is through the schedule. Mass timber construction is quicker, uses lighter equipment, and has less on-site labor than a comparable building of steel or concrete. Thus, fewer resources are required for a shorter period, creating ripple effects on other costs for the building owner.

Identical buildings are rarely constructed using different structural materials, however, so apples-to-apples cost comparisons are rare. Cost comparisons among structural materials may be made, but they are based on plans and estimates, not on actual construction costs. Developers often want to test different structural materials for the same project in a comparative cost analysis. In this process, when high-unit-cost items are flagged for replacement with lower-cost materials, mass timber is often eliminated. Looking holistically at estimated schedule impacts is crucial when comparing mass timber with other building materials. Just as important is considering materials reductions throughout the building, such as reduced foundation and excavation costs, and the elimination of drywall, framing, and painting of exposed wood surfaces.

Oakland-based developer oWOW produced a full-building cost comparison between the final design of their residential tower 1510 Webster (scheduled for completion in 2024) and a concrete and curtain wall analogue. The Type IV-A 19-story tower was built using 17 stories of Mass Plywood Panel (MPP) slabs and Mass Ply Lam (MPL) columns over a 2-story concrete podium. The team took advantage of the expedited structural erection schedule by installing a prefabricated light-gauge steel facade (see **Figure 6.5**) that allowed the in-house construction crews to raise each floor in 3–4 days with enclosure following closely behind. When compared with the concrete alternative, the mass timber building saved over 25 percent on costs and 6 months of construction time.

3 www.buildingCarbon12.com
4 https://www.woodworks.org/wp-content/uploads/wood_solution_paper-Mass-Timber-Design-Cost-Optimization-Checklists.pdf

FIGURE 6.5: 25 PERCENT COST SAVINGS WITH MASS TIMBER STRUCTURE AND PREFABRICATED FACADE PANELS

1510 Webster, Oakland, CA
Source: APA — The Engineered Wood Association

Insurance

Elevated premiums for builders' risk insurance for mass timber buildings continue to be a challenge. While insurers' perception of combustibility is shifting away from comparisons with light framing, no alternate between this paradigm and "noncombustible" exists yet as a standard in the industry. Some insurers are starting to see the future market in decarbonized construction and find assurance in successful projects with trusted builders.[5]

Procurement

The advantages of contractor involvement in early project planning include adding valuable insight into material availability. The number of mass timber manufacturers in North America is increasing every year, but available capacity can still vary greatly depending on regional project demands. This supply-and-demand pressure will continue to shift as the market matures, more facilities come online, and mass timber building designs become more common. Establishing a rough timeline with a manufacturer well in advance of breaking ground will ensure a project meets delivery expectations and avoids the high cost of storing massive elements between fabrication and construction. One often-overlooked aspect driving lead time is custom detailing work during component production. Selecting and engaging with a manufacturer early on can also help ensure that the planning team has plenty of time to coordinate and approve shop drawings.

5 https://axaxl.com/press-releases/axa-xl-announces-tailored-insurance-to-help-clients-address-mass-timber-construction-risks-in-north-america

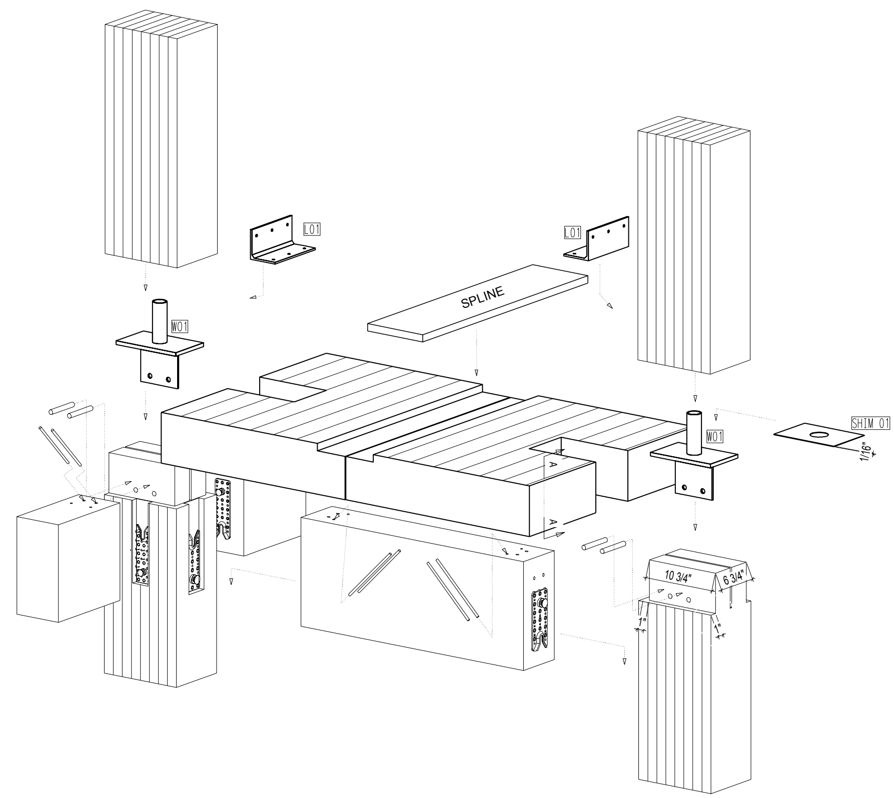


FIGURE 6.6: KIT-OF-PARTS ASSEMBLY DIAGRAM FOR TIMBER COLUMN, BEAM, AND CLT FLOOR ATTACHMENTS

Carbon12, Portland, Oregon
Source: Kaiser+Path

Engineered mass timber components are custom products composed of wood fiber that is subject to the fluctuations of a commodity market. Wood fiber prices can change from week to week, playing a part in estimating and timing orders.

BIM and CNC

Mass timber, BIM, and CNC (see chapter 5 for more information) are coming of age together, a synergy that is contributing to the exponential uptake of mass timber technologies. The planning and coordination required for reducing on-site construction time through prefabrication is well supported by a collaborative virtual building model that feeds information directly to the manufacturing equipment. BIM's potential to streamline coordination through design, manufacturing, and construction is developing rapidly.

During design, the most common and effective way to use BIM for mass timber coordination is for the architectural, structural, and MEPF designers to create intersecting three-dimensional (3D) models. These 3D models can also be shared with the mass timber manufacturer to create shop drawings for fabrication. Leading mass timber companies and specialized construction companies working with mass timber panels also use BIM for coordinating construction and optimizing sequencing of construction and building finishing jobs.

The process often reaches higher levels of sophistication and can involve both the design team and the build team, depending on the skills of the contracted teams and the objectives of the project. Possibilities include detailing down to the level of fasteners (see **Figure 6.6**), using the model for materials takeoffs and ordering, clash detection (a digital analysis of potential field conflicts) for all building systems, and modeling for prefabrication of each building component. Up-front coordination avoids major adjustments of massive components on the construction site, when adding even small cuts to address unforeseen conflicts with other systems can be laborious, costly, and risky. In these cases, on-site construction activity should be treated more like the assembly of a kit-of-parts. The confluence of BIM and mass timber is leading to increasing conversations about the potential of fabricating more—and more complex—components off-site.

6.3 PREFABRICATION

Successful projects that maximize prefabrication are pushing the building industry to reconsider project delivery. The Modular Building Institute estimates that modular construction projects reduce construction schedules by 30 percent to 50 percent.[6] Prefabricating an entire structural system has benefits for on-site safety, schedule efficiencies, and precision, appealing broadly to installers, building owners, and designers. In this way, mass timber has become a catalyst for prefabrication in North America, following successful European precedents.

The potential for off-site fabrication is huge, but facilities are limited in North America. The most common approach is component-based, where large, complex, precise elements are manufactured off-site and set in place, reducing off- and on-site buffer storage needs, installation time, and overall schedules. Flat-pack wall systems (panelized) and volumetric (modular) strategies are designed to install multiple interacting materials, utilities, and finishes in a climate-controlled interior environment. The benefits include a higher level of quality control and faster on-site erection times. Whatever the approach, local jurisdictional inspection requirements, transportation limitations, and shipping and handling expenses should be considered. These added costs should be weighed against the potential advantages that can be realized in all project phases, from design to project delivery, when increasing prefabricated processes.

Large-scale timber components typically arrive on-site in stacks organized for rapid erection of walls and floors. Because a crane is necessary to move these large components into place, the design and build teams can take advantage of the investment and look for opportunities to fabricate other time-consuming building elements into larger components, such as facades or mechanical systems. This is especially true for sites where transportation and labor costs are high or staging space is minimal, such as remote locations or constrained urban sites.

Prefabrication and a design-build partnership were key to significant schedule savings at the 4-story residential building Project One (see **Figure 6.7**). Located on a site in San Francisco with no lay-down area, the building's original structural framing schedule was estimated at 3

6 https://www.modular.org/what-is-modular-construction/

FIGURE 6.7: PRECISION COMPONENTS QUICKLY ASSEMBLED ON A CONSTRAINED SITE
Project One, San Francisco, California, Gurnet Point Construction, DCI Engineers, Freres Lumber Co.

months. Using precision-fabricated MPP components for the floors and roof, and panelized light-frame walls and moment frames, the structure was completed on budget in just 24 working days.[7] The design-build team worked closely with the MPP manufacturer on design coordination and delivery, and the owner deemed the approach a huge success.

When MEPF penetrations are precisely located, as with a coordinated BIM process, many components can be fabricated off-site and installed directly in place. Improved planning results in fewer trade conflicts on-site, whether or not additional off-site construction is part of those trades' strategies. Maximizing prefabrication can also lead to a rapid sequencing of other trades' critical path components that is able to keep up with—and take advantage of—the speed of mass timber structural erection.

Brock Commons, an 18-story student residence hall at the University of British Columbia (UBC) in Vancouver, was erected at 2 floors per week, following the concrete foundation and cores. The CLT and glulam levels were closely followed by a panelized timber facade (see **Figure 6.8**), providing immediate weather protection and savings in

7 Information from Freres Lumber Co. Inc.

FIGURE 6.8: PREFABRICATED FACADE PANELS FOLLOW CLOSELY BEHIND STRUCTURAL FRAMING

Brock Commons, University of British Columbia
Source: Ralph Austin at Seagate Structures

on-site scaffolding, time, labor, and risk. In fall 2017, only 66 days from when the first panels arrived on-site, the building was structurally topped out and enclosed.

A modular building approach naturally leads to less time and labor on-site, cutting down on construction-related disruptions such as increased traffic, lane closures, and noise. Large structural components delivered in predetermined sequences can be off-loaded relatively quickly and immediately set in place, with fewer overall deliveries. In Europe, where urban site constraints frequently have high impacts on construction approaches, mass timber has been found to reduce structural site deliveries by as much as 80 percent. Plus, less lay-down space is needed when installation coincides with just-in-time delivery.

Relocation of Labor

When more labor takes place at a manufacturing facility (see **Figure 6.9**), on-site construction crews become smaller (see **Figure 6.10**). This naturally reduces overhead costs and risks associated with coordinating on-site trades. Increased prefabrication of building components also has excellent implications for workforce health, safety, and quality of life as labor moves from site work to a factory setting. In a study of 100 mass timber

FIGURE 6.9: ASSEMBLING PREFABRICATED COMPONENTS IN A FACTORY SETTING

Source: Katerra; Credit: Kristopher Grunert

buildings in the United Kingdom, Waugh Thistleton Architects found a 50 percent to 70 percent reduction in site staff for structural framing. In Oregon, the 38,000-square-foot Carbon12 required only 4 carpenters for the 10-week duration of structural erection for all 8 stories.

FIGURE 6.10: A SMALL FRAMING CREW GUIDES PANEL PLACEMENT

Source: The Canyons
Credit: Marcus Kauffman, Oregon Department of Forestry

Safety

In a factory setting, the hazards experienced on a construction site are dramatically reduced. Worker safety is improved, and the likelihood of accidents decreases by about half. According to research from University of Utah, "By moving to prefabrication, the construction industry and its workers can experience a much safer environment by a factor of 2."[8]

8 Ryan E. Smith, *Prefab Architecture* (2010), 86.

Climate Control

In some climates, harsh conditions are challenging for human health and limit the hours available for construction. A framing crew working in a hot climate, for example, will arrive on-site as early in the day as possible to avoid noon sun exposure, possibly conflicting with local noise ordinances. Prolonged exposure to extreme conditions, as on an unshaded or freezing jobsite, stresses human health and increases safety risks. Controlled temperatures, air quality, noise, and comfortable light levels can be provided in an interior environment. Such conditions are healthier and safer for long-term work, and they open jobs to more candidates.

Commute

Construction workers who commute to a jobsite are at the mercy of the project location and its distance from their home and community. Some remote jobsites require temporary accommodations, and laborers travel home only for weekends. Long and always-changing commutes are challenging for families and workers, and they must sacrifice family time, sleep, or other healthy habits.

Ergonomics

For repetitive tasks, a factory can provide more ergonomically designed support. A work surface, for example, can be set at a comfortable height for tasks that might require kneeling on-site.

Diversity

Because of the factors cited above, factory environments make jobs more accessible to women, people with health concerns or disabilities, and older workers. Diversity within a company has many proven benefits, including increased productivity, creativity, engagement, and profit, and reduced turnover. The benefits ripple beyond projects and companies into healthier, more sustainable communities.

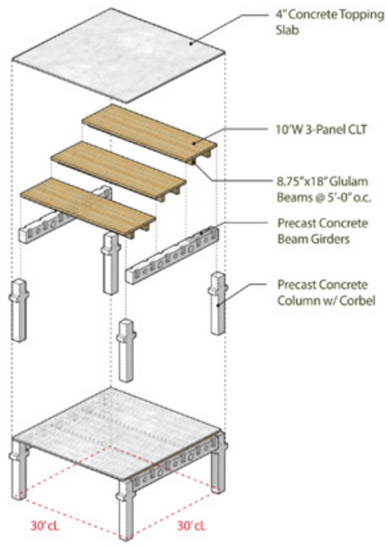
Skills and Training

In a factory producing complex building components, greater opportunities exist for a wide range of skill sets. A mass timber manufacturing facility will have positions that require little training, as well as positions that require high-level skills with more earning potential. Unskilled workers are more easily supervised and represent less risk in a controlled facility than on a construction site. Skilled labor might range from craft and finish work to operating computer-aided equipment (like a CNC machine) to coordinating BIM processes with external design teams. "[T]he prefabrication architecture laborer is much more skilled than any mass-production laborer in previous generations, moving to more intellectual, computer, or even management tasks."[9] Such a range of job opportunities supports diverse communities—especially beneficial in rural communities with limited job options.

6.4 PRECISION AND CONNECTIONS

Custom-engineered timber components are very precise, with tolerances in the range of $^1/_{16}$ inch. They must be fully coordinated in advance to ensure no field modifications are necessary. Interfaces between mass timber components and other building materials should be identified and proper tolerances allowed for in the details. Designers

9 Ryan E. Smith, *Prefab Architecture* (2010), 87.



ABOVE AND RIGHT — FIGURE 6.11: COMPOSITE TIMBER AND PRECAST CONCRETE STRUCTURE

Adidas North American Headquarters, Portland, Oregon
Source: Lever Architecture and Turner Construction

should identify where greater levels of precision are most crucial, and contractors can advise on where constructability issues may arise.

Installation conflicts can be reduced or eliminated through close advance coordination of fabrication. Constructability analyses for tolerances are especially important at frequently repeated intersections. A thorough analysis can result in huge risk reductions by avoiding the multiplying effect of repetitive field modifications. Recurring details are an important opportunity to optimize the sequencing of the build to find schedule and cost savings.

Attention to tolerances at common material interfaces like timber/concrete and timber/steel is crucial to project success. Options for achieving required fire-resistance ratings where material tolerances may create gaps at floors, walls, shafts, and other structural connections should also be evaluated for aesthetics, cost, and constructability.

Concrete

Cast-in-place concrete can incur inconsistencies of up to 1 inch in multiple planes. Because foundations are typically cast-in-place, the transition between concrete and other framing materials is a connection point that will occur on almost every mass timber project. Concrete shear walls likewise may have variances from floor to floor, or across a face. A general contractor should

MASS TIMBER DELIVERY AND INSTALLATION
Source: Timberlab Inc.

CASE STUDY: BUILDING 4

FINANCIAL SERVICES CAMPUS EXPANDED WITH MASS TIMBER

PROJECT OWNER: CONFIDENTIAL FINANCIAL SERVICES CLIENT

PROJECT LOCATION: WILMINGTON, NC, 28401

COMPLETION DATE: MAY 1, 2024

ARCHITECT/DESIGNER: LS3P

MASS TIMBER ENGINEER/MANUFACTURER: SMARTLAM NORTH AMERICA

GENERAL CONTRACTOR: SWINERTON/MONTEITH

STRUCTURAL ENGINEER: LYNCH MYKINS

MECHANICAL, ELECTRICAL, AND PLUMBING: HARRELSON

OTHER CONTRACTORS: TRIPLE-R ELECTRIC

BUILDING 4 IS a 67,000-square-foot addition to a financial services campus located along the coastline in Wilmington, North Carolina. The client pursued mass timber for its constructability and aesthetic benefits. The ownership team was committed to a sustainable, low-carbon structure to boost employee

SOUTHERN YELLOW PINE MASS TIMBER
Source: Timberlab Inc.

MASS TIMBER OFFICE
Source: Timberlab Inc.

satisfaction and retention, and to pay homage to the forested terrain that surrounds the development.

Even though the client has a portfolio in hybrid timber buildings, this project is its first 100 percent mass timber building and one of the first full-scale projects in the region. The project team was able to show that a full mass timber build would provide a faster schedule for construction than a conventional building using structural steel. That was a high priority for the client.

The inception of this mass timber office was marked by strategic partnerships that played pivotal roles in bringing the vision to life. The collaboration facilitated the seamless integration of mass timber into the project, ensuring structural integrity and aesthetic appeal. The design team involved LS3P, architect; Lynch Mykins, engineer of record; and Timberlab Inc., delegated design. Building 4 was constructed via a joint-venture collaboration between Swinerton and Monteith. The mass timber elements were regionally supplied by SmartLam, while Timberlab Inc.'s East Coast team fabricated and erected the timber structure.

The owner was dedicated to a regional procurement strategy to keep project emissions low. Timberlab worked with SmartLam to locally source the Southern Yellow Pine (SYP), a species that is abundant in the region. The 4-story structure spans 67,000 square feet and includes nearly 1,000 pieces of glulam and 250 Cross-Laminated Timber (CLT) panels. All the timber was delivered to the jobsite in 40 truckloads.

The project team's expertise in mass timber design and engineering played a crucial role in shaping the structural elements. The decision to employ a double girder system not only maximized head height but also enabled ease of implementing cantilevered framing. The incorporation of cantilever connections at the building's corners allowed for columnless features, providing unobstructed views and enhancing the building's visual appeal.

Because the structure is in a hurricane-prone coastal region, the connections are engineered to resist net uplift wind forces. Withstanding hurricane-force winds is a formidable challenge, and this structure showcases the potential of mass timber in such demanding environments as the Carolina coast.

FIGURE 6.12: CLT WALL AND ROOF PANELS WITH STEEL FRAMING

Lincoln City Police Department, Oregon
Source: Swinerton Builders

FIGURE 6.13: CLT FLOOR DECKS WITH STEEL FRAMING

Brentwood Public Library, Brentwood, California
Source: Holmes Structures
Credit: Blake Marvin Photography

impress upon the concrete team to take special care in areas requiring more precision and to flag details that may require more precision than industry-standard installation practices do.

Precast concrete is more precise than cast-in-place concrete. This prefabricated solution is worth considering for exposed components with a high level of finish quality (see **Figure 6.11**).

Steel

Structural steel columns, beams, and braced frames have tolerances greater than engineered wood, typically about ¼ inch to ⅜ inch and, depending on the length of the steel, up to ¾ inch[10] (see **Figures 6.12** and **6.13**).

The design and fabrication method of exposed or concealed steel connectors, especially details that occur frequently, can significantly impact a project's schedule. Rolled steel connections require more tolerance, and it may be wise to plan for shims or other field modifications as needed. As with larger structural components, greater length brings more potential for variation. Highly accurate cast-steel connections may have a higher up-front cost, but they may contribute to schedule savings by reducing field conflicts and retrofits (see **Figure 6.14**).

6.5 ON-SITE MATERIALS MANAGEMENT

Perhaps the most important lesson from the first mass timber projects developed in North America is that on-site materials management is crucial for efficient construction. The following topics outline the advantages and challenges of handling mass timber components on a jobsite.

10 American Institute of Steel Construction.

FIGURE 6.14: OFF-THE-SHELF BEAM CONNECTIONS AND CUSTOM COLUMN CONNECTIONS

Carbon12, Portland, Oregon
Source: Kaiser+Path

Just-in-Time Delivery

In situations where on-site storage is limited, mass timber panels can be delivered on flatbed trucks using just-in-time delivery. The challenges of materials management within a given space at a building site aren't specific to mass timber. However, each prefabricated mass timber element has a precise installed location, creating additional site coordination issues. Such a system requires planning and coordination with both the trucking company and the mass timber manufacturer; many mass timber companies use their own trucking for that reason. A side benefit is that loading in construction sequences may take more time than conventional trucking companies are willing to tolerate without extra charges. Another benefit is the ability to care for the integrity of weatherproof packing that may need some attention and adjustments during transportation in inclement weather.

The just-in-time approach can be complicated by greater distances between the building site and the mass timber manufacturer; regional restrictions on oversize loads; and routes with clearance constraints, challenging terrain, or constrained urban sites (see **Figure 6.15**). The transport team can advise on route strategies and restrictions, and any added costs associated with oversize loads. Unusually shaped panels are more challenging to balance for transport, potentially increasing the number of trucks required or complicating sequencing. But efficient and safe loading of the materials on the trucks often takes precedence over the installation sequence. Shipping loads are also informed by weight distribution, as well as by panel size and shape. A building design with many similarly sized panels will be more straightforward to coordinate than one with many unusual shapes. In the latter case, some lay-down space should be set aside for resequencing (see **Figure 6.16**).

Understanding the loading and shipping approach before the materials arrive on-site reduces delivery conflicts. Coordinating a huge volume of

FIGURE 6.15: TIMBER CONSTRUCTION ON CONSTRAINED URBAN SITES

(LEFT) *Sideyard, Portland, Oregon; Contractor: Andersen Construction*
Source: Catena Engineers; Credit: Skylab Architecture
(RIGHT) *District Office, Portland, Oregon; Source: Andersen Construction*

FIGURE 6.16: STAGING AND HANDLING

Source: Nordic Structures

mass timber materials has storage, schedule, and liability implications at both the manufacturing facility and the construction site. A 2018 case study published by the DLR Group[11] recommends that the construction team dedicate an engineer to manage a project's mass timber fabrication and delivery schedule.

11 DLR Group, *Tall with Timber: A Seattle Mass Timber Tower Case Study* (November 2018), https://issuu.com/dlrgroup/docs/seattle_mass_timber_tower_book_issu.

FIGURE 6.17: CRANE LIFTING WITH SLINGS

District Office, Portland, Oregon
Source: Andersen Construction; Credit: Pete Eckert

FIGURE 6.18: PICK POINT LIFTING DEVICE

Source: https://mtcsolutions.com/ (formerly My-Ti-Con)

Support Equipment

It is important to determine the amount and type of support equipment needed at the site to ensure efficient operation. Some case studies describe using forklifts or similar equipment to move mass timber (an option only in 1- or 2-story buildings) versus using a crane. If small equipment is to be used, the vehicles must be large enough to carry heavy timbers and panels. For example, a 5-ply, 10-foot-by-60-foot panel made from Douglas-fir weighs over 5 tons. If panels arrive in containers, common for materials supplied from overseas, the equipment on-site must be robust enough to remove and lift the heavy panels and timbers. Additionally, enough space is needed to safely maneuver around the site.

Most project managers opt to use cranes, allowing for panels or timbers to be “flown” from a truck or site storage into the designated place in the building, as in **Figure 6.17**. Key aspects of this process are the placement, number, and strength of the “pick points,” or lifting devices.

Figure 6.18 illustrates a typical lifting device called a Yoke 1T, which has been designed and tested for use in mass timber construction. The device is screwed into a mass timber panel using ½-inch screws, and it is designed to safely lift panels of up to 7,000 pounds. Other lifting devices designed for lighter or heavier panels are available. A key to efficient construction is placing the lifting device on the panel in a way that allows it to balance plumb and level, easing installation. The pick points also en-

CASE STUDY: PERMITS, DESIGN, ZONING: HOW LOCAL GOVERNMENTS CAN HELP EXPAND MASS TIMBER CONSTRUCTION

STUDY SHOWS HOW LOCAL GOVERNMENT REGULATIONS CAN SUPPORT MASS TIMBER

CONSTRUCTION OF 1 LONSDALE AVENUE PROJECT IN NORTH VANCOUVER, BC
Source: naturallywood.com; Credit: KK Law

PROJECT OWNER: VANCOUVER

PROJECT LOCATION: SFU RENEWABLE CITIES, 580 W HASTINGS ST, VANCOUVER, BC, CANADA V6B 1L6

COMPLETION DATE: JANUARY 17, 2023

WHILE EVERY AREA has its own unique conditions, British Columbia, Canada, offers examples of how other jurisdictions—and manufacturers, architects, and government officials—might adopt or evolve policies and practices that are more welcoming to mass timber buildings.

Research by the Renewable Cities program at Simon Fraser University (SFU) has found that local government approaches to mass timber construction play an essential role. The province of British Columbia helped fund the SFU study to explore and recommend ways local governments in the province can become more mass timber-friendly.

Renewable Cities in Vancouver, British Columbia, worked with a team of architects, developers, building officials, and other industry professionals to produce the study, "Building Capacity: Local Prefab Mass Timber Solutions." It emphasizes 3 areas crucial to the success of mass timber: the building permit process, design guidelines, and zoning.

Building permits: One of mass timber's greatest benefits is that it shortens construction timelines. Buildings get finished faster, meaning that they're occupied sooner and developers have fewer interest payments. But if a city's building permit process has not been modernized for off-site construction, that benefit—and maybe the project—is lost. Thus, updating that process, perhaps including the accommodation of digital submissions (e.g., Building Information

CLT PANEL DELIVERY AT 1 LONSDALE AVENUE PROJECT IN NORTH VANCOUVER, BC
Source: naturallywood.com; Credit: KK Law

Modeling [BIM]) and the issuance of partial permits is crucial to accommodate prefab construction.

Design guidelines: Mass timber comes with unusual structural considerations that influence the form and design of the building because it is more difficult, for example, to step floors and add balconies. It also has implications for design guidelines that were written with long-established construction methods and materials in mind (i.e., concrete and steel, constructed on-site). Jurisdictions need to update their design guidelines to accommodate mass timber's unusual structural considerations so as not to inadvertently penalize this building form. Mass timber buildings have thicker floor assemblies, for example, so revised height regulations that account for this minor increase in floor thickness would level the playing field.

Zoning: Zoning is also a crucial topic because, in British Columbia at least, high-density, 12-story buildings are not common. Local governments might not have official community plan categories and zoning to address them. The report suggests that this is an opportunity for cities to develop a new, high-density, mid-rise land-use category or modify existing zones to better accommodate mid-rise mass timber that can provide the much in-demand middle housing. Without a dedicated mid-rise zone, 12-story mass timber buildings are at a competitive disadvantage because developers will pay more for the site for higher heights and densities using concrete construction.

Mid-rise mass timber building forms are coming to communities, and, just as the industry must innovate to keep up with building advancements, so should municipalities be prepared by changing land-use regulations and permitting processes—perhaps even building with mass timber themselves.

Mass timber construction carries benefits for many, and it will take many hands across the industry and across governments to build those benefits.

FIGURE 6.19: TIMBER FRAME AND STEEL CORE PROGRESSING IN COLD, SNOWY WEATHER

Carbon12, Portland, Oregon
Source: Kaiser+Path

hance safety by serving as a place for construction workers to "tie in" after the panel/timber is in place.

Some mass timber suppliers cut small penetrations that engage with lifting slings or crane fixtures. These strategically positioned penetrations are plugged at the construction site. Others offer quick-mount/quick-release fixtures to reduce lifting cycle time. Some of these are designed to reduce the size and visibility of the permanent mark on the panel.

Waste Management

Because mass timber is prefabricated, little to no field cutting of the material is required at the jobsite, resulting in very little wood waste. Builders report that this contributes to enhanced safety because the site stays clean, and storage and removal of waste don't require managers' attention.

Panels often come wrapped in plastic for protection during transport and on-site storage. Though it is lightweight, this plastic makes up the bulk of on-site waste volume associated with mass timber, and it is destined for the landfill. If the protection can be made reusable or multifunctional, this waste stream could be reduced or eliminated.

Metric Units of Measurement

Although the capacity of North American mass timber manufacturers is ramping up, some building projects are using mass timber produced in Europe, where the measurement units are metric, rather than the imperial system used in the

MOISTURE CONTENT (MC) IN WOOD	
At harvest	May exceed 100%
Lumber dried for EWP	12% +/- 3%
Acceptable for encapsulation	Less than 15%
Stabilized in-place	6-8%
Risk of fungal growth	26-60%

TABLE 6.2: MOISTURE CONTENT IN WOODS
Multiple sources

US. Several builders who have dealt with this issue reported that they (and their carpenters) were initially worried about the differing units of measurement. Crews were supplied with tape measures showing both imperial and metric measurements. That approach created confusion. The solution reported by all builders was to use tape measures calibrated only in metric units, to which the crews quickly adapted.

6.6 WEATHER PROTECTION AND MOISTURE MANAGEMENT

Mass timber has inherent advantages and challenges associated with weather. Concrete has curing limitations around temperature and precipitation, and steel requires certain conditions for proper welding, but mass timber components can be installed regardless of weather conditions. This has excellent implications for reducing weather delay contingencies when timelines overlap challenging weather months.

For example, the framing for Carbon12 took place between December 2016 and February 2017, one of the wettest and coldest winters in Oregon's recent history (see **Figure 6.19**). Although most construction sites in town were closed for several days at a time through the season, Carbon12 was delayed for only one day, when key members of the 4-person framing crew were unable to travel due to road conditions.

Once in place, wood components require some protection against exposure to wet weather to prevent moisture uptake, and it is helpful to understand how wood behaves as a hygroscopic material. **Table 6.2** lists common moisture content (MC) reference values. Short of coordinating construction around a dry season (only occasionally a viable option), a moisture management plan will help the team manage site practices and invest in protection measures that best fit the project. This plan should be distributed and discussed with all trades on-site during wet weather. Top concerns include staining, swelling, shrinkage, and decay, all of which can be avoided by following a well-considered protection and mitigation plan.

Industry standard practices for moisture management in mass timber buildings are developing. In 2020, RDH Building Science Inc. published advice on moisture risk management for mass tim-

FIGURE 6.20: DISTRICT OFFICE IMPLEMENTED A MOISTURE MANAGEMENT PLAN
District Office, Portland, Oregon
Source: Andersen Construction

ber builders.[12] Experienced builders, meanwhile, are developing best practices. While constructing both the George W. Peavy Forest Science Center and the District Office (see **Figure 6.20**) during Oregon's wet months, Andersen Construction created a 4-part moisture management plan for wood structures: sealers, stain prevention, moisture control, and dry out. The sections below elaborate on each. (For more on managing moisture throughout design and construction, see chapter 5.)

Sealers

Shop-applied sealers can protect against moisture intrusion during construction and may come standard—or as an option—with some mass timber products. All component surfaces may benefit from different types of sealers, whether applied before delivery or on-site. Application capabilities will vary by facility and should be fully understood if sealers are to be relied upon for weather protection.

The top surface of a floor panel is more susceptible to standing water, while the bottom face is

12 Graham Finch, RDH Building Science Inc., *Moisture Management for Mass Timber Buildings* (2020).

FIGURE 6.21: CLT PANELS PROTECTED WITH WRAP FOR TRANSPORT AND ON-SITE STORAGE

Hillsboro Community Center, Hillsboro, Oregon
Source: Swinerton Builders; Credit: BREWSPHOTO LLC

more likely to be left exposed as a finished surface and to need protection from staining. Moisture uptake is quickest where timber components are most vulnerable, at the end-grain. That is also where components are typically joined, creating hidden spaces with less air circulation for dry out. Often, the manufacturer will apply a temporary wax coating to edges where end-grain is exposed for protection during transport and installation.

Stain Prevention

Water readily transports pigments from debris—such as rust from metal-work shavings or other untreated metals, or from a spilled beverage—resulting in stained surfaces. Because multilevel buildings often have repetitive floor layouts, stacked penetrations and panel seams can create pathways for water to move from floor to floor. Managing construction activity on a mass timber structure intended for finish exposure is crucial for preventing stains. Many tradespeople are unaccustomed to working around finished surfaces, so communication is an important part of a stain prevention plan. Superficial stains can be cleaned or sanded, but proper stain prevention will avoid the risk of permanent marks, as well as reduce cleanup time and expense.

Moisture Control

Two basic concepts are paramount to controlling moisture in structural wood. First, wood should be protected from prolonged exposure to water. Second, if wood becomes wet, it must be allowed to release moisture via proper ventilation.

As soon as mass timber components leave a climate-controlled fabrication facility, they are subject to shifting MC, depending on the envi-

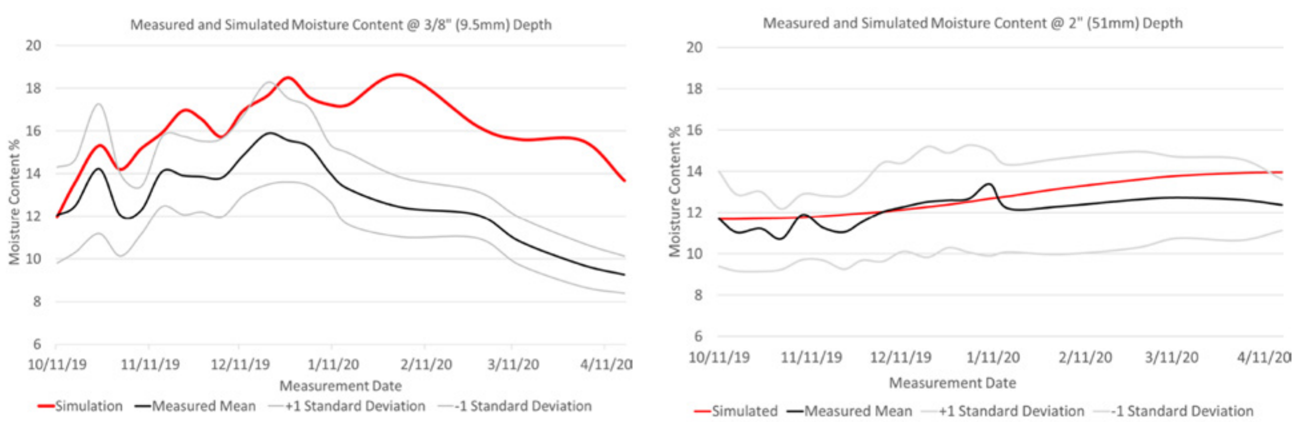


FIGURE 6.22: TWO DEPTHS

The Canyons, Portland, Oregon

Source: 4EA Building Science; Credit: Brad Carmichael, Emily Dawson, Jeff Speert

ronment to which they are exposed. Mass timber manufacturers are responsible for protection during transport, commonly accomplished by durable plastic wrap, as shown in **Figure 6.21**. Once the timber is delivered to a project site, the contractor is responsible for protection, whether stored or in place.

Strategies for protection may be holistic (like tenting the entire structure) or local (such as using tape at panel seams and penetrations).

In Nordic countries, mass timber construction is often conducted under large-scale tents doubling as overhead crane supports. Fully tenting a structure eliminates the need for many of the practices described in this section, but it is often prohibitively expensive, and most projects will need to implement a multipronged approach. Standing water should be minimized and removed as quickly as possible. The construction team should also prepare for dewatering activities by having adequate equipment and personnel on-site after rain events, as well as a planned approach for continuous wet weather.

A study[13] conducted during the construction of a 6-story CLT structure during a wet winter in a marine climate found that, though the structure was exposed to prolonged wet conditions, it dried out more quickly than simulated values would predict. The measured MC over time at the 2-inch depth was more responsive to weather changes than the simulation, and it tracked the corresponding peaks and valleys of the ⅜-inch (see **Figure 6.22**) depth more closely. The measured results show a time lag of about 2 weeks to 3 weeks for moisture to fluctuate at the 2-inch depth, but also that the highest MCs were at lower overall percentages at that depth. MC readings were consistently lower than 16 percent at the 2-inch depths, remaining at suitable levels for encapsulation and flooring installation. The findings show that, when reasonably protected from direct rain and standing water, mass timber MC can generally remain within an acceptable range

13 https://www.youtube.com/watch?v=JtYk6MBzHLs

for several weeks to months, even during winter in the Pacific Northwest.

Dry Out

In addition to protection, the basic principles of any approach must allow for wood to release excess moisture at an appropriate rate until the structure has reached equilibrium with ambient environmental moisture during occupancy (see also chapter 5). Moderate drying conditions and slower, longer drying times help prevent surface checks.

Industry-standard best practices for acceptable MC in mass timber have not been firmly established. However, in the Pacific Northwest, where wet winters significantly impact construction sites, teams have found that mass timber components above 15 percent MC should not be enclosed or encapsulated but given a controlled opportunity to release moisture.

Mass timber naturally dries out more slowly than light framing because of its larger dimensions. Because of the greater volume, more potential exists for MC differentials within a single panel or member. The greater the differential in moisture, the greater the potential for tension, compression, and movement—created by swelling and shrinking—as the wood takes on water or dries out. These stresses in the wood can lead to cracking and checking that, while typically structurally insignificant, can be aesthetically undesirable.

SYCAMORE & OAK, 1110 OAK DR SE, WASHINGTON, DC
Credit: © Dror Baldinger FAIA

CASE STUDY: SYCAMORE & OAK

SYCAMORE & OAK: A COMMUNITY WITHIN THE COMMUNITY

PROJECT OWNER: EMERSON COLLECTIVE & REDBRICK

PROJECT LOCATION: 1110 OAK DR SE, WASHINGTON, DC 20032

COMPLETION DATE: JUNE 14, 2023

ARCHITECT/DESIGNER: ADJAYE ASSOCIATES

MASS TIMBER ENGINEER/MANUFACTURER: STRUCTURECRAFT

THE RETAIL VILLAGE at Sycamore & Oak is a community-led development in the heart of the vibrant Congress Heights neighborhood of Washington, DC, and it blends sustainability, community engagement, and economic empowerment. Born out of extensive collaboration with the local community, the project is committed to inclusivity; innovation; and a resilient, healthy living environment.

This 23,000-square-foot venue on St. Elizabeth's Parcel 15 is not just a retail space; it is a hub designed to feel like a community within the community. From the outset, the project reflected the aspirations of the Congress Heights neighborhood and its residents. The design, characterized by sustainable materials and low-carbon construction techniques, shows a commitment to regenerative construction.

The Retail Village offers wellness and entrepreneurial support services, food vendors, and convening and

ABOVE AND RIGHT — SYCAMORE & OAK,
1110 OAK DR SE, WASHINGTON, DC
Credit: © Dror Baldinger FAIA

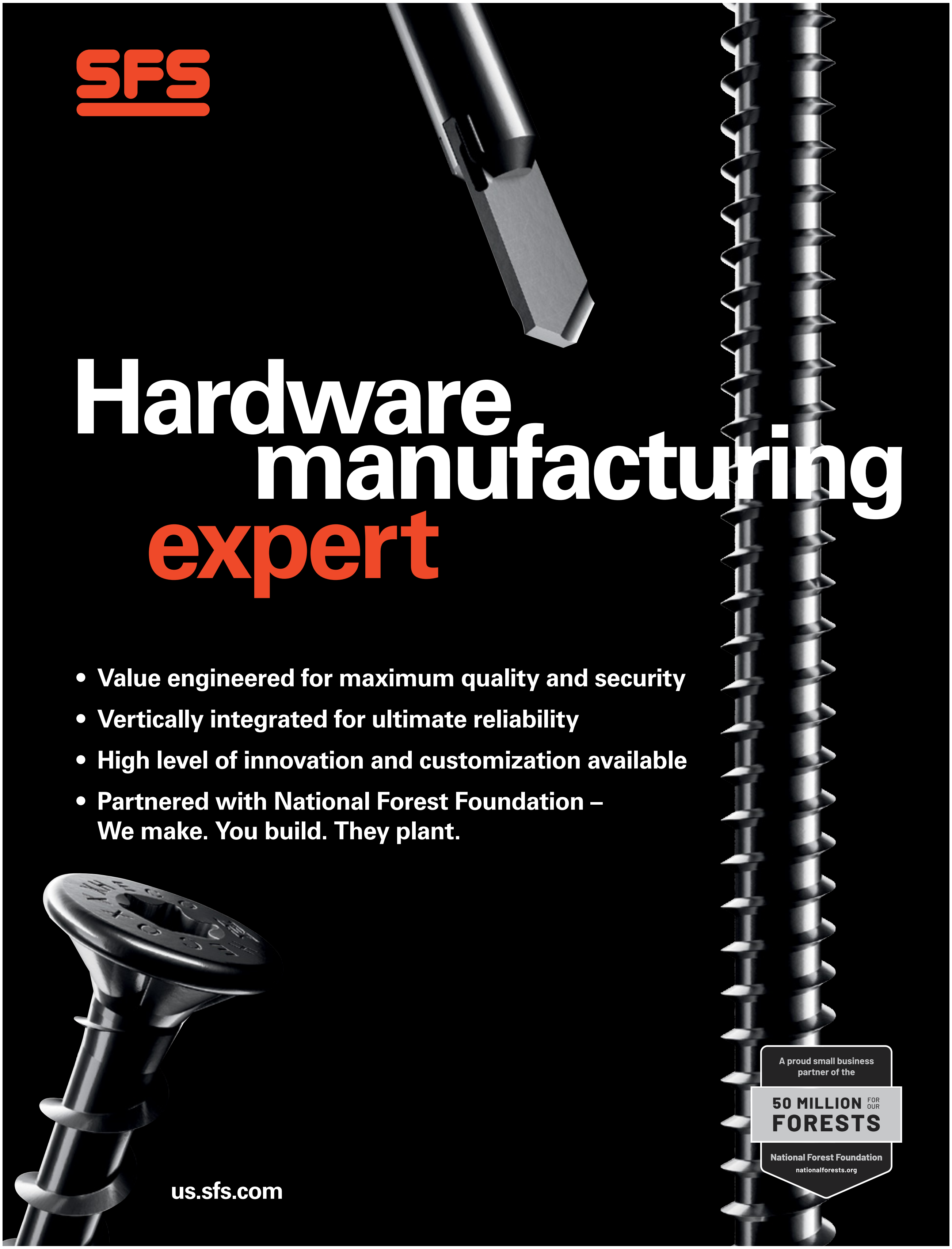
event spaces. The modularity and low-carbon construction techniques make the structure, entirely built of timber, easy to assemble and reassemble.

The two main modules along Cherry and Oak streets are linked by a bridge accessible by people with handicaps. These modules house community-centric facilities, including a dining hall, a fresh food market, retail storefronts, and education and fitness centers. The mezzanine connecting the modules serves as a central gathering space, performance hall, and event venue.

The open-air design, covered by a timber canopy, provides a warm, welcoming space that not only offers shade and protection from the elements but also fosters a sense of intimacy. The canopy, punctuated by skylights for natural light, doubles as a platform for photovoltaic panels that will eventually power the facility with solar energy. The project is a Forest Stewardship Council 2023 Leadership Award winner.

The Retail Village also serves as an incubator for local businesses through programs like "Incubate the Eight," supporting emerging Black entrepreneurs by sharpening their business and marketing skills. The "Chefs-in-Residence" program, in collaboration with the José Andrés Group, provides mentorship and operational guidance to food and drink vendors.

The Retail Village is the first phase of a 650,000-plus-square-foot, mixed-use development that is expected to include local stores, affordable housing, an office building, and a hotel, all made from mass timber and employing regenerative building techniques.


SFS
Hardware manufacturing expert
• Value engineered for maximum quality and security
• Vertically integrated for ultimate reliability
• High level of innovation and customization available
• Partnered with National Forest Foundation – We make. You build. They plant.
us.sfs.com
A proud small business partner of the
50 MILLION FOR OUR FORESTS
National Forest Foundation
nationalforests.org

CHAPTER 7: OCCUPANTS

EMILY DAWSON
OWNER, SINGLE WIDGET

Mass timber buildings can boost the health, well-being, comfort, productivity, and prosocial behaviors of their residents. Human health, comfort, and behavior are closely related, but in this chapter, they are divided into 3 sections. The health section looks at our acute biological responses to indoor environments; in the comfort section, we review the universal characteristics of those spaces and of human preferences; and the third section, on behavior, considers how indoor environments influence how we interact with one another.

FIGURE 7.1: PEAVY HALL

Source: Oregon State University
Credit: Josh Partee

7.1 HEALTH

The focus on the health benefits of wood in the built environment is based on a well-established body of research showing that exposure to nature has health benefits such as lower blood pressure, lower heart rate, increased ability to focus, increased concentration, and increased creativity.

Biophilia

The powerful influence of nature in all aspects of indoor environments is known as biophilia, the innate human love for natural forms.[1] The idea of enhancing human health through building design has been described as the application of biophilia in the built environment; our bodies, as biological organisms, are supported by biophilic spaces. Biophilic buildings connect occupants to nature by featuring natural materials, shapes, and patterns; orienting a building to take advantage of daily and seasonal light patterns; and providing views and access to the outdoors and nature.

According to a growing number of studies,[2] nature-oriented design improves health by lowering stress and blood pressure; improves mental functions, stamina, and focus; improves moods and learning rates; and decreases violence and criminal activity.

1 Biophilia is a term that was coined by biologist Edward O. Wilson, a professor emeritus and researcher at Harvard University. He defined it as the urge to affiliate with other forms of life in nature.

2 Some of the most comprehensive data gathered around the benefits of biophilic building design on human health is captured in a document by Terrapin Bright Green, "The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense" (2022).

Stress Reduction

A 2015 study[3] connected the use of wood to the support of human health in the built environment. The study documented lowered sympathetic nervous system responses when occupants could see more wood surfaces in a mock office environment. Stress levels, as measured by heart rate and skin conductivity, were lowest for the participants in the office with the wood design. If the use of wood is extended to an entire building, the study suggests that mass timber is well-positioned to enhance the health of a building's occupants.

Another study by Japanese researchers[4] monitored subjects' physiological responses to different ratios of wood surfaces in an environment and found measurable results. They discovered that a moderate ratio (45 percent wood coverage) was subjectively "comfortable" and "restful." A larger ratio of wood surfaces (90 percent) "caused significant and large decreases" in the blood pressure results of test subjects. The study surmises that further research could seek to identify the ideal surface-area ratio of exposed wood for optimum health for most people.

This topic is drawing increased cross-disciplinary interest. Similar projects are being conducted at the University of Helsinki in Finland, at the University of Primorska in Slovenia, and likely by other academic and private research groups.

Recovery and Healing

Another emerging area of occupant health is evidence-based design involving the analysis of the design of a building to assess how it impacts human health. Architects specializing in the design of health-care buildings are using wood to enhance patient recovery and health, and to optimize the well-being of staff and visitors. One study of human response to health-care facilities found that using cedar panels in hospital rooms reduced stress as measured by cortisol levels.[5]

Biophilic design in health-care environments is linked to shorter hospital stays, faster recovery rates, fewer negative comments, and reduced medication use.[6]

Infection Control

This decade has brought an increased awareness of how the air and the surfaces around us contribute to our safety or exposure to contagion. Concerns about surface transmission led to a heightened interest in findings about how wood performs compared to other surfaces, a topic researchers have been interested in since well before the COVID-19 pandemic. A 2015 study[7] from Cornell University tested 3 types of pathogenic bacteria on three types of surfaces—plastic, varnished beechwood, and untreated beechwood—and found that, at initial "infection" and after 24 hours, bacterial counts were highest on the plastic and lowest on the untreated wood. Like-

3 Michael D. Burnard and Andreja Kutnar, "Wood and Human Stress in the Built Indoor Environment: A Review," *Wood Science and Technology* 49, no. 5 (2015): 969–86.

4 Yuko Tsunetsugu, Yoshifumi Miyazaki, and Hiroshi Sato, "Physiological Effects in Humans Induced by the Visual Stimulation of Room Interiors with Different Wood Quantities," *Journal of Wood Science* no. 53 (2007): 11–16.

5 FPInnovations, "Wood as a Restorative Material in Healthcare Environments" (2015).

6 Terrapin Bright Green, "The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense" (2022).

7 Alan Hedge, "Survival of Escherichia Coli, Pseudomona Aeruginosa, Staphylococcus Aureus on Wood and Plastic Surfaces," *Journal of Microbial & Biochemical Technology* 07, no. 04 (2015).

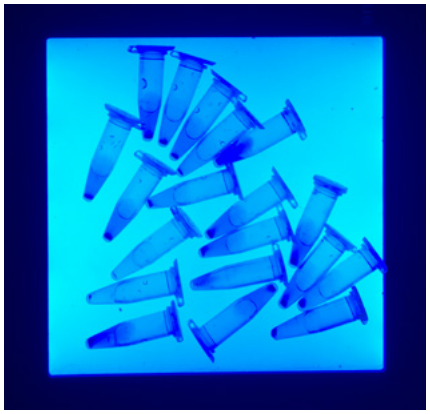


FIGURE 7.2: LAB TESTING VISIBILITY OF MICROORGANISMS LIKE BACTERIA, VIRUSES, AND FUNGI ON WOOD SURFACES

Samples treated with photoreactive PMA dye (Propidium Monoazide) used in PCR (polymerase chain reaction)

Source: University of Oregon, Biology and the Built Environment Center

wise, a 2019 study[8] and a subsequent 2021 study[9] that focused on "hygienically important places" like health-care and food-service facilities found lower microbial counts on wood surfaces and found that the results varied depending on species, cut, and age. A Finnish study showed that "the contagiousness of coronaviruses decreases much more rapidly on a wooden surface than on other materials, such as plastics."[10] These studies all found that wood is an effective antimicrobial surface, compared to smooth materials like glass or plastic. Additionally, concerns about the cleanability of porous, untreated wood surfaces were debunked in experiments with disinfectants in hospitals and in comparisons of wood versus plastic cutting boards.

The Institute for Health in the Built Environment (IHBE) at the University of Oregon is engaged in ongoing research that observes how wood's natural properties could make it difficult for pathogens to survive on it or to be transferred from person to person. Wood has a porous surface that can both sequester and desiccate microbes. Wood also contains aromatic organic compounds called terpenes that are found in many plants and appear to have antimicrobial effects. These IHBE studies are investigating the effects of wood species, coatings, humidity, and simulated flooding events on the surface and air microbiomes in exposed wood buildings. IHBE studies are evaluating wood's promise for promoting healthy bacteria and supporting diverse indoor microbiomes that could contribute to human health.

These studies have the potential to significantly increase the adoption of wood in health-care environments.

Resiliency

Building codes ensure that occupants are as safe as possible from catastrophic events such as earthquakes, fires, and high winds. Wood performs very well relative to building code standards, and it goes even further by contributing to highly resilient designs. Resilient buildings can recover quickly after disasters. Buildings that can be safely occupied following a disaster are invaluable to recovering communities, a fact that is made painfully clear every time a large-scale disaster displaces people for a long period.

8 Muhammad Tanveer Munir, Hélène Pailhoriès, Matthieu Eveillard, et al., "Antimicrobial Characteristics of Untreated Wood: Towards a Hygienic Environment," *Health* 11, no. 02 (2019): 152–70.

9 Muhammad Tanveer Munir,, Hélène Pailhoriès, Florence Aviat, et al., "Hygienic Perspectives of Wood in Healthcare Buildings," *Hygiene* 1, no. 1 (2021): 12–23.

10 Antti Haapala, University of Eastern Finland.

THE BUILDING'S CENTRAL HUB
Source: FFA Architecture and Interiors Inc.; Credit: Christian Columbres

CASE STUDY: CHEMEKETA COMMUNITY COLLEGE, AGRICULTURE & HORTICULTURE COMPLEX

MASS TIMBER — CONNECTING A COMMUNITY

PROJECT OWNER: CHEMEKETA COMMUNITY COLLEGE

PROJECT LOCATION: 4000 LANCASTER DRIVE NE, SALEM, OR 97305

COMPLETION DATE: JUNE 1, 2021

ARCHITECT/DESIGNER: FFA ARCHITECTURE AND INTERIORS INC.

MASS TIMBER ENGINEER/MANUFACTURER: FRERES LUMBER CO.

GENERAL CONTRACTOR: SWINERTON

STRUCTURAL ENGINEER: KPFF

MECHANICAL, ELECTRICAL, AND PLUMBING: PAE

OTHER CONTRACTORS: LANGO HANSEN (LANDSCAPE); WESTECH ENGINEERING (CIVIL); LUMA (LIGHTING DESIGN)

THE CHEMEKETA AGRICULTURE & Horticulture Complex serves as a hub to expand classes and facilities to better meet the training needs of farms and nurseries in the region.

Chemeketa Community College, near Salem, Oregon, decided to expand its Agriculture & Horticulture Complex to better meet the need

EARLY AERIAL SHOT SHOWS THE AGRICULTURE & HORTICULTURE COMPLEX WITH THE MAIN ACADEMIC BUILDING ON THE LEFT.

Source: Swinerton; Credit: Swinerton

for trained workers at farms and nurseries in the Willamette Valley region.

FFA Architecture and Interiors Inc. led the design team in close collaboration with Lango Hansen Landscape Architects; the college; and its partners from educational extension programs, local businesses, and community outreach groups. The result is the new Net-Zero Energy Agricultural Complex.

The college's agriculture and horticulture studies program serves the larger community and supports the agricultural sector, from corporations to migrant farm workers. The complex was also designed to be a community resource for indoor and outdoor gatherings when classes are not in session. It is used throughout the day and into the evening for meetings, banquets, and lectures for community groups, and it hosts a thriving weekend outdoor farmers market.

The large central space in the main academic building—called The Hub—was designed to maximize flexibility. It can be opened up to adjacent classrooms with movable partition walls and to the surrounding outdoor spaces with large, roll-up glass doors, allowing for a variety of configurations and uses. The superstructure is made of mass timber, including Mass Plywood Panels (MPP) for the roof. They double as the finished ceiling, supported by exposed glulam columns and beams, creating a warm indoor-outdoor learning environment.

STRUCTURE

The design team and contractor refined the structural system using a 2-inch MPP roof deck that spans 10-foot structural bays and a 5-inch-high bay roof with 40-foot-long MPP that also bridge 20-foot bays and 10-foot cantilevers at each end. The need for multiple sets of glulam columns and beams was reduced by using the cantilever capacity of the MPP in multiple locations throughout the main classroom building and outbuildings.

CELEBRATING WOOD

The use of wood provided numerous benefits to both the design and construction—from community building to cost savings to direct educational benefits. The school celebrated and honored its curriculum while creating a connection between the facility and locally harvested Oregon products.

STRENGTHENING COMMUNITY

With multiple custom furniture elements created using off-cuts from the MPP, not only was construction landfill waste minimized, but community connections were deepened. The college collaborates with Oregon Corrections Enterprises (OCE) to offer educational opportunities to incarcerated people. The OCE carpentry shop fabricated all the custom wood furniture components while providing training and reinforcing both parties' educational missions.

The finished furniture also provides cues to the major building components, allowing occupants a direct visual connection to the story of the structure.

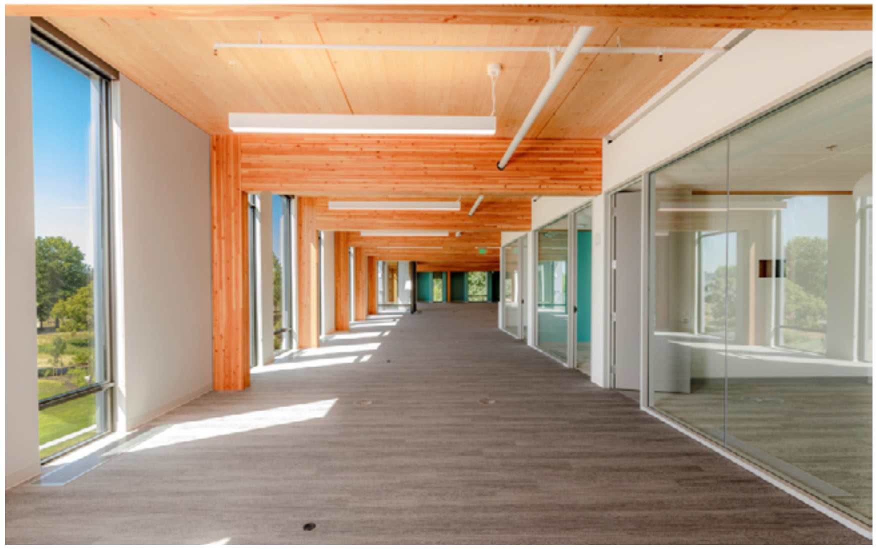
ABOVE — FIGURE 7.3: ASCENT, MILWAUKEE, WI
Source: New Land Enterprises

RIGHT — FIGURE 7.4: PEAVY HALL
Source: Oregon State University
Credit: Josh Partee

7.2 COMFORT

Indoor environmental quality (IEQ) is a measurement of how a building affects its occupants' comfort and health. The Environmental Protection Agency (EPA) found that US residents spend about 90 percent of their time indoors.[11] Canadians and Europeans fare about the same, at 94 percent and 90 percent respectively. The EPA suggests that people should spend more time outside because a growing body of scientific evidence links interactions with nature to greater levels of health and happiness. It also suggests that interior spaces should incorporate natural elements as much as possible to boost health.

11 https://www.epa.gov/air-research/indoor-air-quality-exposure-and-characterization-research



ABOVE — FIGURE 7.5: FLOOR-TO-STRUCTURE WINDOWS BRING DAYLIGHT DEEPER INTO THE BUILDING

First Tech Federal Credit Union, Hillsboro, OR
Source: Swinerton Mass Timber

RIGHT — FIGURE 7.6: MEYER MEMORIAL TRUST

Source: LEVER
Credit: Jeremy Bittermann

IEQ in relation to occupant comfort is multidimensional and includes thermal comfort, indoor air quality (IAQ), acoustics, visual comfort, and safety. In the simplest terms, when people feel comfortable in a built environment, they also tend to be healthier and more productive. As outlined below, mass timber buildings can enhance occupants' comfort in several ways.

Visual Comfort

Key factors in the visual comfort of building occupants are visual access to nature and the amount of daylight that is allowed in.

Human beings' circadian rhythm, our natural 24-hour cycle of waking and sleeping, is supported by exposure to different types of light at different times of the day related to the pattern of the sun. Although this is easy to accomplish by spending time outside, achieving this indoors has many benefits to human health.[12] Research shows links between access to daylight and improvements in mood, productivity, and sleep patterns. A building designed to maximize daylight access for occupants will be oriented to take advantage of daily and seasonal sunlight patterns. It will also limit floor plate depth, the distance from exterior walls to the core, so occupants

12 "Indoor Air Quality," *United States Environmental Protection Agency (EPA)*, https://www.epa.gov/indoor-air-quality-iaq.

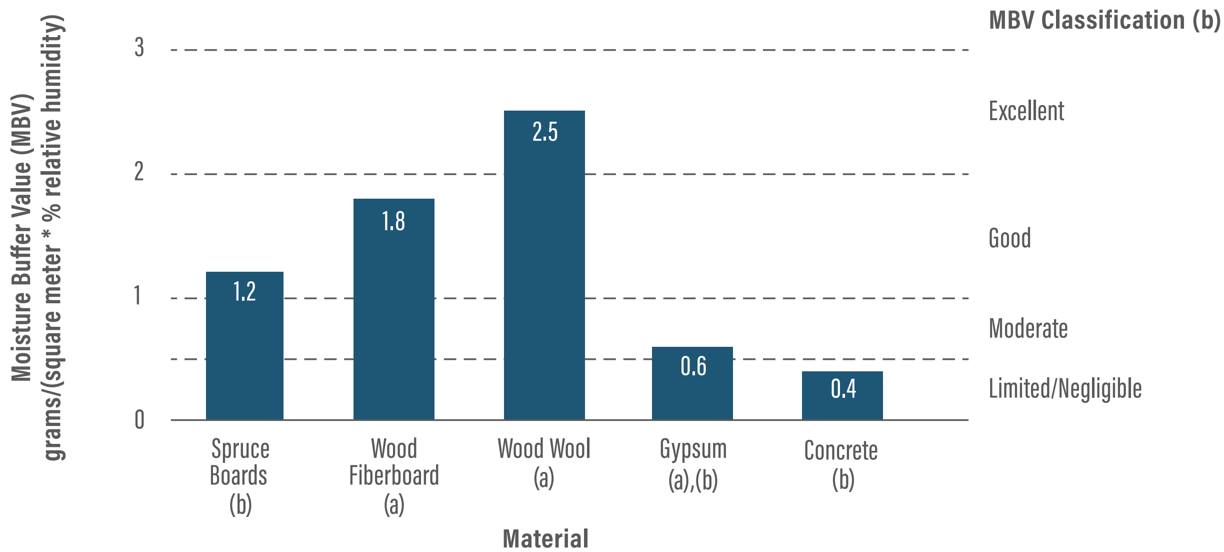


FIGURE 7.7: MOISTURE-BUFFERING VALUES OF COMMON BUILDING MATERIALS

(a) Bruce King et al., "A New Carbon Architecture, referencing Holcroft, N.A. 2016, Natural Fibre Insulation Materials for Retrofit Applications" (PhD thesis, University of Bath, UK).

(b) Rode, Peuhkuri, Time, Svennberg, and Ojanen, Moisture Buffer Value of Building Materials (2006).

spend most of their time near the perimeter of the building where daylight is most prevalent.

Views of nature can dramatically affect mood and productivity as well. Mass timber often supports good design practices by allowing for thinner floor plates, higher ceilings, and 2-way spans that can eliminate perimeter beams. These qualities allow for more and taller windows to provide better access to views and allow daylight farther into buildings.

Indoor Air Quality

Many factors that contribute to healthy IAQ are beyond the scope of this report, including ventilation rates, filtration systems, outdoor air quality, and occupant behavior (like smoking or burning incense). We focus here on providing information about how using exposed wood in interior spaces can support high IAQ characteristics as part of a complete healthy building system.

Wood is considered hypoallergenic, meaning it is very unlikely to cause allergic reactions, and its surfaces are easy to keep clean and free of particles (see earlier section, "Health"). The terpene-based aromatics that contribute to these properties are also responsible for the pleasant, relaxing[13] aroma we associate with cut wood. Relative humidity (RH) is the amount of moisture in the air, expressed as a percentage of moisture in the air at the same temperature as in the environment. The optimum range for human health is 40 percent to 60 percent RH, coinciding with the least optimal range for human health-challenging organisms like bacteria, viruses, fungi, and mites. Just as materials with high thermal mass (such as stone or concrete) absorb heat on a sunny day and release it

13 Harumi Ikei, Chorong Song, and Yoshifumi Miyazaki, "Effects of Olfactory Stimulation by α-Pinene on Autonomic Nervous Activity," *Journal of Wood Science* 62, no. 6 (2016): 568–72.

in the cool of night, so too can different materials help to moderate humidity levels in indoor air.

Because wood is hygroscopic, it assists in moderating humidity levels by absorbing moisture during periods of high humidity and releasing moisture during periods of low humidity. The ability of any given material to perform this function is measured by its Moisture Buffering Value (MBV). Values over 1 (g/[m²-%RH]) are good, and materials with values over 2 are excellent. As illustrated by **Figure 7.7**, wood products perform very well—2 times to 5 times better than other tested common indoor materials, including gypsum board and concrete.

A common question about IAQ and mass timber panels is whether the adhesives used in manufacturing are harmful to human health in situ. Mass timber manufactured with adhesives can use resins that result in virtually no formaldehyde off-gassing. A 2020 study[14] from the Energy Studies in Buildings Laboratory (ESBL) measured formaldehyde off-gassing in samples representing 4 different mass timber bonding methods: polyurethane (PUR); a cold-set soy adhesive (not commercially available); dowels (no adhesives); and melamine formaldehyde (MF). The samples that fell well below the Leadership in Energy and Environmental Design (LEED) v4 IAQ maximum allowable formaldehyde concentration (33 micrograms of pollutant per cubic meter of air) were PUR (1.4), soy (2.5), and dowels (2.3), while MF (54.4) exceeded the accepted limit. PUR is the most-used adhesive globally for mass timber, but if IAQ is an important project consideration, product specifications should be confirmed with the manufacturer. Many mass timber products are "Red List-free"[15] and approved for use in certified Living Buildings; and some options, like Nail-Laminated Timber (NLT) and Dowel-Laminated Timber (DLT), are adhesive-free.

Acoustics

Acoustics from an occupant's perspective can be classified in 2 ways: structure-borne and ambient. Buildings with design features that control for both can significantly enhance occupant satisfaction. Adding mass to an assembly is an important aspect of acoustic mitigation. The sound-dampening qualities of solid wood have long been recognized, and mass timber performs well in managing structure-borne sound. The massive arrangement can help mitigate the transfer of low-frequency sound vibrations when combined with other building materials to create relatively thin assemblies (see also the section in chapter 5, "Acoustic Properties").

Ambient sound experience can be managed with sound-absorbing materials to control reverberation of noise in a space. Architectural finishes, furnishings, and even occupants themselves can absorb sound. Wood is a porous material, which makes it less sound-reflective than some other common building materials with smooth, flat surfaces (like stone, concrete, tile, glass, or plastic).[16] That said, smooth, flat surfaces are sound-reflective, and additional elements are necessary for sound-dampening a space.

14 Michael Yauk, Jason Stenson, Micah Donor, et al., "Evaluating Volatile Organic Compound Emissions from Cross-Laminated Timber Bonded with a Soy-Based Adhesive," MDPI Buildings, 2020.

15 The Red List contains 19 classes of chemicals prevalent in the building industry that the International Living Future Institute (ILFI) has designated as worst in class.

16 https://soundproofliving.com/sound-reflecting-materials/

CIC CENTRAL STAIR
Source: ZGF Architects

CASE STUDY: COLLABORATIVE INNOVATION COMPLEX

OSU MASS TIMBER LAB WILL SUPPORT SCIENCES

PROJECT OWNER: OREGON STATE UNIVERSITY

PROJECT LOCATION: SW MONROE AVE, CORVALLIS, OR 97331

COMPLETION DATE: AUGUST 1, 2024

ARCHITECT/DESIGNER: ZGF ARCHITECTS

GENERAL CONTRACTOR: ANDERSEN CONSTRUCTION

STRUCTURAL ENGINEER: KPFF

MECHANICAL, ELECTRICAL, AND PLUMBING: PAE

SCHEDULED TO OPEN in 2026, the 3-story, 150,000-square-foot Collaborative Innovation Complex (CIC) at Oregon State University (OSU) will be a futuristic research laboratory and technology and teaching center.

The $200 million complex in Corvallis, Oregon, will support the advancement of sciences with a semiconductor lab, extended-reality theater, and a robotics and drone playground. In addition, faculty and students will focus on critical global challenges such as climate science and sustainability. The design of the site kickstarts these initiatives by incorporating mass timber for the first time in laboratory spaces on the West Coast.

OPEN EXIT STAIR
Source: ZGF Architects

The goal of the project is to design sustainable, flexible spaces that will foster the next generation of researchers and entrepreneurs through collaborative and impactful learning experiences. From a code and fire safety perspective, breaking ground on an innovative site comes with unusual challenges—many of which the code has not yet addressed.

The project team delivers options for safety with alternate means protection measures that keep a building's occupants safe during a fire emergency. The team showed the jurisdiction that open stairs using deep wood beams allowed safe egress and that wood was not a hazard with the highly flammable materials that will be used in some of the labs.

To foster the interactive nature of this innovative education experience, the open entry lobby and the separation of the hazardous materials labs became primary code concerns, with exposed wood as the theme of human environment.

The open entry lobby with its 3-story wood stairs will be used as a means of egress, and 1 of the 2 exit stairs will open into that lobby, providing safe egress and a welcoming use of the stairs to the lab floors above. Mass timber will also protect a supercomputer as well as the flammable hazardous materials that will be used as the technology evolves. Mass timber, with its rigidity and robustness, also allowed the openness to reconfigure labs.

Seeing the safety benefits of mass timber allowed the jurisdiction to accept the human and environmentally friendly design with the tech-intensive spaces the client wanted to provide.

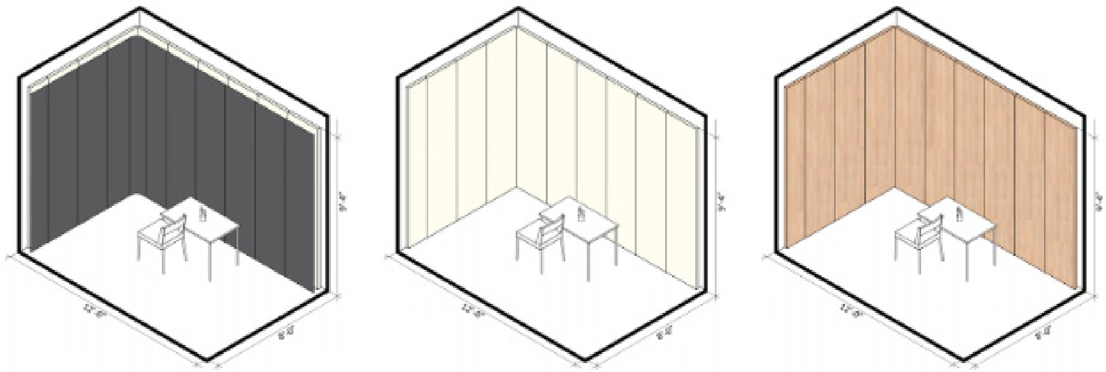


Figure 1. Wall conditions: 1.1 Black curtain (left), 1.2 White painted drywall (center), and 1.3 Wood (right)

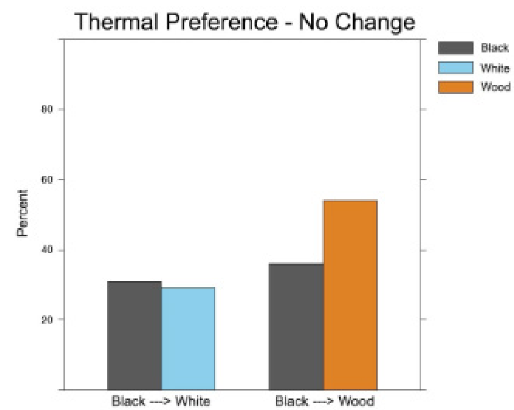


FIGURE 7.8: STUDY FINDINGS ON THERMAL COMFORT

Visual effects of wood on thermal perception of interior environments
Denise Blankenberger, Kevin Van Den Wymelenberg, Jason Stenson, University of Oregon, Eugene, OR, 2019

Thermal Comfort

Wood is a natural insulator, giving designers increased flexibility when detailing insulation to meet energy efficiency codes. It makes *actual* thermal comfort a feature of a well-designed wood building. Wood also contributes to a *perceived* sense of thermal comfort, broadening acceptable temperature ranges and saving on operational carbon emissions and energy costs.

A study performed by the ESBL suggests that exposed wood supports the thermal and visual comfort of a building's occupants. The study found that "visually 'pleasant' or 'warm' surroundings can positively impact perceived thermal comfort, even when the space may call for cooling." Researchers investigated the perception of thermal comfort in the presence of wood versus white-painted drywall in a climate-controlled chamber. After a 40-minute acclimation period to slightly warm conditions in the chamber, black curtains were pulled back to reveal either the white or wood walls. Test subjects answered survey questions reporting their level of thermal comfort at intervals throughout. When the wood walls were exposed, most people reported their thermal sensation improved to "neutral." Visual perception of each material was also evaluated by test subjects using a series of word pairs, with the wood walls receiving significantly more positive associations. The greatest differential response found the wood walls to be "natural" and white walls "artificial." Other word pairs included "like: dislike," "pleasant: unpleasant," "expensive: cheap," "interesting: uninteresting," and "clean: dirty."

7.3 BEHAVIOR

When people are healthy and comfortable, they are much more likely to exhibit behaviors that benefit them and the people around them.

Economic Benefits

Terrapin Bright Green's "The Economics of Biophilia" documents economic benefits of incorporating natural elements into buildings in 6 different sectors: offices, education, health care, retail, hospitality, and communities. Regarding offices, the report states: "The main causes for deficient productivity include absenteeism, loss of focus, negative mood, and poor health. The built environment, though not always the cause of these stressors, when well-designed, can be a reliever of these undesirable symptoms." The author adds that "10 percent of employee absences can be attributed to architecture with no connection to nature." Many employers understand the financial and social effects of a healthy workplace on employee productivity and will seek spaces that best meet those needs. In fact, workers self-reported increased productivity, and researchers have measured a 10 percent improvement in speed and accuracy in spaces with natural wood finishes.

Positive changes in student academic performance and medical patient outcomes are correlated with natural design elements like exposed wood. Benefits are also present in retail and hospitality environments. "Retail customers judge businesses surrounded by nature and natural features to be worthy of prices up to 25 percent higher than businesses with no access to nature." An environment where customers feel both relaxed and stimulated will be more conducive to spending, contributing to the success of a business. The ESBL study cited above in the section on thermal comfort also found that test participants perceived wood surfaces as being "expensive" and "pleasant," which has implications for customer behavior.

FIGURE 7.9: OREGON CONSERVATION CENTER

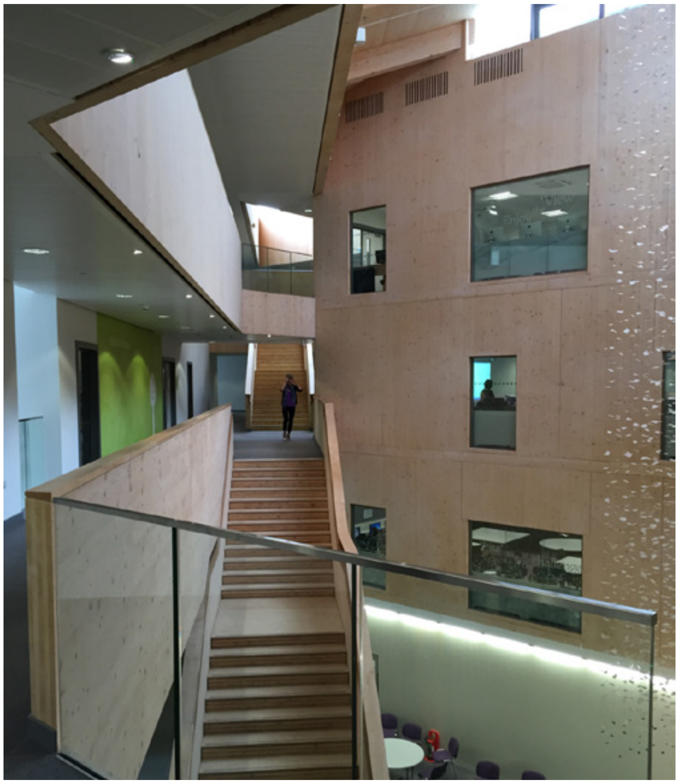
Source: LEVER
Credit: Lara Swimmer

When a space makes occupants feel good, prosocial behavior is more likely. From an economic perspective, occupant behavior is important because it can have a direct impact on building maintenance costs. Occupants who enjoy a space and feel respectful toward a building will be less likely to be careless or destructive .

Social Benefits

The same effects that the presence of trees and green spaces have on lowering violent and criminal behaviors in communities can be seen inside buildings as well, reducing vandalism and other aggressive behaviors.

One example pertinent to mass timber is the William Perkin Church of England High School, completed in 2014. It was constructed with exposed Cross-Laminated Timber (CLT) walls and floors as an economic strategy to meet a tight 12-month



LEFT — FIGURE 7.10: EXPOSED WOOD ENCOURAGES CALM, RESPECTFUL BEHAVIORS
William Perkin Church of England School
Source: Emily Dawson

RIGHT — FIGURE 7.11: THE CANYONS, PORTLAND, OR
Source: Kaiser + Path, Credit: Jeremy Bittermann

construction schedule. The new building replaced an outgrown and dilapidated predecessor that served a student body with noted behavior issues. The administration was concerned about how the new building would be treated, as vandalism may be as tempting—or even more tempting—on the new, exposed wood walls than in the previous building, and even more challenging to remove. Before the new building opened, school officials planned for and encouraged a behavior strategy of quiet voices in the halls using graphics, words, and quotes reminding students to be peaceful and wise. To the administration's delight, the students were remarkably calm and respectful in the new space. Behavior issues and subsequent disciplinary actions decreased significantly. Students reported that the space made them feel valued.

A report investigating the use of wood structures and finishes in schools in British Columbia similarly found that wood surfaces are less likely to be vandalized than other surfaces.[17]

Though more research has been done on office environments and hospitals focusing on productivity or infection, researchers of biophilic effects agree that the potential for schoolchildren to benefit from the healing effects of natural materials is very promising.

17 https://www.naturallywood.com/wp-content/uploads/wood-use-in-bc-schools_report_stantec-fastepp.pdf

LEFT — RENDERING SHOWS AN ISOMETRIC VIEW OF THE BUILDING
RIGHT — RENDERING SHOWS A SIDE VIEW OF THE BUILDING
Source: SRG Partnership

CASE STUDY: WSU LIFE SCIENCES BUILDING

MASS PLYWOOD USED IN NONCOMBUSTIBLE ASSEMBLIES

PROJECT OWNER: WASHINGTON STATE UNIVERSITY VANCOUVER

PROJECT LOCATION: 14204 NE SALMON CREEK AVE VANCOUVER, WA 98686

COMPLETION DATE: APRIL 1, 2024

ARCHITECT/DESIGNER: SRG PARTNERSHIP

MASS TIMBER ENGINEER/MANUFACTURER: CATENA

GENERAL CONTRACTOR: ANDERSON CONSTRUCTION

STRUCTURAL ENGINEER: CATENA CONSULTING ENGINEERS

MECHANICAL, ELECTRICAL, AND PLUMBING: AFFILIATED ENGINEERS

THE WASHINGTON STATE University (WSU) Vancouver Life Sciences Building will be a fully sprinklered, 3-story research laboratory with associated teaching and office spaces. The main part of the higher education building is classified as Group B occupancy, and the entire building is considered a single laboratory suite. Although the building construction is classified as Type III-B , the exterior wall and some portions of the interior structural systems use Mass Plywood Panels (MPP).

The Jensen Hughes team worked through construction details with SRG Partnership and developed solutions by referencing a white paper drafted by the team. Additional alternatives were developed to gain approval for use of mass timber in a noncombustible exterior wall assembly. The project includes mass timber panels in the floor assemblies that intersect with a mechanical and elevator shaft. The team outlined a strategy that included the use of a shaft liner, fire caulking at the intersecting joints, and mineral wool in void spaces to maintain the required fire ratings for the assemblies at the penetrations. The project has been approved, and the building is expected to be opened in spring of 2024.

CASE STUDY: REDMOND PUBLIC LIBRARY

SUSTAINABLE AND FLEXIBLE PUBLIC LIBRARY

PROJECT OWNER: DESCHUTES COUNTY LIBRARY

PROJECT LOCATION: 827 SW DESCHUTES AVE, REDMOND, OR 97756

COMPLETION DATE: NOVEMBER 1, 2024

ARCHITECT/DESIGNER: THE MILLER HULL PARTNERSHIP (DESIGN ARCHITECT), STEELE ASSOCIATES ARCHITECTS (LOCAL ARCHITECT)

MASS TIMBER ENGINEER/MANUFACTURER: STRUCTURECRAFT, ZIP-O-LAMINATORS, WESTERN WOOD STRUCTURES

GENERAL CONTRACTOR: KIRBY NAGELHOUT CONSTRUCTION CO.

STRUCTURAL ENGINEER: KPFF

MECHANICAL, ELECTRICAL, AND PLUMBING: INTERFACE ENGINEERING

RENDERING SHOWS THE SOUTH FACADE WITH CIVIC PORCH, MAIN PEDESTRIAN ENTRANCE, AND DLT/STEEL CANOPY

Source: The Miller Hull Partnership
Credit: The Miller Hull Partnership

MILLER HULL DESIGNED the Deschutes Public Library Redmond branch in Oregon to meet the client's goals of a warm, inviting interior; a flexible layout; and reduced emissions. The project uses mass timber for aesthetic and embodied carbon reduction goals, raised access floors for flexibility, and photovoltaic panels to pursue net-zero energy operation.

To calculate the up-front embodied carbon emissions, the team used Tally for Revit to perform a Whole Building Life Cycle Analysis (WBLCA). During the production stages of this project (A1-A3), the metal, concrete, and insulation generate the most emissions (53 percent, 21 percent, and 11 percent respectively). The timber's sequestered biogenic carbon accounts for 46 percent of the building's upfront carbon. The project is targeting Gold recognition for Leadership in Energy and Environmental Design, and Miller Hull has committed to purchasing carbon offsets equivalent to ⅓ of the project's A1-A3 emissions through Miller Hull's Emission Zero program.

To design efficiently with wood, the team limited the amount of wood fiber by selecting an optimal grid layout and used thin Dowel-Laminated Timber (DLT) floor panels. In addition, the team used a hybrid queen post truss with double glulam beams and thin steel rods to economically span 65 feet, creating a large, open library space.

The Redmond Library uses DLT for its structural, environmental, and acoustic benefits. Structurally, DLT can span the needed distances. Environmentally, DLT's dowel wood system eliminates the need for adhesives, reducing carbon emissions and improving indoor air quality. The project used a special type of DLT that has slots with acoustic strips to absorb sound, reducing the noise that would reverberate off the ceiling and could disrupt large, open spaces. By using DLT, the team eliminated drop ceilings, thereby reducing embodied carbon while allowing the occupants to benefit from the beauty of the exposed natural wood.

For flexibility, the project uses raised access floors on top of the DLT, so floor boxes and air diffusers can be repositioned in the future. The access floor cavity also conceals ducts, conduits, and pipes. Concealing these mechanical, electrical, plumbing, and fire (MEPF) systems leaves the DLT exposed and uninterrupted. The team was able to leave 80 percent of the DLT exposed throughout the building.

Another acoustic consideration is sound transition, where sound travels between 2 spaces from people talking or walking. The team chose to add acoustic pads underneath the access floor pedestals to mitigate sound vibrations between the floors and to avoid a concrete topping slab.

The DLT performs structurally as flooring, architecturally as an attractive finish material, and acoustically as a sound-absorbing feature, making it a true all-in-one product while also reducing carbon.

The project used DLT, which has structural, environmental, and acoustic benefits over cross-laminated timber (CLT). Structurally, the DLT can span farther than CLT, because all the wood fiber is oriented in 1 direction rather than in 2 directions. Environmentally, DLT's dowel wood-system eliminates the need for any toxic adhesives, making it more sustainable and healthier for humans than CLT. The project utilized a special type of DLT that is acoustically much better than CLT. The underside of the DLT has slots with acoustic strips to absorb sound, significantly reducing sound that would reverberate off the ceiling and disrupt large open spaces. By contrast, CLT requires dropped acoustic ceilings to mitigate sound reverberations. By using DLT, the team eliminated drop ceilings, thus reducing cost and carbon, while leaving the wood exposed.

For flexibility, the project utilized raised access floors on top of the DLT, so that floor boxes and air diffusers can be easily repositioned in the future. The access floor cavity also conceals ducts, conduits, and pipes. Concealing these MEPF systems allows for the DLT to remain exposed and uninterrupted. This contrasts with traditional CLT and concrete topping slab systems that leave MEPF systems exposed below, obscuring the wood. Ultimately, the team was able to leave 80 percent of the DLT exposed throughout the building.

Another acoustic consideration is sound transition, where sound travels between 2 spaces from people talking or walking. To absorb footfall traffic, CLT systems often utilize a heavy and carbon-intensive concrete topping slab and acoustic mat. Instead, the team chose to add acoustic pads underneath the access floor pedestals to mitigate sound vibrations between the floors and to remove the concrete topping slab.

The DLT performs structurally as flooring, architecturally as an attractive finish material, and acoustically as a sound-absorbing feature, making it a true all in one product, while reducing carbon.

https://www.woodworksinnovationnetwork.org/projects/redmond-public-library

CHAPTER 8: OWNERS AND DEVELOPERS

EMILY DAWSON
OWNER, SINGLE WIDGET

Many designers and building owners are drawn to mass timber for its environmental credentials. Innovators in the building industry recognize that the carbon impact of any investment likely will soon factor into its viability and/or market value, and that the development of forest carbon markets has the potential to inform timber use in real estate. Many believe that consumers who support sustainable forestry practices and policies will push the market toward the maximum carbon storage potential of forest products because sustainably harvested wood fits naturally into a circular carbon economy.

But to meet such ambitious goals, an array of other concurrent advantages must be realized. At this stage in the evolution of mass timber, building owners are true pioneers in adopting a relatively new technology while exploring evolving targets for cost and schedule savings, financing paradigms, and procurement approaches. Although the data that developers typically rely on for pro forma validation is still nascent for mass timber real estate investments, many educational resources, case studies, and anecdotes illuminate the reasons the market is seeing such strong growth.

8.1 MARKET DEVELOPMENT

Decarbonization and digitalization are both trends that lead to a promising economic forecast for prefabricated, bio-based construction

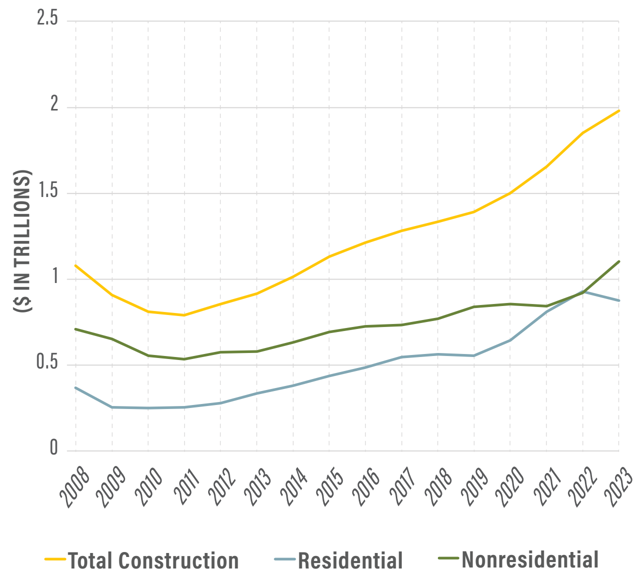
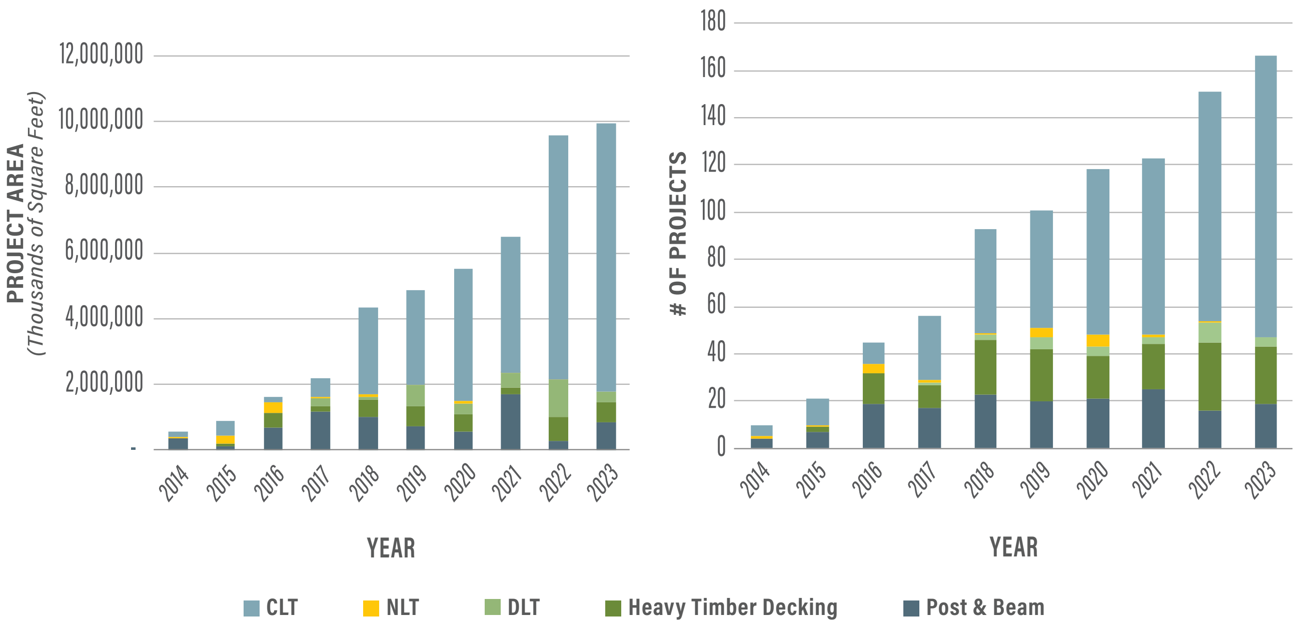


FIGURE 8.1: ANNUAL VALUE OF ALL CONSTRUCTION, 2013 TO 2023 ($ IN TRILLIONS)

https://www.census.gov/construction/c30/historical_data.html

materials like mass timber. According to the *2023 International Report* by global construction consultant firm RLB, "one of the most significant impacts [redefining traditional construction delivery] is the shift towards sustainable development, creating new client offerings, such as carbon quantification in buildings."[1] Following the global 2022 inflation rate of 12.5 percent, alongside interest rate and energy cost increases, 2023 brought relief. Although the market remains somewhat tentative, a "greater-than-expected resilience in the United States and several large emerging market and developing economies,"[2] lowered the risk of a global recession significantly from just 12 months ago.

1 Rider Levett Bucknall, *International Report, Construction Market Intelligence* (second quarter 2023).
2 International Monetary Fund, *World Economic Outlook* (Update, January 2024).



LEFT — FIGURE 8.2: UNITED STATES PROJECTS BY PRIMARY MASS TIMBER MATERIAL

RIGHT — FIGURE 8.3: UNITED STATES BUILDING SQUARE FOOTAGE BY PRIMARY MASS TIMBER MATERIAL

Data provided by WoodWorks

US Construction Market Context

When compared with other advanced economies globally, total US construction spending showed the strongest growth in 2023. **Figure 8.1** shows the value of all construction in the United States, which was $1.98 trillion in 2023, an increase of about 7 percent from 2022. That represents a rebound when compared with the equal growth/inflation rates of 2022; inflation cooled to 3.4 percent in 2023. Although residential construction accounted for 30 percent to 40 percent of total US construction values in the last 15 years, it rose sharply during the pandemic, and in 2022 exceeded 50 percent. This year, the 44 percent market share indicates a rebalancing may be in effect. The residential market represents a significant growth opportunity for mass timber; most residential construction is wood-based. Around one-third of all mass timber projects to date are residential.

US Mass Timber Projects

The following figures and tables illustrate the development of the mass timber industry in the US and provide insights into the popularity of primary materials, the regional popularity of mass timber, occupancy types, building sizes, the total square footage, and number of projects by construction start date. The data behind the visualizations and analysis were provided by WoodWorks's – Wood Products Council, a nonprofit group that provides free project support to the Architecture, Engineering, and Construction (AEC) community on multifamily, institutional, and commercial buildings. Growing the mass timber market is the objective of the organization.

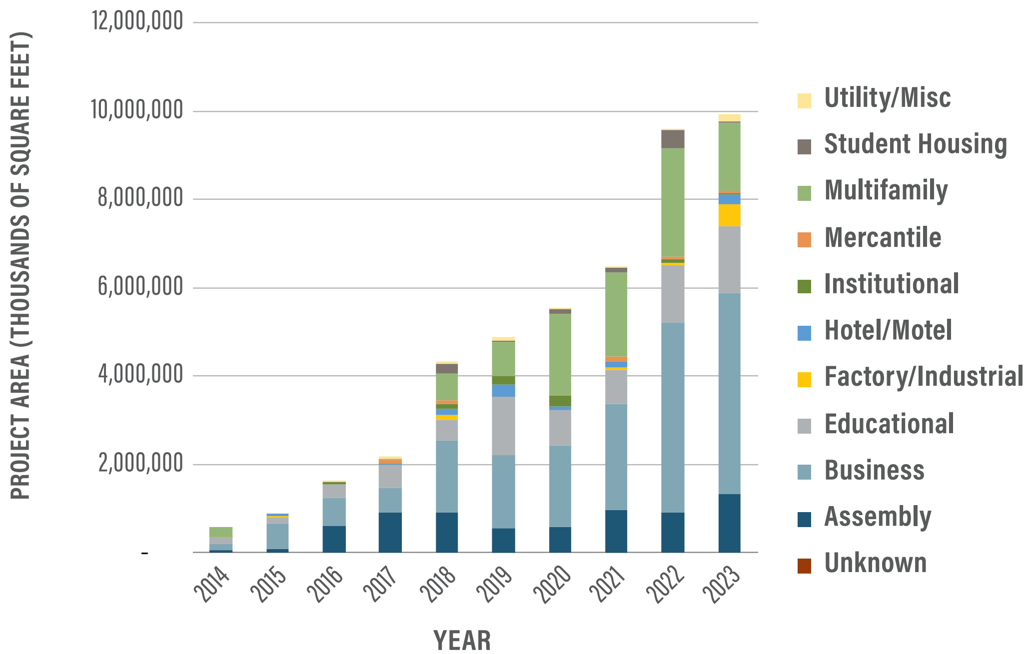


FIGURE 8.4: UNITED STATES MASS TIMBER BUILDING SQUARE FOOTAGE BY OCCUPANCY

Data provided by WoodWorks

For mass timber in the US, 2023 was another year of growth and progress. The number of projects under construction or completed each year continues to grow steadily, increasing by about 10 percent from last year. Despite another year of declines in architectural project billings in the country,[3] the number of proposed mass timber projects increased 18 percent.

Figure 8.2 illustrates the increasing number of mass timber building projects, broken out by type of timber technology. On a project-count basis, annual growth has consistently been the strongest in the use of Cross-Laminated Timber (CLT).

Figure 8.3 illustrates the total constructed square footage of the buildings in **Figure 8.1**. In 2023, mass timber projects totaled 9.9 million square feet, a modest 4 percent increase from the previous year. The average project size was 60,000 square feet, with CLT accounting for over 80 percent of the total square footage and 72 percent of all projects that broke ground.

Figure 8.4 shows total built square footage by building occupancy type. Business and assembly occupancies continue to dominate, together representing 60 percent of both the total number of buildings and the built square footage in 2023. Residential and educational uses are the next most significant occupancy categories.

Figures 8.5 and **8.6** combine the data depicted in the previous charts to show the total square footage and total number of projects, either under construction or completed, by occupancy type.

3 Rider Levett Bucknall, *North America Quarterly Construction Cost Report*, (fourth quarter 2023).

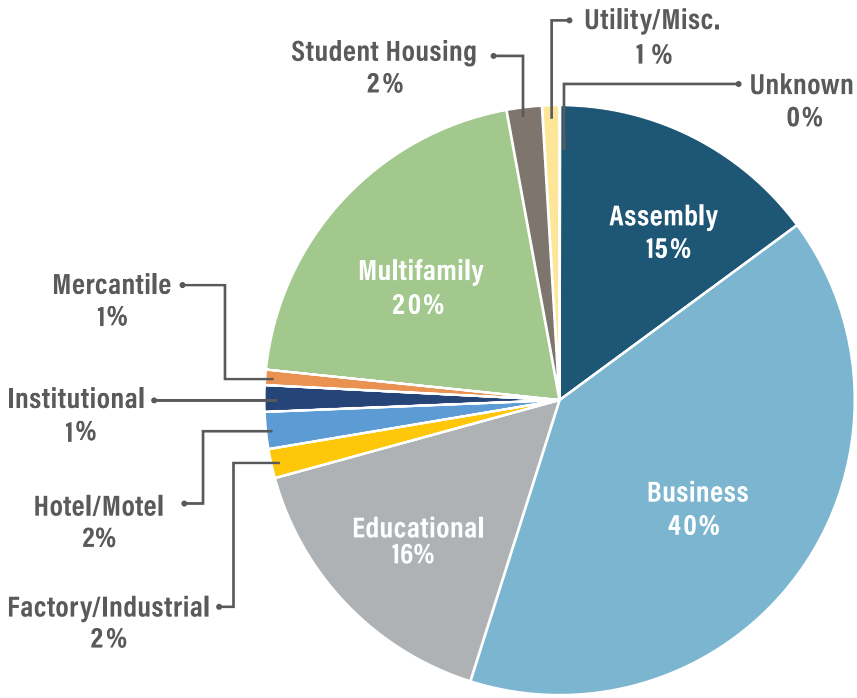


FIGURE 8.5: US TOTAL MASS TIMBER BUILDING SQUARE FOOTAGE BY OCCUPANCY TYPE

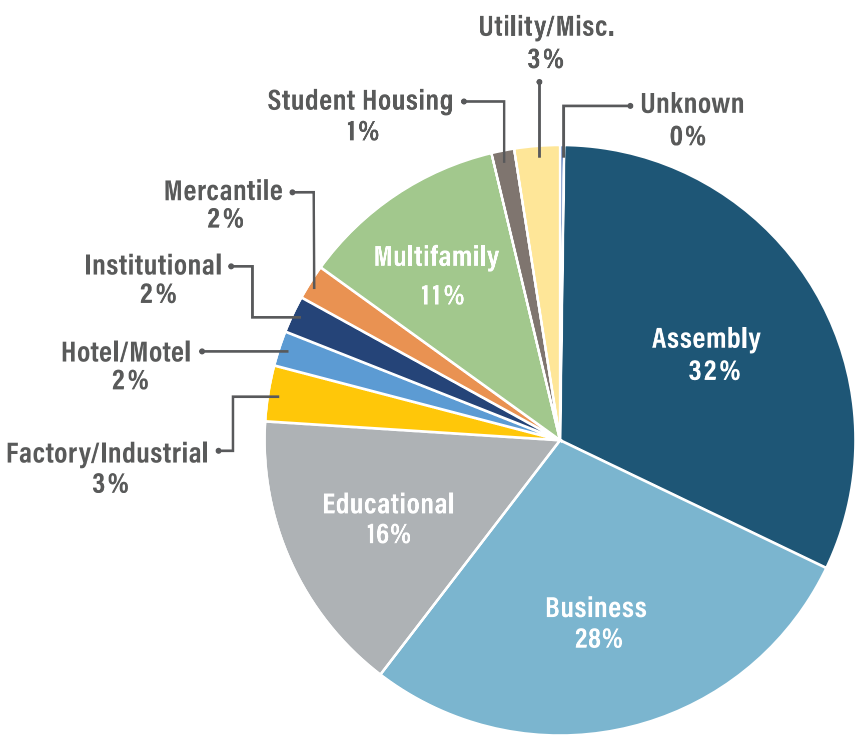


FIGURE 8.6: US TOTAL NUMBER OF MASS TIMBER BUILDINGS BY OCCUPANCY TYPE

Table 8.1 shows the total number of mass timber projects in the US by state. Three states—California, Oregon, and Washington—host nearly half of all constructed projects in the country.

8.2 RATIONALE AND MOTIVATION

In a 2014 survey[4] of tall wood building owners worldwide, their most cited motivations were market leadership and innovation, the environmental benefits associated with wood, and construction schedule savings. Owners must balance those rationales with their responsibility to seek the best return on their investment and the need to deliver a building within the allotted time frame, while ensuring the safety of construction workers and building occupants. As expertise grows in the AEC community and more mass timber projects go to market, successes are helping to allay the perceived risks.

Mass timber market data is limited by the relatively small number of buildings and the short amount of time these buildings have been on the market. Mass timber buildings have, however, been shown to perform well in terms of lease-up rates, tenant retention, sales, and market premiums. This performance is likely related to the topics discussed in chapter 7, including the biophilic and human health benefits of being near natural materials.

Environmental and carbon sequestration credentials likely will be attractive to a growing market of environmentally conscious tenants and buyers, particularly in the housing and corporate markets (see **Figure 8.7**). These buildings may also

4 Perkins&Will, *Survey of International Tall Wood Buildings* (2014).

STATE	STAGE		
	CONSTRUCTION STARTED / BUILT	IN DESIGN	GRAND TOTAL
AK	7	0	7
AL	12	11	23
AR	24	6	30
AZ	3	4	7
CA	122	172	294
CO	32	39	71
CT	13	7	20
DC	10	14	24
DE	1	1	2
FL	33	55	88
GA	22	42	64
HI	2	2	4
IA	7	2	9
ID	11	10	21
IL	18	28	46
IN	6	5	11
KS	3	3	6
KY	7	8	15
LA	3	11	14
MA	35	76	111
MD	9	18	27
ME	13	15	28
MI	11	30	41
MN	14	17	31
MO	10	19	29
MS	2	11	13
MT	19	17	36
NC	46	36	82
ND	2	1	3
NE	6	7	13
NH	4	8	12
NJ	8	10	18
NM	3	3	6
NV	1	5	6
NY	30	37	67
OH	12	19	31
OK	5	3	8
OR	107	40	147
PA	9	12	21
RI	6	2	8
SC	24	10	34
SD	2	1	3
TN	13	31	44
TX	62	90	152
UT	15	15	30
VA	13	30	43
VI		1	1
VT	3	11	14
WA	106	62	168
WI	28	18	46
WV	2	1	3
WY	3		3
2023 GRAND TOTAL	959	1,076	2,035

TABLE 8.1: US MASS TIMBER PROJECTS BY STATE
Data provided by WoodWorks

FIGURE 8.7: LARGE CORPORATE BUILDING OWNERS ARE TURNING TO MASS TIMBER.

Source: Microsoft, Holmes structures
Credit: Blake Marvin Photography

have a place in the carbon markets discussed in chapter 9.

8.3 COST OF CONSTRUCTION

With over 1,500 mass timber projects in the last decade in the US alone,[5] and with a growing community of designers and builders who have completed multiple projects, cost trends are emerging. Architects, engineers, and builders with a depth of experience in mass timber projects report[6] that when mass timber replaces concrete and steel construction, it usually generates greater savings than when it replaces light framing. For commercial projects, however, the overall trends are similar for all 3 structural materials.

There generally is a premium for a mass timber project, up to 15 percent. But the median project premium is less than 2 percent, and the gap continues to shrink as teams and markets become more experienced. A 20 percent reduction in overall schedule is now the norm, driven by a 25 percent median schedule reduction in the superstructure. The slight overall cost premium seen across projects disappears when other building system efficiencies are also realized. The additional potential to capture more in lease rates and lower tenant turnover, or the advantage to the building owner's return that results from shortened schedules will not be apparent in a builder's cost estimate, and the building owner can only investigate them accurately within their overall pro forma.

5 https://www.woodworks.org/resources/u-s-mass-timber-projects/
6 The companies that participated reported on commercial projects in the United States (2023).

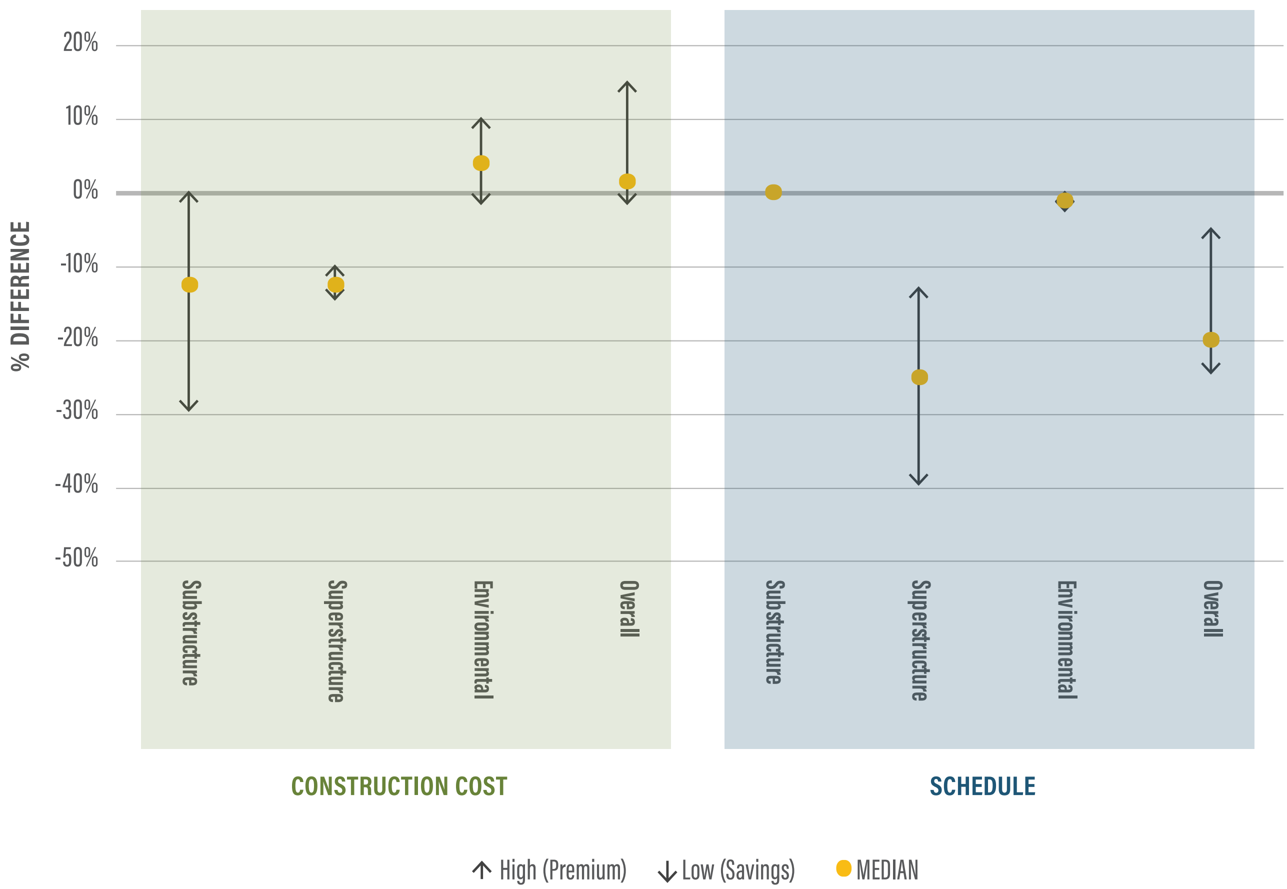


FIGURE 8.8: COST AND SCHEDULE DIFFERENCES BETWEEN MASS TIMBER AND OTHER STRUCTURAL MATERIALS (2023)

Cost information in **Figure 8.8** is grouped into the 3 macro systems that make up every building: (1) the superstructure, all above-grade structural components; (2) the substructure, all below-grade structural components and foundations; and (3) the environment, which groups the building envelope, systems (mechanical, electrical, plumbing and fire protection [MEPF]), and interior finishes. Mass timber offers distinct advantages, challenges, and potential in each of these 3 categories.

The greatest cost savings are found in the superstructure's construction schedule. The total construction schedule can be reduced significantly, up to 25 percent. Resulting cost reductions include overhead, carrying costs, earlier occupancy, and reduced risk. Contractors report significant cost savings in general conditions, even with increased levels of coordination. In fact, increased coordination is exactly what creates the greatest savings in the field.

Notably, these savings are often missed in a hard cost analysis of materials and labor. If the estimator understands labor savings, however, the findings can impact early cost models. In a study of 100 mass timber buildings in the United Kingdom, Waugh Thistleton Architects found a 50 percent to 70 percent reduction in site staff for structural framing. The choice of lateral systems matters, too, and it can often drive the overall material and labor premiums. Concrete cores

FIGURE 8.9: 19-STORY MPP TOWER SAVED OVER 25% ON COSTS AND 6 MONTHS OF CONSTRUCTION TIME.

1510 Webster, Oakland, California
Source: oWOW
Credit: Andrew Nelson

may slow the overall schedule, for example, because the mass timber framing has to pause while the core is constructed. The timing of material procurement, which can often be impacted by a fluctuating commodity market, can also make a difference between an overall premium or savings.

Savings in foundations, when they occur, are seen primarily in hard costs. Because a timber building on average weighs only 20 percent as much as a steel or concrete structure,[7] the outcome can be quite promising when soil conditions are more complicated. Significant savings occur when a much lighter structure allows for less complex and costly foundation solutions. In these cases, total overall construction costs are likely to be lower than for buildings with heavier structural systems. The savings are maximized for projects in high seismic zones, where the lighter mass timber structure translates to lower seismic forces that must be resisted by the foundations.

Every project takes a different approach to the building's envelope, MEPF systems, and interior finishes. Although more exposed structural surfaces can mean savings on finishes, cost increases

7 https://www.thinkwood.com/blog/4-things-to-know-about-mass-timber

in timber buildings commonly stem from additional acoustic treatments and higher appearance criteria for drywall detailing and exposed mechanical components. When paired with a highly coordinated construction team, prefabricated enclosure, systems, and finish elements can take advantage of the superstructure's rapid assembly superpower. In fact, highly modular projects can expect an overall schedule savings of up to 50 percent.[8] As mass timber and modular industries mature, options for prefabricated finish and environmental systems components will multiply to best take advantage of reduced schedule cost savings.

Incentives

Incentives for sustainable and low-carbon buildings vary by jurisdiction and project type. Mass timber construction may have associated financing or zoning incentives (such as increased floor area ratio [FAR]) for reducing embodied carbon or other innovative technologies.

Rigorous whole-building and structural Life Cycle Analysis (LCA) studies are becoming more numerous as the mass timber industry matures. Collectively, these studies indicate that wood products do significantly contribute to lower embodied-carbon construction. To cite 2 examples, a study of Katerra's Catalyst Building[9] in Spokane, Washington, determined that the building's wood product carbon stores nearly offset the up-front carbon required to construct it. Another completed office building, Platte Fifteen in Denver, Colorado, gained a 70 percent to 76 percent savings in Global Warming Potential (GWP) by choosing a mass timber structural system when compared to primarily steel or concrete systems. And it did so for a negligible (2 percent) cost premium.[10] Over 99 percent of the GWP in that system was contributed by the reinforced concrete topping slab.

Maximize Allowable Building Area

On sites with challenging soil conditions and bearing pressure limitations, a lighter building could be built larger or taller than a heavier one. The lighter weight of a timber structure can be particularly advantageous in regions with high seismic activity. In areas where foundations that can support a heavier building are prohibitively expensive, a lighter building may be the difference that makes a project viable.

Another opportunity for increasing overall building area is with additional floors because of reduced floor-to-floor heights. Mass timber floor sections can be designed more thinly than other options and have inherent fire resistance, requiring no added fireproofing layers at certain building heights.

Leasing and Tenant Retention

Increased demand for biophilic buildings is driving down the leasing period for exposed mass timber buildings (**Figure 8.10**). Securing tenants early allows the building to more quickly reach stabilization, when the building is at full occupancy and generating regular income. Once the building is stabilized, permanent financing can be obtained at a fixed interest rate or the build-

8 https://content.aia.org/sites/default/files/2019-03/Materials_Practice_Guide_Modular_Construction.pdf

9 Carbon Leadership Forum and Center for International Trade in Forest Products, *Life Cycle Assessment of Katerra's Cross Laminated Timber Catalyst Building* (2020).

10 https://info.thinkwood.com/platte-fifteen-life-cycle-assessment

THE MASS TIMBER FRAME IS ERECTED AT SAN MATEO COUNTY'S COB3.
Source: Truebeck Construction; Credit: Cesar Rubio

CASE STUDY: COUNTY OF SAN MATEO, COUNTY OFFICE BUILDING 3 (COB3)

FIRST CLT PUBLIC, CIVIC BUILDING IN THE US IN THE WORKS

PROJECT OWNER: COUNTY OF SAN MATEO PROJECT DEVELOPMENT UNIT

PROJECT LOCATION: 555 MARSHALL ST. REDWOOD CITY, CA 94063

COMPLETION DATE: JANUARY 15, 2024

ARCHITECT/DESIGNER: SKIDMORE, OWINGS & MERRILL (SOM), WATRY DESIGN

MASS TIMBER ENGINEER/MANUFACTURER: SMARTLAM NORTH AMERICA

GENERAL CONTRACTOR: TRUEBECK CONSTRUCTION

STRUCTURAL ENGINEER: SKIDMORE, OWINGS & MERRILL (SOM)

MECHANICAL, ELECTRICAL, AND PLUMBING: CRITCHFIELD MECHANICAL (MECHANICAL), D&B TRADE PARTNER; CSI ELECTRIC (ELECTRICAL), D&B TRADE PARTNER; JW MCCLENAHAN (PLUMBING), D&B TRADE PARTNER

OTHER CONTRACTORS: TRUEBECK CONCRETE, ARCHITECTURAL GLASS & ALUMINUM, DALEY'S DRYWALL AND TAPING, SPACETONE ACOUSTICS, ALCAL GLASS, COSCO FIRE PROTECTION, REDWOOD ELECTRIC GROUP

CONSTRUCTION CONTINUES ON COB3.
Source: Truebeck Construction; Credit: Cesar Rubio

COB3'S INTERIOR FEATURES LARGE EXPANSES OF EXPOSED WOOD.
Source: Truebeck Construction; Credit: Cesar Rubio

TRUEBECK CONSTRUCTION AND Skidmore, Owings & Merrill (SOM) are building the first public, civic Cross-Laminated Timber (CLT) structure in the nation.

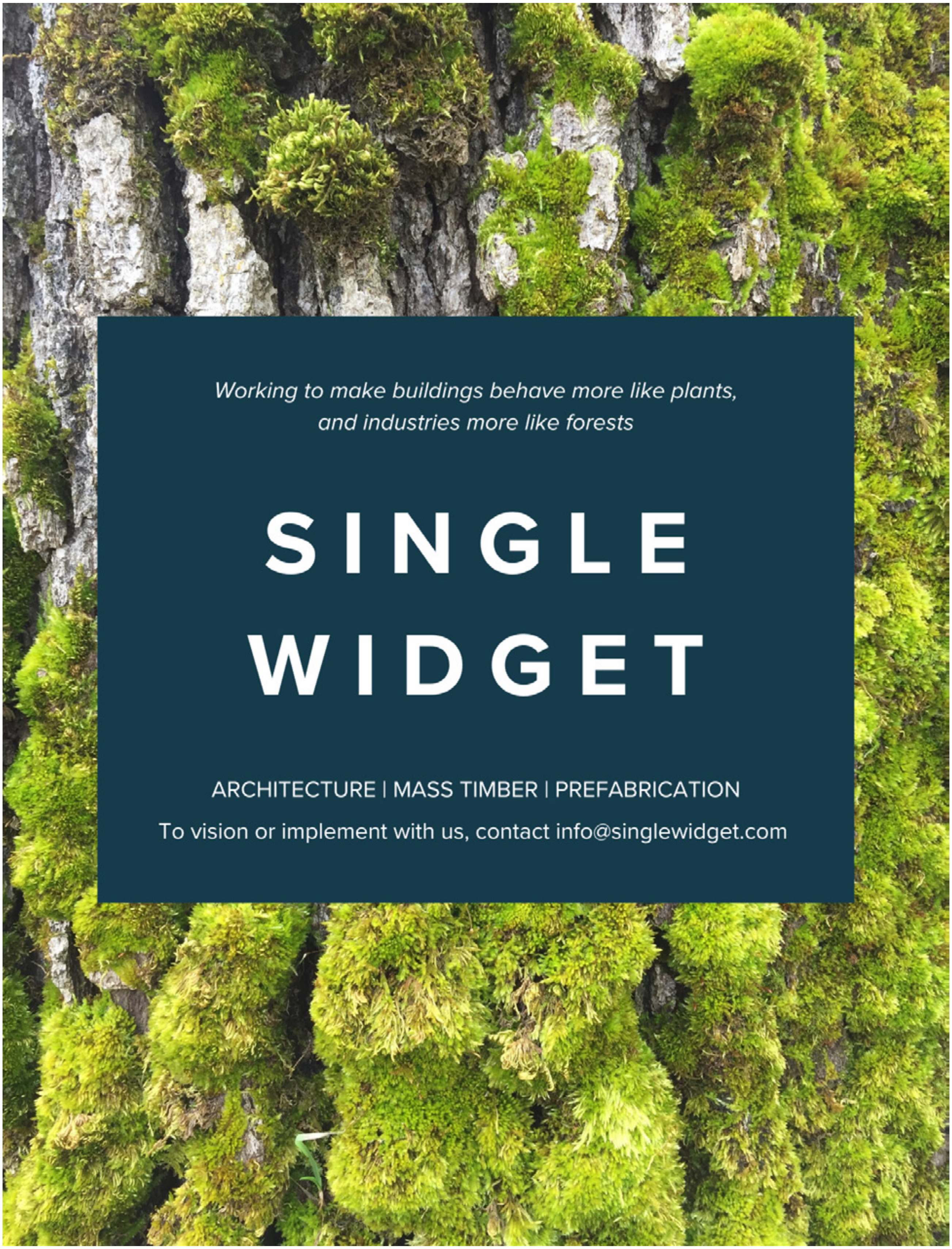
Configured in an I-shape that incorporates two generous public plazas, the new 208,000-square-foot, 5-story County Office Building 3 (COB3) will consist of an unusual mass timber structure—glulam columns/beams and CLT flooring. It includes flexible office spaces, a gym, a café, multipurpose rooms, and board chambers for the San Mateo County Board of Supervisors. The interior features many areas of exposed wood, and the facade incorporates complementary copper anodized aluminum panels alongside sizable glass segments, inviting natural light throughout the building.

The project includes extensive areas with exposed mass timber ceilings; therefore, the team made a concerted effort early in the design phase to conceal as much of the infrastructure as possible. As a result of this detailed coordination between the architecture and construction teams, precut panels and beams arrived to be installed directly off the truck with all of the penetrations measured and cut.

A new 368,000-square-foot, 7-story parking structure designed by Watry Design has 1,200 stalls, and it includes 124 EV chargers. It's designed to meet the parking needs of the new COB3 and the other facilities in the County Government Center.

The design team responded to new needs that emerged during the pandemic by ensuring access to daylight, natural ventilation, and green open space throughout the project. Bioretention planters will capture, treat, and manage 100 percent of the stormwater runoff from the roof and site pavers.

Photovoltaics on the COB3 structure and parking garage offset 100 percent of the building's predicted energy use. Prioritizing best sustainable design practices and performance optimization supports the project's goal of net-zero energy and Leadership in Energy and Environmental Design (LEED) Platinum certification.


Working to make buildings behave more like plants,
and industries more like forests
SINGLE
WIDGET
ARCHITECTURE | MASS TIMBER | PREFABRICATION
To vision or implement with us, contact info@singlewidget.com

ing can be sold. The earlier the building is fully leased, the better the return on the investment.

While aggregated studies have not yet been done on the market success of mass timber real estate, case study evidence is increasingly positive. A 2023 study (available through WoodWorks, see **Table 8.2**) of 10 housing and office buildings found lease/sale rates between 11 percent and 65 percent higher (with outlying statistics of 6 percent lower and 325 percent higher) than market rate. The Platte Fifteen LCA study cited in the "Incentives" section also reflected the economic success of the project; the building was 85 percent leased only 1 month after completion, and its lease rates were higher than any comparable building in the area.

The Portland metro area in Oregon has the highest concentration of mass timber building projects in the US, and local developers are reporting significant leasing advantages for offices:

- Beam Development opened the district office in 2020, and it was 66 percent leased at project completion, doubling comparison expectations of 20 percent to 30 percent. By January 2022, the building was 73 percent leased. 811 Stark opened in 2015 with 100 percent of its office space leased, and half its retail space leased shortly thereafter. The building has remained completely leased since opening.[11]
- The PAE Living Building, developed by PAE and Edlen & Co., opened in fall 2021 with 88 percent of its office space and 25 percent of its retail space leased.[12]

FIGURE 8.10: RADIATOR BUILDING
Source: Andrew Pogue Photography

- Killian Pacific's growing mass timber portfolio includes Nova and The Hudson. Both opened in 2016 and stabilized in 2 months and 5 months, respectively. Two years later, Convene was completed and stabilized at opening. Skylight was also completed in 2018, quickly leased to 84 percent, and stabilized in 14 months.[13]
- One North, a collaborative development by Karuna Properties II and Kaiser Group Inc. (see **Figure 8.11**) was completed in 2014, with key anchor tenants committed before groundbreaking. Even with unprecedented lease rates for the east side of Portland and very little parking, the buildings were fully

11 Interview with a representative of Beam Development.
12 Interview with a representative of PAE and Edlen & Co.
13 Interview with a representative of Killian Pacific.

TOPIC	WOODWORKS RESOURCE
Building Development & Ownership	Mass Timber Business Case Studies
	How Can a Developer/Owner Get Started with Mass Timber?
	Repair of Fire-Damaged Mass Timber
	Mass Timber Project Questionnaire for Builder's Risk Insurance
	Mass Timber: The Optimal Solution for Multi-Family High-Rise Construction
	Meeting Sustainability Objectives with Wood Buildings

TABLE 8.2: WOODWORKS RESOURCES FOR BUILDING OWNERS
Source: WoodWorks.org/resources/

leased 6 months faster than the pro forma had assumed.[14]

In addition to faster lease-up rates, mass timber buildings can demand premium rental income. Exposed wood ceilings are a premium finish when compared with painted drywall or concrete. Floor-to-ceiling dimensions can be greater because of the strength and spanning capacity of the panels, and the beauty of exposing the structural deck (see **Figure 8.12**). These factors contribute to higher lease rates for little to no added construction costs, translating to a higher sales price for the building in the long term.

Construction Risk Reduction

The modularity, precision, and beauty of large engineered timber components has refreshed conversations about the benefits of off-site construction for other building systems. When a modular structural system like CLT is assembled in half the time a traditional structure would take—with lower risk and a higher level of craftsmanship—designers and builders start to look for ways to shift the fabrication of other components into more controlled environments.

Site-built construction is often challenged by weather, traffic, noise ordinances, labor shortages, and any number of physical site constraints, as shown in **Figure 8.13**. Customized prefabrication can alleviate these issues, depending on the project and the extent to which the design and build teams can plan and coordinate it. The resulting buildings are more precise than site-built structures because of the increased quality control afforded by climate-controlled factory environments.

Chapters 5 and 6 go into depth on the advantages of off-site fabrication, and the design processes and collaboration necessary to achieve success. In short, collaborating and making final decisions earlier in the design process and shifting time typically spent during construction administration into the design phase can pay off in construction-phase speed and predictability. The precision of custom components and a highly organized

14 Interview with a representative of Kaiser+Path.

TOP — FIGURE 8.11: ONE NORTH DEVELOPMENT

Source: Kaiser+Path

LEFT — FIGURE 8.12: HIGH WINDOW BAYS MADE POSSIBLE WITH MASS TIMBER STRUCTURAL SLABS

Soto Building, San Antonio, Texas
Source: Lake | Flato; Credit: Erika Brown Photography

RIGHT — FIGURE 8.13: SIDEYARD

Source: Project: Sideyard; Credit: Skylab Architecture modular structural package expedite construction with fewer field modifications, change orders, and delays. Other associated benefits include fewer opportunities for weather delays and lower costs associated with traffic disturbances.

Considering that a building's superstructure is usually about 20 percent to 25 percent of the total construction cost, investing in a highly predictable assembled structure may significantly reduce risk. MEPF systems account for another 30 percent to 35 percent of a building's cost, or about 15 percent for core-and-shell projects. These systems may also be fabricated off-site for schedule savings. If well-coordinated with the structure, the associated change risk also drops.

Carrying Costs

The construction cost savings of a prefabricated structural approach such as CLT is multiplied when financing impacts are also considered. Comparative information about the construction duration of different structural options can have a significant impact when applied to carrying costs such as loan interest payments, property taxes, and other fees. Reduced carrying costs translate into tangible savings that should be included in comparative cost models.

8.4 TALL TIMBER

Although mid-rise construction is the most common new building stock for all construction types, buildings over 20 stories create an impact from both market and environmental resource standpoints. Using mass timber in buildings above the current US code limit of 18 stories shows increasing potential. The tallest mass timber buildings in the world use CLT and glulam as the primary structural materials, and concrete for cores and/or additional mass:

- 18 stories, 174 feet (53 meters): Brock Commons, University of British Columbia, Vancouver, BC (2017)
- 20 stories, 239 feet (73 meters): Sara Kulturhus Centre, Skelleftea, Sweden (2021)
- 21 stories, 240 feet (73 meters): HAUT, Lingotto, Amsterdam, Netherlands (2022)
- 24 stories, 276 feet (84 meters): HoHo Vienna, Woschitz Group, Vienna, Austria (2019)
- 18 stories, 279 feet (85 meters): Mjøstårnet, AB Invest, Brumunddal, Norway (2019)
- 25 stories, 284 feet (87 meters): Ascent, New Land Enterprises, Milwaukee, Wisconsin (2021), **Figure 8.14.**

A growing number of studies and proposals are validating the effectiveness of timber structures up to 35, 40—even 80 stories.[15,16,17,18] In Australia, a 590-foot (180 meters) hybrid timber and steel tower[19] is under construction, and will potentially be followed by a 50-story, 626-foot (191-meter) office building[20] that received permits in late 2023. The next round of US building code updates, to be formalized in 2024, increases the

15 https://www.woodworkingnetwork.com/news/woodworking-industry-news/worlds-tallest-timber-residential-building-planned
16 https://www.gensler.com/blog/developing-worlds-tallest-net-zero-timber-building-sidewalk
17 https://perkinswill.com/project/canadas-earth-tower/
18 https://perkinswill.com/project/river-beech-tower/
19 https://www.shoparc.com/projects/atlassian-hq/
20 https://grangedevelopment.com/project/c6-south-perth/

FIGURE 8.14: ASCENT IS THE TALLEST TIMBER TOWER IN THE WORLD.
Milwaukee, Wisconsin
Source: New Land Enterprises

allowance of exposed wood surfaces (see chapter 5 for more information) for buildings 12 stories and below. However, wood buildings that are taller or include more exposed wood than codes allow can be proven viable and safe. Depending on the jurisdiction, such designs may be permissible through an alternate means-and-methods, performance-based permitting approach.

The Council on Tall Buildings and Urban Habitat (CTBUH) is developing resources for project teams pursuing tall mass timber buildings, supported by grant funding from the US Forest Service. The group worked to establish the inclusion of timber projects in the CTBUH height criteria and published *Timber Rising*, a compilation of the best research and resources for tall timber projects.

8.5 EXECUTING AN INNOVATIVE PROJECT

Although mass timber uptake in North America continues at an exceptional rate, it is still an emerging technology in most markets. Finding an experienced team is one effective way to mitigate the risks associated with innovative approaches, but strong goals and leadership on the ownership side are just as crucial. This section identifies key issues that building owners and developers face when using mass timber.

Choosing a Team

Investors in mass timber buildings can benefit from recognizing that a high level of integration between the design and build teams is a necessity, not an option. Some high points are listed below, but the relevant sections in chapters 5 (design) and 6 (build) provide more detail on integrated approaches.

The British Columbia Construction Association (BCCA) sponsored a study of innovative technologies and strategies in building construction procurement.[21] It found that successful projects include the following:

- A highly effective and collaborative project team that puts the interests of the project first
- Multiproject engagements of consultants and contractors to foster collaboration, learning, and team cohesion
- Greater collaboration, leading to more successful outcomes and higher-level team performance
- Starting the procurement process as early as possible to allow collaboration to start and creative ideas to blossom
- Allowing the project team input on when research and development, tours, and project documentation activities can best occur to maintain an efficient and safe site
- Construction Management at Risk (CMAR) or Single-Purpose Entity (SPE) for Integrated Project Delivery (IPD) contracts (such as multiparty agreements) that encourage collaboration may be best suited for innovative projects that are not well-defined in scope
- Requiring evidence of the qualifications of individuals as part of the evaluation; the names of key project team members, including important trade companies, need to be written into contract documents to ensure their expertise is being applied to the project and that the project is not passed on to others in the company
- The owner ensuring that it has the capacity to carry out project leadership and oversight effectively, potentially through an external project manager (operations and maintenance personnel should also be involved)
- Encouraging businesses of all sizes to participate because small- to medium-size enterprises are sometimes the most innovative
- Reducing barriers to participation by simplifying the procurement process as much as possible, e.g., admitting bidders who may not have directly relevant project experience but have transferable expertise with a similar project type; focus is on the quality of the references rather than quantity

In summary, highly collaborative, nimble teams of people who are eager to innovate and willing to solve problems are more likely to achieve success with new approaches.

Design-Phase-Forward Planning

Mass timber is a catalyst for design-phase-forward planning that can have significant impacts on construction schedules. An experienced team will plan for adequate coordination time before the start of construction to reduce costly field labor and project overhead. The advantages to

21 British Columbia Construction Association (BCCA), *Procuring Innovation in Construction: A Review of Models, Processes, and Practices* (2016).

investing in early coordination of the superstructure include the following:

- Precision placement of mechanical, electrical, and plumbing (MEP) penetrations results in fewer trade conflicts on-site and allows for off-site fabrication of components for rapid sequencing.
- A custom mass timber package is predictable to install and precise to a ⅛-inch tolerance. If the package is fully coordinated, it should require no field modifications.
- Change orders associated with the structure and MEP trades are minimized by up-front coordination.

These advantages are amplified by strategically applying prefabrication approaches to envelope and finish components.

Understanding the schedule savings and the reduction of on-site risk is crucial for producing an accurate cost model. According to Swinerton, a commercial construction company with experience in mass timber, "A large-scale mass timber project can be up to 2 percent higher in direct costs, but a minimum of 20 percent lower in project overhead costs. The net result is cost neutrality and higher value."[22]

By investing more time in the design phase to facilitate more efficient manufacturing and fabrication, project managers can reduce construction time and increase construction predictability. This may have implications for how the project is financed, increasing up-front soft costs but decreasing hard costs and interest payments.

Cost Certainty

The marketplace for mass timber products is increasingly competitive as the number of manufacturers grows, both in North America and abroad. Although the learning curve for mass timber construction is relatively easy to overcome, inexperienced builders will have difficulty estimating the savings associated with using mass timber and learning to be part of an up-front planning process. The number of manufacturers, designers, and builders who understand how to deliver efficient, cost-effective mass timber buildings is growing because the value of completed buildings is being proven in the marketplace.

As the industry evolves, evidence is growing that, although the materials cost for a mass timber building may be higher than for concrete or steel, mass timber construction remains competitive because of labor savings, less costly foundations, reduced project and financing timelines, and more quickly realized revenue from a completed building (see also chapter 6).

When there is a comparative cost increase associated with using mass timber over other structural systems, the premium should be balanced by adjusting the pro forma to include increased market value, illuminating payback periods. The development team for The Canyons, a 6-story apartment building completed in late 2020 in Portland, Oregon, compared a CLT structure to light framing and painted drywall. They discovered that the payback period for the premium structure was just over 3 years, and they proceeded with the mass timber option. Ensuring premium market

22 Erica Spiritos and Chris Evans, Swinerton Builders, "Mass Timber Construction Management: Economics & Risk Mitigation" (presentation, Mass Timber Conference, 2019).

differentiation with a short payback period justified the relatively small capital cost increase.

Procurement Processes

Standard procurement processes can be a barrier to maximizing the cost benefits of mass timber, as discussed at length in chapters 5 and 6.

A traditional Design-Bid-Build (DBB) procurement process is common and, as such, preferred by many investors. For the purposes of this section, the issues are like those of the Construction Manager/General Contractor (CM/GC) process:

- Design a building to a given program, budget, and the local jurisdiction's requirements.
- Request bids from building contractors who seek the best value from a variety of installers and manufacturers.
- Select a contractor (or subcontractors) to construct the building based on the apparent best value.

An effective mass timber design, however, requires extensive coordination with a procurement and installation team before putting the project out for bid. Efficiencies in materials layout and site logistics can be accurately incorporated into early cost estimates only if an experienced team is consulted. A mass timber building can be designed with average assumptions about efficient fiber use, fire ratings, cost, and availability. This approach, however, carries risks because of possible delays and costs associated with the unanticipated need for redesign further along in the process, including design fees, permit revisions, constructability issues, and materials availability. The earlier a procurement and installation team is brought on board, the more refined and cost-effective the design and construction process will be.

One option in a traditional DBB contract model is to partner with a manufacturer during the design phase, using a separate contract or a letter of intent to select that manufacturer during bidding. This can be done as an agreement with the owner or with the CM/GC. The advantages of this approach include design optimization, detailed pricing feedback during design, and early assurances of product delivery dates. The risks include lack of precedent, resulting in limited availability of fabrication teams who are accustomed to design team integration. But remaining flexible until a project is ready to order can have advantages in a changing market. Until manufacturing supply catches up with the increasing demand for mass timber products, the lead time for detailing on the manufacturer's end can be a deciding factor.

Building owners may also choose a different, inherently more collaborative procurement model to avoid these issues and support an integrated design process. Design-Build, where the contractor and the design team are chosen and contracted together (see **Figure 8.15**), or IPD, where all parties are financially incentivized for project success, naturally support early and efficient coordination. Having a design optimized early on will help ensure that fabrication timelines will be met if market demand is high. An experienced procurement team will be able to navigate these challenges.

The necessary prefabrication of massive panel elements creates an incentive for panel manufacturers to integrate along the traditional building project supply/value chain and to offer an integrated solution package rather than fabricated elements alone. As a result, many companies

FIGURE 8.15: COMMUNITY ROOTS HOUSING'S HEARTWOOD PROJECT ELECTED FOR A DESIGN-BUILD CONTRACT.

Swinerton & atelierjones
Source: atelierjones
Credit: Lara Swimmer

incorporate internal design, project management, and construction teams—or they ally with experienced companies. When possible, it makes sense for investors to consider such an integrated package and to make sure there are good reasons for seeking alternatives.

Insurance

Insurance coverage for building owners is classified by susceptibility to damage by fire as determined by past incidence rates. Without a breadth of experience or data on mass timber buildings, the insurance industry perceives all wood buildings similarly. A lack of data, to insurance underwriters, indicates high risk. To date, mass timber structures have been grouped with light frame structures, despite markedly different performance regarding fire, seismic, and water damage. As a result, premiums are often just as high as combustible construction types, though timber structures are more analogous to noncombustible types. A 2018 study[23] found that mass timber had yet to be fully recognized by the insurance industry as comparable to a concrete-and-steel structure. Since then, the insurance industry has begun

23 Perkins&Will, *Mass Timber Influencers: Understanding Mass Timber Perceptions among Key Industry Influencers* (October 2018).

to recognize mass timber as a distinct structural building category. In a 2021 paper exploring these issues, WoodWorks stated that a new classification code is a possibility.[24] Recognizing this need, a 2023 Dovetail report[25] lists insurance and project financing as still among the biggest challenges for mass timber's economic competitiveness.

Project teams may find support with resources like *The Mass Timber Insurance Playbook*[26] from the UK-based Alliance for Sustainable Building Products. Not surprisingly, European companies are more comfortable with the construction type, as they've had more time to build mass timber structures into their portfolios and observe how they perform. Swiss-based insurance company Zurich North America recognizes the increasingly popular segment of the construction market[27] and has increased builders' risk capacity in the mass timber sector. A 2023 article[28] interviewed major insurers operating in the US who acknowledged that mass timber should be evaluated as a separate category of construction, somewhere between combustible and noncombustible, and that premiums will need to evolve as data becomes available.

Beyond fire resistance, additional characteristics of mass timber structures that could reduce perceived risks include the resiliency (or the ability to swiftly recover from catastrophic events) of some mass timber designs. Further development of moisture protection and construction schedule reference data would likely also support lower builders' risk insurance premiums. Understanding how moisture control methods are implemented and monitored could reassure providers about the level of risk involved in the construction of timber buildings in wet climates. The risk may not be as high as presumed.[29] And, as developers turn to more sustainable portfolios, insurance offerings will naturally become more competitive. Some North American insurance companies have recognized the growing market and the opportunity to align with sustainable practices.

Public Perception of Mass Timber

According to a 2015 public survey[30] by Perkins&Will, the public perceives the following factors to be the greatest barriers to wider adoption of mass timber:

- The flammability of wood
- Wood's strength compared to concrete and steel
- Deforestation concerns

The same study found that these barriers diminish as the public gains knowledge about and experience with mass timber buildings. Nevertheless, these perceptions remain as obstacles that building developers must address.

24 WoodWorks, *Insurance for Mass Timber Construction: Assessing Risk and Providing Answers* (2021).
25 Dovetail Partners, Kathryn Fernholz, Mark Jacobs, Gloria Erickson et al., *Mass Timber and Tall Wood Buildings: An Update* (2023).
26 https://asbp.org.uk/project/mass-timber-insurance-playbook
27 https://www.zurichna.com/knowledge/articles/2021/10/mass-timber-is-taking-root-in-commercial-construction
28 https://riskandinsurance.com/mass-timbers-resilience-makes-it-an-increasingly-popular-choice-but-are-insurers-pricing-its-risks-accurately/
29 Brad Carmichael, Emily Dawson, and Jeff Speert, *Mass Timber Moisture Monitoring and Simulation: A Marine Climate Case Study* (2022).
30 Shawna Hammon, "Tall Wood Survey," *Perkins&Will Research Journal* 8, no. 1 (2016).

THE 2ND-FLOOR COMMONS AT MISSISSIPPI WORKSHOP IS AN INVITING SPACE.
Source: Waechter Architecture; Credit: Lara Swimmer

CASE STUDY: MISSISSIPPI WORKSHOP

MISSISSIPPI WORKSHOP: A NEW MODEL FOR 'ALL-WOOD' CONSTRUCTION

PROJECT OWNER: WAECHTER ARCHITECTURE

PROJECT LOCATION: 4224 N MISSISSIPPI AVE, PORTLAND, OR 97217

COMPLETION DATE: JUNE 1, 2022

ARCHITECT/DESIGNER: WAECHTER ARCHITECTURE

MASS TIMBER ENGINEER/MANUFACTURER: KLH MASSIVHOLZ / KLH USA

GENERAL CONTRACTOR: WAECHTER ARCHITECTURE WITH OWEN GABBERT AND CUTWATER PDX

STRUCTURAL ENGINEER: KPFF

OTHER CONTRACTORS: MUSTANG RIDGE (MASS TIMBER ASSEMBLY); CISTUS NURSERY (LANDSCAPING); CASCADIA (WINDOWS AND DOORS)

DESIGNED, DEVELOPED, AND built by Waechter Architecture, the Mississippi Workshop is a mixed-use mass timber infill project on a prominent street in Portland, Oregon. It is equally a prototype for an ecological, enduring, and experientially rich construction method that can lead to a new generation of mass timber architecture.

THE OPEN-AIR COURTYARD IS A VENUE FOR MANY EVENTS.
Source: Waechter Architecture; Credit: Lara Swimmer

Material Innovation: Mississippi was designed to explore the environmental performance and expressive potential of mass timber. Built with sustainably sourced Cross-Laminated Timber (CLT) and glulam beams from KLH, the building's embodied carbon was offset in approximately 15.3 minutes of regrowth in sustainably managed forests, and it sequesters a net estimate of 180 tons of carbon dioxide (CO_2). It is also the first mixed-use project on the West Coast to use mass timber for its load-bearing structure, shear walls, spatial definition, and interior surfaces without the need for additional fireproofing or finishes.

Systems Innovation: Integrating advanced building systems was also essential to the project's success. The building is served by an all-electric, refrigerant-free radiant heating and cooling system that provides user comfort even during extreme weather. All primary spaces have narrow cross-sections and operable windows to provide ample daylight and natural ventilation on temperate days.

Program Innovation: Distributed over 3 floors, 6 primary volumes or lofts are equipped as "plug and play" units with ancillary spaces, plumbing rough-ins, outlets, and framing anchor points to support varied configurations and allow each space to operate autonomously or in an ensemble with others. All of these spaces frame a generous open-air courtyard that functions as an informal "pocket park" by day and as a venue for a wide array of performances and special events.

The Mississippi Workshop is a 21st-century upgrade of the classic industrial loft in that it provides a durable and beautiful space that can be adapted to almost any purpose. It is a proof of concept for a flexible, sustainable, and economically feasible infill development that many have only theorized about. It also succeeds in serving each of its primary functions, with retail, workshop, assembly, creative office, and residential spaces coexisting seamlessly.

As the first of its type, the building was subject to rigorous code review, and the Waecther team worked closely with consultants and mass timber fabricators to develop compliant solutions. This work effectively opens the door for a new class of buildings to enter the market, and it is hoped its success will speed the adoption of new regulations regionally and nationwide.

Waechter also received a United States Department of Agriculture (USDA) Wood Innovation Grant to study the building's performance, conduct post-occupancy analysis, and share findings and details. This work is going forward in partnership with builders, consultants, fabricators, and researchers from the University of Oregon. Detailed testing and analysis has already been conducted to evaluate the building's acoustics, thermal performance, resistance to infiltration, and indoor air quality. The Waechter team will be able to share this data and offer insights and lessons learned throughout the design and construction process, and from the last year of occupancy and testing.

Sources of Reliable Information

WoodWorks and other organizations have provided extensive support to mass timber building projects. Resources in the form of handbooks, standards, networks, conferences, published best practices, case studies, and more are growing exponentially with the expansion of the market.

8.6 MAINTENANCE AND BUILDING MANAGEMENT

Operational ease and savings can be additional results from a building owner's decision to invest in a highly planned mass timber superstructure. Like all materials, timber has specific upkeep recommendations, but from a maintenance standpoint, the natural beauty of wood translates into some surprising benefits.

Utilities

Exposed wood is often a primary reason to use timber as a structural material. This decision should be paired with a deliberate approach to locating utilities, whether visible or concealed within chases and soffits. Mass timber buildings require more planning in the design phase, often leading to predetermined slab and wall penetrations for ductwork, conduits, and piping. This provides an opportunity to design utility systems with ingenuity and precision, and it ensures that systems are installed according to plan. Having reliable as-built documents can lead to more efficient routine maintenance, and when systems issues arise, to more timely action.

Durability

Coatings such as sealers or paints may be added to structural timber to protect it from ultraviolet light and weather, to add aesthetic appeal, or to make cleaning easier. Coatings on any surface require some upkeep and reapplication. Maintenance timelines vary by product, application method, and exposure; the more the wood is protected from light, temperature, and moisture changes, the longer the coatings will last.

Wood naturally changes color over time, with the hue depending on exposure and species. In Europe, it is more common to let exterior wood naturally age with weather and sunlight, creating a facade with a varied texture that is considered by many people to be quite beautiful. In the US, it is more common to seek a controlled, even look. The preference is cultural, as wood that is given sufficient protection through good architectural detailing will take a long time to degrade, even without protective coatings.

Because wood is porous, many building owners are concerned about occupant-inflicted degradation such as staining, impact damage, or vandalism. But owners of wood buildings have reported higher levels of occupant care with wood surfaces and reduced occurrences of vandalism. (See the chapter 7 "Behavior" section for more information.) Staining can often be sanded away. The susceptibility of wood surfaces to visible damage from minor impacts depends on the species. Some variation and patina will occur over time; again, it is a matter of preference whether the change is considered negative or positive.

FIGURE 8.16: PEAVY HALL

Source: Oregon State University
Credit: Josh Partee

FIGURE 8.17: TRINITY UNIVERSITY BUSINESS & HUMANITIES DISTRICT AND DICKE HALL

Source: Lake | Flato
Credit: Robert G. Gomez

8.7 RESILIENCY AND END-OF-LIFE VALUE

A building that consists of high-quality modular components that can be easily reappropriated for new uses will have an inherently higher value at the end of its life than a building slated to go entirely to the landfill. Design for Disassembly (DfD) is a growing area of knowledge for designers and builders, and one a building owner may be inclined to pursue as a point of interest for future buyers.

Though it is far too early to generate data on the deconstruction advantages of the recent wave of mass timber construction, the potential for reuse is likely to be an asset as these buildings age. Most other primary structural systems are difficult and costly to salvage, and total demolition is often the only viable solution from a cost standpoint. When salvage is possible, material is not usually reused as a complete element but as recycled material in newly formed components. But if we look at the precedent of reusing large steel members, salvaged mass timber elements could have viable market use with a minimum of reconfiguration.

There are a few important issues to resolve before mass timber panel buildings reach their end of life in substantial numbers:[31]

- Current practice promotes long, self-tapping screw connectors that are strong and easy to install. However, they are difficult to remove without damaging the panel perimeter.
- Current practice favors concrete finishing of hybrid mass timber panels in certain classes of public and industrial buildings. It is also used in residential buildings for vibration and impact sound mitigation. These integrated floors may pose challenges to orderly disassembly and may preclude reuse.
- Mass timber panels are custom-made for specific projects. No current market exists for blank panels unassigned to specific projects. It is reasonable to presume, therefore, that finding a market for panels prefabricated for a decommissioned project could be difficult, especially for those that are integrated with multiple other materials and trades, including windows, doors, conduit openings, and connector nests.

These concerns are all possible to address through a DfD process that promotes circular use of decommissioned elements. DfD is achieved through mindful design and detailing. Investors can lead the way by emphasizing the importance of designing pathways for cost-effective deconstruction and reuse of recovered elements. An architectural design team following DfD principles may consider the potential for reusing entire subassemblies to reduce the substantial costs of refabrication and related waste. The cascading use of recovered elements should be planned during the initial design of the building, well ahead of deconstruction.

A building that has been designed for disassembly will also be easier to retrofit or repair after a disaster.

Resiliency

In the building industry, resiliency is a term used to describe a building's ability to recover from a disaster such as an earthquake, fire, hurricane, or flood. Mass timber has several resiliency advantages over steel, concrete, and light frame structures.

Mass timber is both strong and flexible; therefore, it is well suited to resisting large forces and returning to its original shape. It is also very fire-resistant because of the thickness of each member. Unlike steel and concrete, failures or compromises in wood structural members are visible, so they require no special forensic equipment or destructive means for analysis, such as radar or core drilling. Being able to quickly verify the safety of a building after an event hastens reoccupation.

If a building design considers the future retrofit of damaged elements (see the earlier section on end-of-life value), mass timber components that show signs of compromise can be more easily replaced. Instead of an entire building being condemned, areas requiring repair can be isolated and retrofitted.

31 Lech Muszyński, Mariapaola Riggio, M. Puettmann, et al., *Conceptualizing the End of Life for Mass Timber Panel Buildings towards Circularity: Mapping the Gaps in Knowledge* (2021).

FIGURE 8.18: CLT ROCKING SHEAR WALL

Wall has steel fuses for dissipating seismic forces. Broken fuses are easily replaced.

Source: Project: Oregon State University Peavy Hall Replacement; Credit: Andersen Construction

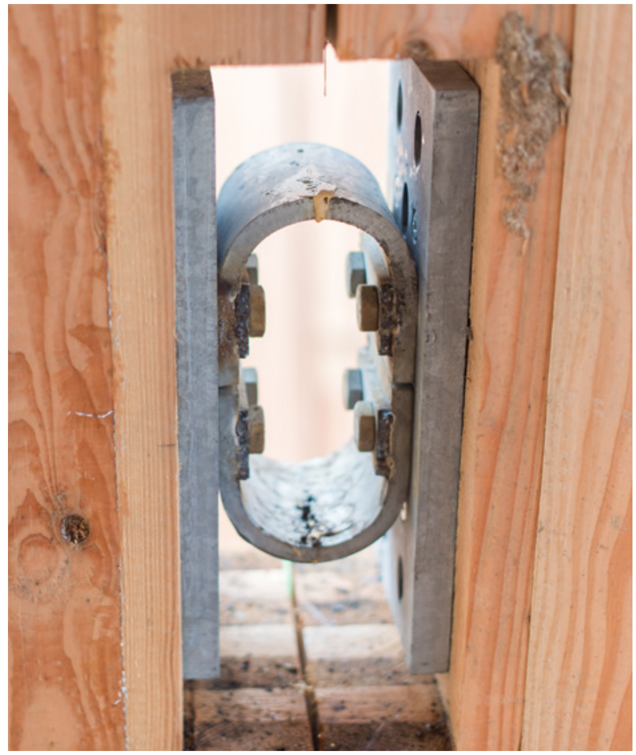


FIGURE 8.19: ROCKING SHEAR WALL FUSE

Source: Project: Oregon State University Peavy Hall Replacement; Credit: Hannah O'Leary

An innovative, earthquake-resistant "rocking" shear wall design has been installed in the new George W. Peavy Forest Science Center building on the Oregon State University campus, the first example of such construction in North America (see **Figure 8.18**). The design allows the wall to shift and return to place during a seismic event, with the added flexibility of steel tension rods that run the height of the wall and energy-dissipating steel "fuses" (see **Figure 8.19**) that connect panels. The easily replaceable fuses are designed to break under high force, rather than allowing the destructive forces to transfer to the structure. They can be easily accessed and are low-cost to replace, if the need arises. Seismic damage is confined to these components.

NEXT IS A PLATFORM THAT ALLOWS TENANTS AND DEVELOPERS TO REIMAGINE A MORE RESILIENT AND INCLUSIVE SCIENCE BUILDING.

Source: Gensler

CASE STUDY: THE NEXT LAB OF THE FUTURE

GENSLER REIMAGINES THE NEXT GENERATION OF SCIENCE BUILDINGS USING MASS TIMBER

PROJECT OWNER: GENSLER

PROJECT LOCATION: SEATTLE, WASHINGTON

COMPLETION DATE: JANUARY 15, 2022

ARCHITECT/DESIGNER: CHAD YOSHINOBU (AND BROADER GENSLER TEAM)

STRUCTURAL ENGINEER: KPFF

MECHANICAL, ELECTRICAL, AND PLUMBING: BURO HAPPOLD

IN A FAST-GROWING market, increased competition among science building developers is driving the demand for lab spaces and science workplaces, challenging the status quo to create different spaces for tenants. Gensler identified an opportunity to develop a conceptual design that reimagines the life science workplace. Gensler's Science Practice Area team conducted a research project funded by the Gensler Research Institute in partnership with structural engineers at KPFF and mechanical, engineering, and plumbing (MEP) engineers at Buro Happold. The study measured the impact of a mass timber science building on tenants, the environment, and the community by prioritizing performance flexibility, market differentiation, climate readiness, and well-being.

LEFT — WITH A MULTITUDE OF OPERABLE WINDOWS AND OUTDOOR SPACES, THE WORKPLACE PORTION OF THE FLOOR WILL HAVE ABUNDANT ACCESS TO FRESH AIR.

RIGHT — FLIPPING THE FIRE STAIR TO THE PERIMETER NOT ONLY FLOODS IT WITH DAYLIGHT AND AMENABLE VIEWS BUT ALSO TRANSFORMS IT INTO A MULTIUSE TENANT AMENITY.

Source: Gensler

Gensler named its 250,000-square-foot conceptual lab building NEXT and put it in Seattle's Uptown Arts District. NEXT represents a point of differentiation, reinventing what a lab is, from a sustainable, aesthetic, functional, and optimized perspective. Designed with an offset core, NEXT provides maximum tenant flexibility for the lab/workplace at 33 by 33 feet. Although a mass timber structure grid of this size doesn't work well for vibration, Gensler partnered with KPFF to achieve the industry-standard vibration of 6,000 MIPS .

Health and wellness for tenants and visitors alike is integral to the NEXT design. The shift of core components provides every floor access to outdoor space. NEXT also provides natural ventilation through operable windows, and it was designed so that the workplace portion of the floor can spend 34 percent of occupied hours in natural ventilation mode. And NEXT is designed to be a community catalyst by creating opportunities for public programs on the ground floor, including opportunities to host a multipurpose arts and entertainment venue and a shared incubation restaurant/kitchen space.

NEXT delivers a resilient building in a shorter speed-to-market time. Mass timber is particularly suited to off-site construction; it can be produced in a nearby factory and delivered to the site as a kit-of-parts, resulting in a 30 percent faster build time and 10 percent in cost savings compared with construction of a typical concrete building. With 85 percent fewer deliveries to the site and 75 percent less construction waste, NEXT uses 80 percent less carbon to build than a conventional concrete lab building. This amounts to a savings of approximately 5,200 total metric tons of carbon dioxide (CO_2).

Gensler extended the sustainable approach to the building's operations. NEXT uses an all-electric heat pump chiller (EL1) system that results in lower building EUI in all markets and achieves zero-carbon emissions on a clean grid. In total, NEXT produces 50 percent fewer greenhouse gas emissions and uses 30 percent less energy annually than a conventional lab building.Through a multifaceted design approach, Gensler demonstrates how a science building can be reimagined to foster renewed investment in urban cores and facilitate a human-centric return to office movement.

CHAPTER 9: CARBON CONSIDERATIONS AND MASS TIMBER

DAVE ATKINS
SUSTAINABILIST, FORESTER, ECOLOGIST, WRITER

One of mass timber's significant strengths is its carbon/climate story. The potential for all members of the building sector, working in concert, to reduce the embodied energy/carbon content of the built environment through mass timber and other means is substantial. Our built environment could function as a carbon storehouse rather than a source of emissions. That is a powerful vision.

The urgent need for reductions in global greenhouse emissions, as identified in the Paris Agreement of 2015, has added impetus to our transition to nonfossil energy sources. Construction techniques and codes have improved dramatically over the past 2 decades, contributing to a decline in operational fossil energy use in new buildings. The transition away from fossil fuels now underway further reduces the operational carbon footprints of buildings. The use of mass timber provides the opportunity to address the embodied fossil carbon and energy footprint of the built environment, from single-family housing to high-rises.

This chapter provides overviews of the 3 Ss: (1) the role of forests as carbon *sinks*, by sequestering carbon out of the atmosphere; (2) the ability of wood products to provide short- and long-term *storage* of carbon in building components; and (3) the *substitution* benefit of using low- or negative-fossil carbon products in place of high-fossil ones. A vital prerequisite is that the wood should come from sustainably managed forests. The challenge is to create a system that provides synergistic rewards for capturing as much benefit as possible from the 3 Ss. The Climate Smart Forest Economy Program (CSFEP) is a global collaboration designed to jump-start the integration of forest management and construction driven by local-, regional-, and national-level efforts to maximize the synergy potential.

Members of the building sector and their clients are asking crucial questions about other values or services of forests because carbon is one of the many benefits forests provide. Biodiversity, watershed function (both quantity and quality), recreation, aesthetics, and carbon storage are often referred to as ecosystem services. We provide contextual discussions about whether all these values are compatible with producing wood products and creating cities that are carbon sinks rather than sources.

9.1 FOREST CARBON: SEQUESTRATION

The Nature Conservancy (TNC) led a global analysis of the potential for natural carbon storage in 2017;[1] it published a similar one focused on the US in 2018.[2] These studies found that the potential contribution of nature-based sequestration is substantial, approximately one-third of the solution toward achieving net-zero carbon. The

1 Bronson W. Griscom et al., "Natural Climate Solutions," *Proceedings of the National Academy of Sciences* 114, no. 144 (2017), accessed December 18, 2022, https://www.pnas.org/doi/10.1073/pnas.1710465114.

2 Joseph E. Fargione et al., "Natural Climate Solutions for the United States," *Science Advances* 4, no. 11 (2018), accessed December 18, 2022, https://www.science.org/doi/pdf/10.1126/sciadv.aat1869.

studies also found that forests provide the greatest percentage of that benefit within the array of natural storage opportunities. This natural role of forests can be managed to enhance the sequestration function and create products that will substitute for carbon-intensive materials and store carbon for the life of the building and beyond.

Forests are crucial to Earth's natural carbon capture and storage system. During photosynthesis, trees take in carbon dioxide, sunlight, and water to create simple carbohydrates, or sugars, that can be used to either nourish the trees' existing cells or create new cells (growth). When used for growth, carbon is stored in woody material. When sugars are consumed for nourishment, the trees release carbon dioxide back into the atmosphere. In the continental US alone, forests store more than 14 billion metric tons of carbon (see **Table 9.1**).

If unaltered by human activity, the complete life cycle of a tree is carbon-neutral. This cycle can take tens to thousands of years to complete, depending on local climatic conditions, the tree species, and the disturbance regimes. (Disturbance regime equals the mix of fires, storms, insects, diseases, etc. that shapes the evolution of a forest.) Some species—such as quaking aspen, loblolly pine, and lodgepole pine—are relatively short-lived (only 80 to 140 years). Others—such as ponderosa pine, Douglas-fir, tulip-poplar, Western larch, longleaf pine, cedars, and oaks—can live many centuries. These are the potential life spans; however, just as most humans do not

STATE	NATIONAL FOREST	OTHER FEDERAL	PRIVATE	STATE & LOCAL	TOTAL
AL	21	9	492	19	541
AR	65	18	318	18	419
AZ	70	12	53	7	142
CA	494	79	352	51	976
CO	184	46	53	7	290
CT	0	0	44	18	62
DE	0	0	9	3	12
FL	22	23	191	70	306
GA	32	21	473	23	549
IA	0	3	49	7	59
ID	318	14	48	24	404
IL	8	2	96	11	118
IN	6	5	106	11	129
KS	0	2	40	1	42
KY	28	12	284	8	333
LA	20	13	262	21	316
MA	0	2	69	33	104
MD	0	2	64	22	88
ME	2	4	299	28	333
MI	65	7	254	83	409
MN	38	4	124	83	249
MO	32	7	251	19	309
MS	39	15	408	13	476
MT	270	25	62	14	371
NC	45	25	414	31	516
ND	11	1	7	1	20
NE	0	1	18	1	21
NH	23	2	97	14	136
NJ	0	3	27	26	56
NM	84	12	63	9	169
NV	21	38	2	0	61
NY	1	4	388	157	549
OH	9	2	185	27	223
OK	9	9	120	7	144
OR	539	159	257	52	1,007
PA	19	5	344	144	512
RI	0	0	8	4	12
SC	20	14	255	19	307
SD	0	0	8	1	10
TN	25	23	313	32	394
TX	21	13	421	13	468
UT	71	46	23	11	151
VA	56	19	387	22	484
VT	14	2	105	15	136
WA	349	111	250	131	841
WI	32	5	226	57	319
WV	43	7	327	13	391
WY	81	30	12	3	126
Total	3,189	856	8,659	1,383	14,087

TABLE 9.1: TONS OF CARBON IN FORESTS BY STATE BY OWNERSHIP TYPE (METRIC TONS IN MILLIONS)

live to their full potential life span of 120 years, most trees do not achieve their potential life span.

Natural forests are often a mix of species with varying life spans and adaptations, but they also can be monocultures. Natural disturbances and competition among trees kill some and truncate the lives of others. Some ecosystems' natural disturbance cycles are only years to a few decades apart, and others have cycles lasting centuries. Death comes in many forms: fires, insect epidemics, diseases, droughts, hurricanes, ice storms, windstorms, competition among trees, and more. Many of these disturbances interact, creating synergies. A windstorm, for example, can blow down hundreds or thousands of acres of trees that then provide food for bark beetles or other insects that breed and expand their populations enough to attack live trees. These events can set the stage for high fuel loads that can feed a severe wildfire. In forests set aside for national parks, wilderness, and other designations, these disturbance cycles are sometimes allowed to proceed.

A landowner who aims to produce timber or capture carbon will try to minimize the effects of these unplanned mortality events through planned disturbances, such as prescribed burns and harvests.

The natural, or unmanaged, tree and forest cycles have three phases: carbon capture, carbon storage, and carbon release. The cycles for an individual tree and the overall forest may not be synchronous, depending on the disturbance regime. In the first phase, a tree grows and uses most of the carbon dioxide it absorbs as building blocks. In the second phase, the tree is mature and no longer uses as much carbon for growth. Instead, the tree consumes a larger portion of its sugars to maintain its systems, so it is not as efficient at capturing and storing carbon. In the third phase, the tree releases more carbon than it captures as it declines in vigor and parts begin to decay or die. It then dies of old age, disease, insect attack, or fire, eventually releasing most of its remaining carbon back into the atmosphere. The entire process may take decades or centuries, depending on the disturbance regime and the tree species. A small portion of the carbon will remain in the soil, if undisturbed.

In a natural forest, some trees decline or die; and others regenerate, grow, and replace them, absorbing and sequestering more carbon in the process. In a forest with a long disturbance cycle, the dead trees might retain large amounts of carbon as they slowly decay, or they might release it relatively quickly if the species is more susceptible to rot fungi. In a forest with more frequent disturbances, a much smaller amount of carbon is stored in dead wood, litter, and duff.

When forests are actively managed, the first phase of carbon capture can be extended through thinning,[3] which helps maintain the rapid growth and carbon capture of the first phase. Thinning also avoids potential mortality from competition among trees, and those thinned trees become products. The thinning extends the overlap of the rapid growth phase with the storage phase because the remaining trees are larger but still growing. Management can thus store more usable

3 Robert O. Curtis, "Extended Rotations and Culmination Age of Coast Douglas-Fir: Old Studies Speak to Current Issues" (research paper PNW-RP-485, US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, 1995).

CHANDLER CENTER FOR ENVIRONMENTAL STUDIES IS A HUB FOR LEARNING AT WOFFORD COLLEGE IN SPARTANBURG, SOUTH CAROLINA.

Source: Wofford College; Credit: @2020, Kris Decker and Firewater Photography

CASE STUDY: CHANDLER CENTER FOR ENVIRONMENTAL STUDIES

CHANDLER CENTER FOR ENVIRONMENTAL STUDIES AT WOFFORD COLLEGE: WHY CLT MADE SENSE

PROJECT OWNER: WOFFORD COLLEGE

PROJECT LOCATION: 429 N CHURCH ST, SPARTANBURG, SC 29303

COMPLETION DATE: AUGUST 1, 2020

ARCHITECT/DESIGNER: MIKE GOLL, MCMILLAN PAZDAN SMITH

MASS TIMBER ENGINEER/MANUFACTURER: SMARTLAM NORTH AMERICA

GENERAL CONTRACTOR: ROBINS & MORTON

STRUCTURAL ENGINEER: BRITT, PETERS AND ASSOCIATES

MECHANICAL, ELECTRICAL, AND PLUMBING: CROW & BULMAN ENGINEERING (MECHANICAL AND PLUMBING); MATRIX ENGINEERING (ELECTRICAL)

THE CHANDLER CENTER for Environmental Studies at Wofford College in Spartanburg, South Carolina, implements visible sustainability features within 3 stories and 18,000 square feet of academic space. Students and faculty are welcomed into an advanced laboratory space, a seminar room,

THIS INTERIOR VIEW OF THE CHANDLER CENTER SHOWS THE ENTRANCE, LOUNGE AREA, AND THE CLT CEILING.

Source: Wofford College
Credit: @2020, Kris Decker and Firewater Photography

classrooms, and office spaces. Constructed using primarily Cross-Laminated Timber (CLT), this building serves not only as a hub for academic learning but also as an educational tool in and of itself.

McMillan Pazdan Smith, the architectural firm behind the project, proposed CLT to Wofford College mostly because of the material's compatibility with the project's ethos. In a building centered on environmental studies, using CLT, installing a green roof, and implementing rainwater capture techniques and other sustainable strategies simply made sense. "For years we dreamed of working in a sustainable space, where our surroundings themselves could be part of our teaching and research," said Dr. Kaye Savage, former head of the Wofford College Environmental Studies Department. "The Chandler Center is that space."

McMillan Pazdan Smith had previous success with CLT in South Carolina's Lowcountry, an area challenged by groundwater, humidity, and rainfall, and knew that the material's propensity to flex increased its resiliency.

Care was taken with detailing and other surface finishes to mitigate potential damage or warping from the CLT's flex. The expertise of the design team and the contractor ensured successful implementation. Although most CLT at the time was sourced from the US West Coast and Europe, the decision to source CLT from SmartLam North America's facility in Alabama aligned with the goal of using regional materials whenever possible. Since the completion of the Chandler Center, new mass timber suppliers have emerged in South Carolina.

The use of CLT significantly contributed to the building's sustainability and health and wellness features. Research highlights CLT's environmental advantages over carbon-intensive construction materials such as concrete and steel. Further, CLT provides a natural aesthetic amid the glass, steel, and concrete prevalent in modern construction. Studies even suggest that wooden interiors can reduce occupants' stress, a meaningful benefit for students, in particular.

Cost considerations, while presenting a slight initial premium compared with conventional construction materials, were outweighed by the long-term benefits. The educational and sustainability values of CLT justified these costs, as evidenced by a tripling in enrollment in the environmental studies program since the Chandler Center's opening.

The Chandler Center earned a prestigious Three Green Globes certification from the Green Building Initiative (GBI), solidifying its status as a sustainable, healthy, and resilient building. This recognition demonstrates its success in resource efficiency, including reducing environmental impacts and improving occupant wellness. The use of CLT, alongside other sustainability strategies, was a big factor in this certification rating. Beyond its sustainable features, the center's calming and natural ambiance enhances the overall well-being of students and faculty.

FIGURE 9.1: FOREST PRODUCTS' CARBON STORAGE

carbon and produce more wood from the same number of acres.

After the harvest, the forests can be regenerated by planting seedlings or relying on seeds from trees left in the area, with vigorous young trees starting a new cycle. Wood from the harvested trees enters the industrial cycle in the form of products that store carbon, such as building structures, furniture, insulation, packaging, paper, and energy (see **Figure 9.1**).

The carbon sequestration impact of a forest and the carbon storage in wood products are contingent on sustainable management. Forest certifications like the Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), and American Tree Farm System (ATFS) for private land, and laws and regulations for public land, help consumers source sustainable materials. (See chapter 2.) Ongoing research and appropriate incentives help shape the evolution of forest practices and set the stage for building design and construction teams to incorporate the use of wood into their Life Cycle Analyses (LCAs).

Triple Bottom Line

The shift to forestry practices that achieve a balanced triple bottom line of economic, environmental, and social goals is underway at each point in the wood products supply chain, but consensus has not yet been reached among all perspectives. Mass timber products have captured the public imagination in ways not seen since Smokey Bear, pushing a wave of multidisciplinary conversations around carbon stewardship.

One of the efforts to facilitate understanding is The Forests Dialogue[4] (TFD), hosted by the Yale School of the Environment. One of their initiatives, Climate Positive Forest Products (CPFP), is hosted in conjunction with the World Resources Institute and CSFEP. Representatives from around the world meet to share information about developing a collective understanding of the potential to significantly reduce greenhouse gas (GHG) emissions. Participants were provided with background papers synthesizing the most recent published research before they met in 2021 and 2022.[5] These papers refer to recently published studies from Europe, North America, and around the world and address wood supply and the carbon benefits of wood versus concrete and steel through the LCAs. They substantiate the carbon benefits of wood, as well as sustainably managed forests' ability to supply the wood needed for expanded use of mass timber. This kind of dialogue and understanding is essential if the potential for mass timber to decrease embodied carbon emissions is to be achieved worldwide.

In recent years, carbon offset markets have paid landowners for the additional carbon value they create through management practices that enhance forests' ability to sequester more carbon.

Land Use

One of the biggest concerns in using forest-sourced products is the fear of deforestation or forest degradation. Deforestation is defined as the conversion of land from growing forests to some other use. Clear-cutting a forest is therefore not considered deforestation as long as a new forest is established. Forest degradation can occur when logging practices cause biodiversity loss or reduce the ecological resilience of an ecosystem. Designers should consider the sources of the fiber they specify, and they can turn to forest certifications as one way to support sustainable forest practices (see chapter 2).

The biggest cause of deforestation is the conversion of forests to agriculture and development. When land is not valued as forests, it tends to get turned into something else. Thus, the idea—counterintuitive at first, but economically logical—that the use of forest products may contribute to an increase in acreage used for forestry. North America and Western Europe have some of the highest per capita wood use in the world, but they also have net-positive forest growth. That's because the demand for and the value placed on wood products create economic incentives to maintain or expand forests.

Creating an economic incentive for storing more carbon can increase the incentive for maintaining or expanding forested lands. The publications led by TNC show that expanding the amount of forestland is the largest natural carbon storage practice among the many options. An essential driver of this process is payment for carbon storage and for timber products at the end of a rotation.

4 https://theforestsdialogue.org/initiative/climate-positive-forest-products-cpfp
5 Edie S. Hall and Barbara K. Reck, "Current State of Mass Timber and Wood Product Value Chains in Europe" (2022), https://theforestsdialogue.org/sites/default/files/tfd_cpfp_finland_backgroundpaper_2022.pdf.

Forestry Practices

An increased demand for forest products appears to also drive more sustainable forestry practices. According to the Carbon Leadership Forum (CLF), "Transitioning construction of low- to mid-rise commercial and nonresidential structures to Cross-Laminated Timber (CLT)/heavy timber construction could have a positive impact on the environment. It could also develop a new market for the smaller diameter and lower quality logs derived from forest thinning and forest health operations, thereby providing an incentive to undertake forest management activities designed to improve forest health and resiliency. Finally, the development of a Cross-Laminated Timber industry would provide substantial economic benefits and employment opportunities for rural timber-dependent communities."[6]

Climate-Smart Forestry

Forest certification systems, as discussed in chapter 2, address many issues in addition to carbon storage and the role of forests in climate change. In recent years, the term "Climate-Smart Forestry" (CSF) has emerged. North Carolina State University's website says that CSF enables "forests and society to transform, adapt to, and mitigate climate-induced changes."[7]

How is this done? By managing for the resilience that protects the carbon stored in the forest and supports its ability to store more. It varies by forest type, ecological setting, and disturbance regimes. Some talk about "carbon defense" management practices. That may mean favoring better-adapted species and/or reducing forest density so the remaining trees are better adapted to droughts, wildfires, and insects.

CSFEP[8] is supported by a coalition of national and international organizations that stress the 3 Ss and are working to integrate them. Their goal is to make them synergistic. They move beyond only suggesting or encouraging landowners to incorporate CSF practices in the forest, to creating economic incentives through the use of wood in the built environment. This reward landowners for using better climate-smart management practices on their land. This creates a circular economic incentive to grow forests in a way that stores more carbon and produces more wood per acre than conventional practices. The organizations also emphasize the management of forests for biodiversity and other environmental services, such as water and recreation.

Some groups advocate for what they call "proforestation" as a climate change mitigation strategy. They say mature and old-growth forests should be left alone so they can store more carbon. Deferring harvest may allow for more carbon capture compared to harvesting and regrowing a new forest. These groups argue that keeping these forests and the carbon they have sequestered intact is more valuable than sustainable harvesting.

Proforestation does not consider the trade-offs for storage and substitution discussed below, or the disturbance regime of a forest ecosystem. Mature and older forests/trees, especially in a drought-stressed environment, are more susceptible to insect attacks and diseases. Forests in several states in the western US have become sources of carbon

6 https://carbonleadershipforum.org/cross-laminated-timber-optimization/
7 Accessed December 18, 2022, https://content.ces.ncsu.edu/what-is-climate-smart-forestry-a-brief-overview.
8 Accessed December 18, 2022, https://www.csfep.org/our-work.

(rather than sinks) as a result of insect epidemics, wildfires, or a combination of the two. The Society of American Foresters recently released a white paper[9] critiquing the concept for these omissions.

Carbon Markets

Carbon offset markets have allowed forest owners to adopt certain management practices that will increase the amount of carbon they capture and store, and get paid for it. These markets, either voluntary or compliance, have different requirements for monitoring and verification. The prices paid for the carbon also differ. Some climate activists have expressed concerns about the potential for carbon leakage and the possibility that companies may use the markets as an excuse to avoid reducing their own emissions from fossil fuels. The United Nations Climate Change Conference (COP26) adopted Article 6 to provide transparent methods developed by the Task Force on Scaling Voluntary Carbon Markets (TFSVCM) to minimize these risks.[10]

The American Forest Foundation and TNC initiated the Family Forest Carbon Program, which helps small landowners access carbon offset markets if they apply a practice that stores more carbon. At the end of their contract, they will also have more wood to sell. The program offers shorter-term contracts of 10 to 20 years (rather than 100 years), making it more attractive for small (50- to 5,000-acre) holdings.

Providing landowners with an additional revenue stream in addition to wood products allows them to conduct better carbon management and achieve better wood production. The synergy between these kinds of practices can expand the availability of wood and sequester more carbon.

A new company, Aureius Earth (https://aureusearth.com/) is a carbon finance company that works with developers and investors to monetize the carbon benefits of using wood in place of fossil intensive materials. This provides another economic incentive for carbon benefits throughout the supply chain.

9.2 WOOD PRODUCTS: CARBON STORAGE

Many designers and building owners are drawn to mass timber for its environmental credentials and the intuitive benefits of storing carbon. A rapidly developing area of research seeks to answer their questions about how to quantify and maximize the benefits of this choice. Architecture 2030, a nonprofit organization, has outlined climate goals adopted by the American Institute of Architects (AIA) in the form of the AIA 2030 Challenge. It has identified a time frame of less than 10 years to reach net-zero emissions in the building industry to curb catastrophic climate change.[11] So getting it right is crucial. The engineered properties of mass timber products help meet that goal and have opened up a whole new suite of uses for wood products.

Tools and Techniques

This section, along with the next section on substitution, outlines the tools and techniques for se-

9 Accessed December 18, 2022, https://www.eforester.org/Main/SAF_News/2022/SAF-Develops-Resource-on-Proforestation.aspx.
10 Accessed December 18, 2022, https://www.iif.com/Portals/1/Files/TSVCM_Phase_2_Report.pdf.
11 *Architecture Magazine*, The Carbon Issue, January 2020, guest edited by Architecture 2030.

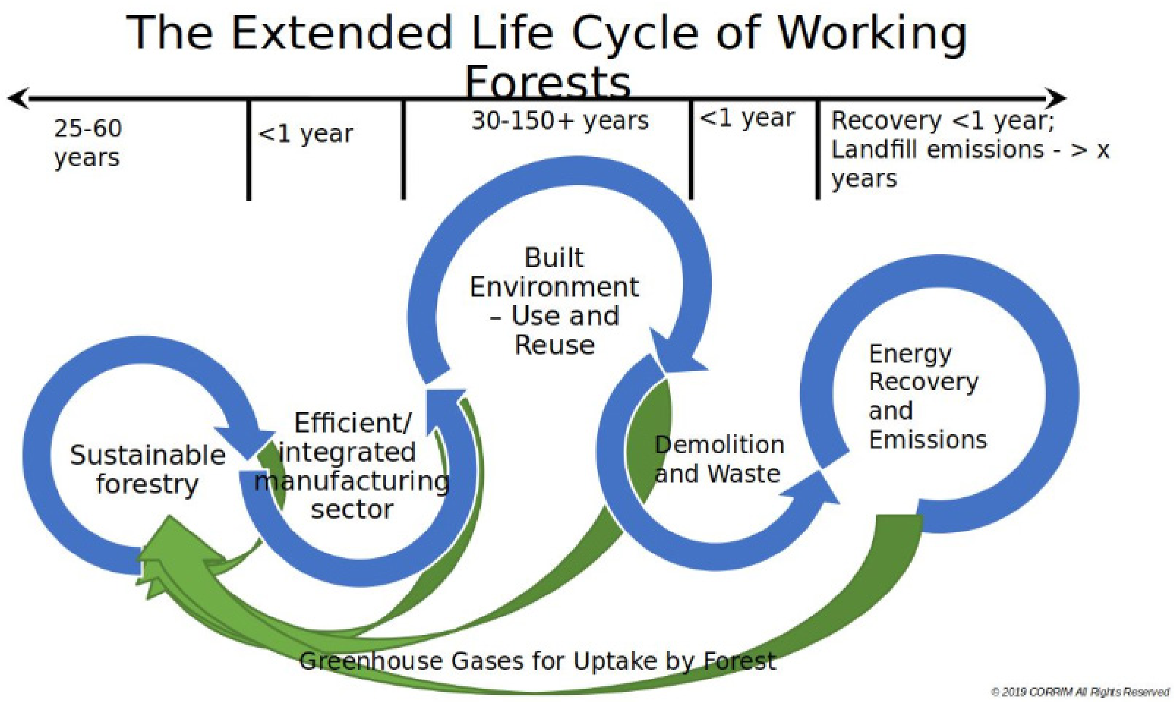


FIGURE 9.2: EXTENDED LIFE CYCLES OF WORKING FORESTS

Source: Reprinted with permission, Elaine Oneil, Consortium for Research on Renewable Industrial Materials (CORRIM), www.corrim.org

lecting and measuring the carbon impacts of mass timber in building projects. We also discuss how choosing to use mass timber, along with other wood products, especially at scale as the market sector grows, also benefits land-use and forestry practices. We separated carbon storage from substitution to clearly differentiate their separate but complementary benefits.

Biogenic Carbon

The ScienceDirect website says, "Biogenic carbon refers to carbon that is sequestered from the atmosphere during biomass growth and may be released back to the atmosphere later due to combustion of the biomass or decomposition."[12] One cubic meter of wood stores approximately one ton of carbon dioxide equivalent. This differentiates biogenic carbon from fossil fuel carbon that is released from geologic storage.

As a building material, wood provides long-term biogenic carbon storage. As illustrated in **Figure 9.2**, carbon storage in long-lived wood products can extend the biogenic carbon cycle. Constructing buildings with wood products increases the length of time that carbon is kept in storage. Wooden buildings 800 to 1,000-plus years old exist in Europe and Asia. They demonstrate that, with proper protection and maintenance, wood can serve us well.

12 https://www.sciencedirect.com/topics/engineering/biogenic-carbon

Biogenic carbon eventually returns to the atmosphere through decomposition or incineration, and that may be acknowledged through a complete LCA that illuminates the long-term impacts (spanning at least 100 years). While end-of-life considerations are crucial to a circular economy, most buildings built today will remain standing long after global net-zero carbon timelines have passed, and they will continue to keep that carbon out of the atmosphere. When calculating the total life cycle of a wood product, project teams should consider whether to include or exclude biogenic carbon, acknowledging the eventual return of the carbon to the atmosphere—or not. Total decomposition is unlikely, based on the expectation that structural wood will be reused or encapsulated in a landfill, rather than incinerated or mulched, thus preventing the carbon's release to the atmosphere. Design and construction with deconstruction and reuse in mind will facilitate continued long-term storage.

Absorbing and preventing the release of as much atmospheric carbon as possible in the next 10 to 30 years is a global priority to avoid irreversible climate change. The World Green Building Council (WorldGBC) stresses the importance of reducing up-front or embodied carbon in its 2019 report, *Bringing Embodied Carbon Upfront*.[13] The report states, "To achieve our vision, we must take urgent action to tackle up-front carbon while designing with whole-life carbon in mind." It can be argued that the embodied carbon stored today is more important than accounting for unknowns in deconstruction approaches, fire, or decay past that crucial timeline. Considering the urgent timeline we face to eliminate emissions in the industry, project teams may choose to emphasize the short-term effects of using sustainably grown wood products.

Buildings as Carbon Banks

On a global scale, the building industry stands out as having the potential to turn from being the largest contributor of carbon emissions to becoming a massive atmospheric absorber. Buildings are long-lived and profoundly materials-intensive. They present an opportunity, therefore, to become carbon storage devices, or carbon banks. To achieve this, the industry must use as many biogenic materials as possible in every building.

The longer a biogenic, carbon-rich building remains standing, the more effective a carbon store it is. And because mass timber components have a high potential to retain value after the life of a building, markets for reuse of mass timber will likely develop,[14] further delaying decomposition. In fact, decomposition is an unlikely outcome. A worst-case scenario would send these valuable building components to a landfill, where LCAs typically assume the wood will decompose. In fact, the US Environmental Protection Agency (EPA) says that "because wood products are not completely decomposed by anaerobic bacteria, some of the carbon in these materials remains stored in the landfill. This stored carbon constitutes a sink."[15]

13 https://worldgbc.org/article/bringing-embodied-carbon-upfront/
14 "Integrating Working Forests and Wood Products into the Circular Economy" (presentation, Consortium for Research on Renewable Industrial Materials, Seattle, Washington, January 21–22, 2020), https://corrim.org/circular-economy-workshop/.
15 *Decarbonization for Greenhouse Gas Emission and Energy Factors Used in Waste Reduction Model (WARM) (2019).*

GREEN CANOPY NODE'S MASS TIMBER MODEL HOME IN SPOKANE, WASHINGTON, IS BASED ON THE INTEGRATED BUILDING KIT.
Source: Green Canopy NODE; Credit: Inside Spokane Photography

CASE STUDY: GREEN CANOPY NODE MASS TIMBER MODEL HOME

ACCELERATING CARBON-NEGATIVE HOUSING

PROJECT OWNER: GREEN CANOPY NODE

PROJECT LOCATION: 19202 GARLAND AVE SPOKANE VALLEY, WA 99027

COMPLETION DATE: MARCH 27, 2023

ARCHITECT/DESIGNER: GREEN CANOPY NODE

MASS TIMBER ENGINEER/MANUFACTURER: MERCER MASS TIMBER

GENERAL CONTRACTOR: GREEN CANOPY NODE

STRUCTURAL ENGINEER: MERCER MASS TIMBER

MECHANICAL, ELECTRICAL, AND PLUMBING: GREEN CANOPY NODE

OTHER CONTRACTORS: FOUST FAB AND ERECTORS, AMERIWEST ELECTRIC , ENERTECH MECHANICAL

THE MASS TIMBER Model Home encompasses prefabrication, logistics, and installation, helping validate Green Canopy NODE's Integrated Building Kit.

Components for the home in Spokane, Washington, were manufactured off-site and assembled on-site. The 1,200-square-foot, 2-story volumetric modular Cross-Laminated Timber (CLT) townhome with a rooftop deck has 2 bedrooms and 1.5 baths and was built in less than 100 days.

The project aimed to prove out a new prefabricated building system capable of providing developers with a housing solution that reduces timelines,

THE INTERIOR OF GREEN CANOPY NODE'S MASS TIMBER MODEL HOME IS SPACIOUS AND WELCOMING.

Source: Green Canopy NODE
Credit: Inside Spokane Photography

WORKERS ASSEMBLE GREEN CANOPY NODE'S MASS TIMBER MODEL HOME.

Source: Green Canopy NODE
Credit: J. Craig Sweat

is scalable for mass production, and is cost-competitive in the market.

In tandem with Green Canopy NODE's commitment to sustainability, the Mass Timber Model Home catalyzes a net-zero transition. Its carbon-negative design and its Design for Disassembly (DfD) integrate seamlessly into the circular economy. It standardizes innovative technologies in the building components. Mass timber was chosen as the primary material because of its precision manufacturability, engineered structural qualities, and carbon storage capabilities, making it an ideal candidate for off-site manufacturing.

Compared to a stick-frame version of the home, the Mass Timber Model Home is 44 percent faster to complete, stores 6.6 times more carbon, and boasts a seemingly effortless 0.8 ACH airtight building envelope.

Integral to the project's success is the deployment of Green Canopy NODE's patent-pending Utility Kit system. Featuring 2 utility walls for the kitchen and bathroom, the kits are manufactured off-site and ensure streamlined on-site assembly and completion. With plumbing, electrical load centers, and mechanical systems preinstalled, the Utility Kits reduce construction time, requiring only 1 hour for wall installation, and shortening on-site mechanical, electrical, and plumbing (MEP) work. Plumbing connections require only 2.5 hours.

The utility walls plug into a raised floor system for rapid horizontal distribution of MEP throughout the home. To create the raised floor, the team used CLT offcuts to produce pedestals, thereby diverting material that would normally become waste. Additional innovation included Computer Numerical Control (CNC)-marked pedestal locations, which eliminated the need for measuring and increased the speed and efficiency of installation.

In essence, the Mass Timber Model Home exemplifies the efficiency and sustainability of the Integrated Building Kit and serves as a beacon for the future of housing, blending eco-consciousness with cutting-edge technology and construction practices.

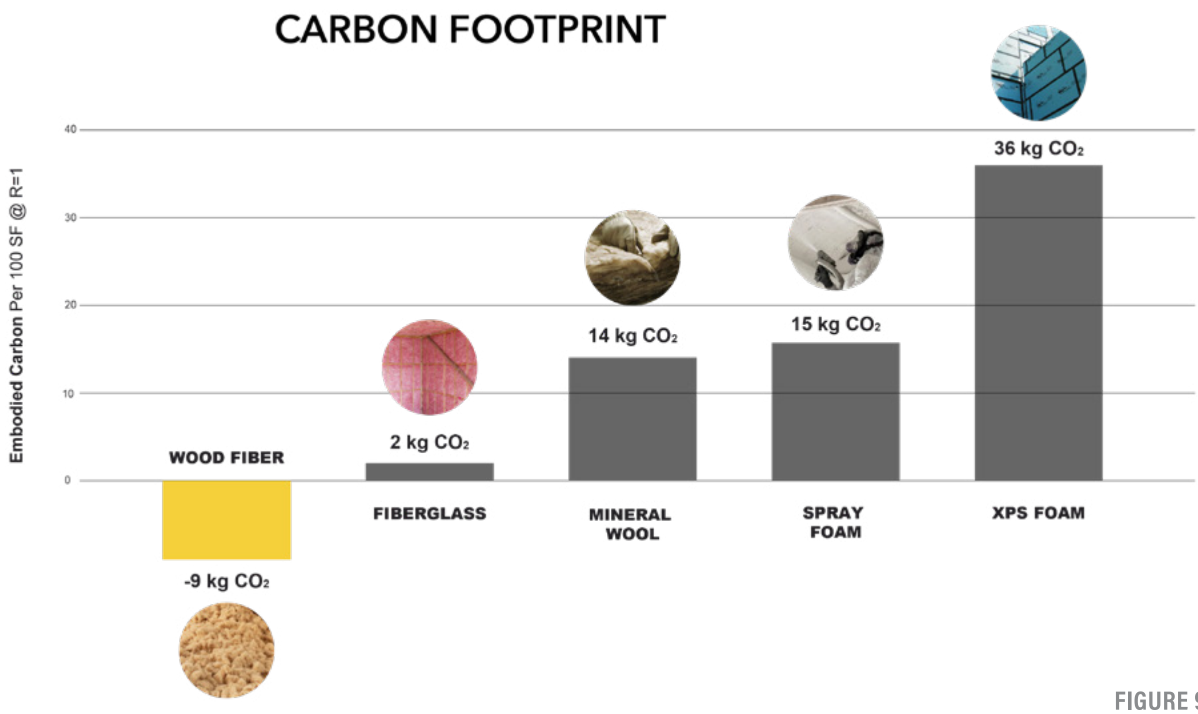


FIGURE 9.3

9.3 SHORT-LIVED VERSUS LONG-LIVED PRODUCTS

The use of trees for wood products is often oversimplified as short-lived versus long-lived products. When a log is run through a sawmill, approximately half of it becomes solid boards used for stick framing, or components for mass timber, flooring, siding, paneling, or furniture. The other half is often lumped together by some LCAs as short-lived or rapid-release carbon products, such as packaging, paper, clothing, renewable energy, fiberboards, and more. Mass timber users might want to understand the fate of those other parts of the log. These products can often substitute for other fossil carbon-intensive products. Cardboard boxes and packaging replace plastics; cellulose-based clothing replaces petrol-based; bark and other scrap wood can be used for heat and power to avoid the release of fossil carbon sources. Much of the sawdust from sawmills goes into medium- and high-density fiberboard that becomes shelving, tables, and cabinets which may have decades-long lives and may potentially replace plastic and metal. We need to put these products into context with the roles they play in society's overall carbon footprint.

New long-lived products are being developed that can use the wood fiber derived from sawing a log into boards, changing the simplified view of what is short- versus long-lived. See the essay, "How to Create a Carbon Sink City," for an expanded discussion of new product development and carbon.

New to North America, but not to Europe, are sound and thermal insulation materials made of wood fiber rather than fossil fuel-based materials. The TimberHP plant started operation in Madison, Maine, in July 2023. It takes sawmill residue materials and small, crooked, or partially rotten trees and turns them into long-lived wood fiber products that store carbon and avoid the use of fossil fuels as a feedstock, providing both storage and substitution benefits. (See **Figure 9.3.**) Insulation products can also be one more method of reusing deconstructed wood buildings through reprocessing and extending the life of the stored carbon.

Concrete and steel have some very desirable construction attributes and applications, and if forest products can make them more climate-friendly, so much the better.

The use of nanocellulose in making concrete is reducing its carbon footprint by approximately 30% according to the USFS Forest Products Labratory. A dam in Georgia was built in 2024 using nanocellulose-infused concrete. The use of biochar to replace coke from fossil carbon, meanwhile, is helping steel be greener. These opportunities for building developers to use lower-emission concrete and other forms of residual wood are steps toward the vision of cities becoming carbon sinks.

Biochar is made from wood residues (produced during logging and lumber manufacturing) and other sources of biomass (ideally produced as part of a bioenergy and carbon storage system). Wood is about 50 percent carbon; the remainder is primarily hydrogen and oxygen. When pyrolyzed, the hydrogen and oxygen are driven off and, as they combust, energy is released that can be used for heat and electricity. The resulting char is about 90 percent carbon, which does not decompose for hundreds to thousands of years. It effectively becomes a carbon capture and storage element that can be used in many valuable ways—as a soil enhancement to improve ecosystem productivity, in mine reclamation, as a carbon-negative thermoplastic, for water and air purification, and more.

These advances in technology are turning "short-lived" products into long-lived ones, and the truly short-lived ones are generally offsetting the use of fossil fuel-derived products.

When sourced from sustainably managed lands, the short-term products' carbon is continually replaced by new forest growth, negating the effects of their short lives. That's especially true when the products are made from the residuals of long-lived products.

Impact of Building Market's Demand on Forests and Carbon

Many architects, engineers, and developers who choose to work with wood will be asked about forestry and logging. For some, that will be the first time they have had to consider exactly where their raw building materials come from. These questions tend not to arise with inorganic materials like steel and concrete, though, of course, everything comes from somewhere. Thus, new questions are surfacing: is it virgin steel, or is it from recycled feedstock?

The emotional connection people have with trees and forests may be behind this investigative imperative. As noted earlier, expanding demand can expand the amount of forested land and the amount of carbon stored in the forest per acre or hectare, with longer rotations supported by thinning, especially if market incentives are aligned.

TOPPED OUT IN DECEMBER 2022, HEARTWOOD BECAME THE FIRST TYPE IV-C BUILDING IN NORTH AMERICA. THE WORKFORCE HOUSING PROJECT, LOCATED IN SEATTLE'S CAPITOL HILL NEIGHBORHOOD, PROVIDES 114 LIVING UNITS.

Source: DCI Engineers; Credit: Kevin Miller

CASE STUDY: HEARTWOOD

FIRST TYPE IV-C BUILDING COMPLETED IN NORTH AMERICA

PROJECT OWNER: COMMUNITY ROOTS HOUSING, SKIPSTONE DEVELOPMENT

PROJECT LOCATION: 1323 E UNION ST, SEATTLE, WA 98122

COMPLETION DATE: NOVEMBER 30, 2023

ARCHITECT/DESIGNER: ATELIERJONES

MASS TIMBER ENGINEER/MANUFACTURER: TIMBERLAB INC.

GENERAL CONTRACTOR: SWINERTON

STRUCTURAL ENGINEER: DCI ENGINEERS

MECHANICAL, ELECTRICAL, AND PLUMBING: HV ENGINEERING (MECHANICAL AND PLUMBING); BERGELECTRIC CORP. (ELECTRICAL)

OTHER CONTRACTORS: DR JOHNSON (GLULAM SUPPLIER); KALESNIKOFF (CLT SUPPLIER)

HEARTWOOD IS A WORKFORCE HOUSING DEVELOPMENT IN SEATTLE. THE TYPE IV-C PROJECT CAPITALIZED ON A MASS TIMBER/STEEL HYBRID SYSTEM AND CUSTOM MORTISE-AND-TENON BEAM CONNECTION TO ACHIEVE ITS SEISMIC AND FIRE RATING PERFORMANCE STANDARDS.
Source: Swinerton

HEARTWOOD APARTMENTS IS an 8-story mass timber apartment building in Seattle, Washington. Its primary structure is Cross-Laminated Timber (CLT) floor panels and glulam beams and columns, making it the first mass timber Type IV-C building under the 2021 International Building Code (IBC) Tall Wood Provisions to be completed in North America. The building is approximately 67,000 square feet, with 126 units of workforce housing, with an outdoor courtyard, bike parking, retail spaces, and laundry in the transit-rich Capitol Hill neighborhood.

The initial project feasibility study was part of a United States Department of Agriculture (USDA) Wood Innovation Grant, requiring DCI Engineers, the engineer of record (EOR), to discuss alternative unit layouts and the implications of these layouts with the architect and contractor team. The team had to balance and coordinate acoustical considerations, fire protection requirements, efficient construction practices, volume of wood fiber, and the desire to visually expose mass timber when determining layout, and glulam beam and column framing configurations.

DCI worked with atelierjones, Timberlab Inc., and Hilti to develop a new all-wood, mortise-and-tenon beam connection. This connection met the requirements of a 2-hour fire rating, while reducing cost by eliminating the need for additional hardware and fasteners. It's now being used on other tall mass timber projects on the West Coast.

The lateral system is composed of steel, Buckling Restrained Braced (BRB) frames, and a diaphragm composed of the CLT panels themselves and their connections, without the need for an additional reinforcing concrete topping slab. The foundation system consists of traditional concrete spread footings, where the size and extent were coordinated with mechanical, electrical, and plumbing (MEP) to allow for underground utilities.

Researchers from the School of Environmental and Forest Sciences at the University of Washington conducted a study in partnership with atelierjones and DCI Engineers to compare the environmental impacts of an equivalent concrete structure. The study determined the mass timber building reduced up-front embodied carbon by 5 percent and stores enough biogenic carbon through the mass timber system to have a net-negative impact during the life of the building. When the second life of the mass timber products after deconstruction was considered, the embodied carbon was reduced by 53 percent. This study was funded in part by the United States Forest Service (USFS) Wood Innovations Grant.

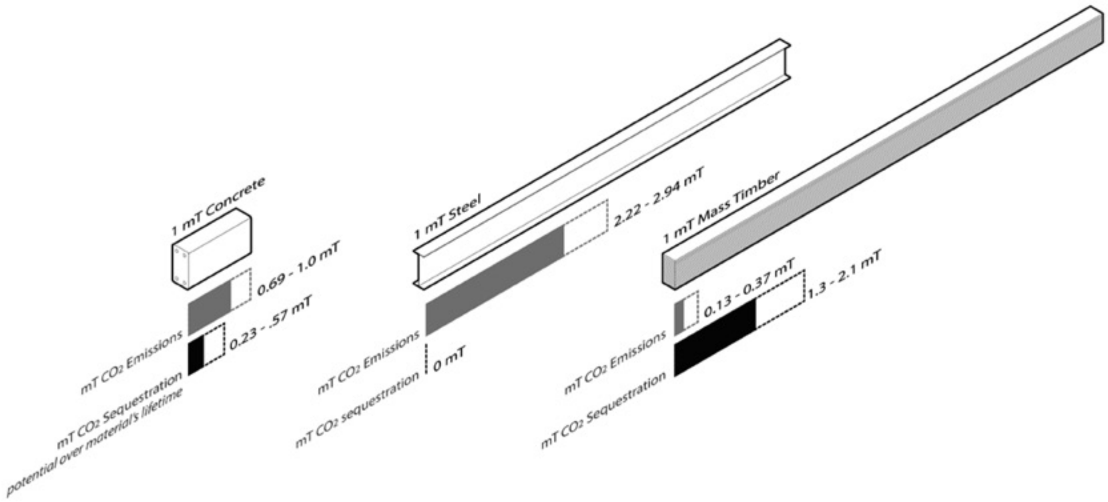


FIGURE 9.4 EMBODIED AND BIOGENIC CARBON IN COMMON STRUCTURAL MATERIALS

Source: Timber City Research Initiative, Gray Organschi Architecture, timbercity.org

9.4 EMBODIED CARBON/ENERGY: SUBSTITUTION

The carbon benefits of substitution occur when a product with lower embodied content carbon/energy product is used instead of a higher-content product. The choice of mass timber in place of steel or concrete usually results in less fossil carbon being released to the atmosphere. This is true of other wood products as well, including furniture, flooring, insulation, and trim.

Environmental Impacts of Building Materials

Analyzing and comparing the environmental impacts of building materials is complicated but crucial to achieving the green building industry's carbon goals. Biogenic carbon, discussed above, and embodied carbon, defined below, are two important concepts underlying such an analysis. To track progress, designers can use tools developed by academic institutions, nongovernmental organizations (NGOs), and the industry to assist with environmentally conscious decision-making processes that include LCAs and Environmental Product Declarations (EPDs). Several certification programs are designed to help building projects measure, meet, and promote their goals, and, as a result, be rewarded in the marketplace.

Embodied Carbon

Most processes involved in the extraction, manufacture, transport, and installation of building products rely on fossil fuels and will continue to for several more decades as our global economy transitions from their use. The total amount of fossil carbon emitted by a given product during this process is the embodied carbon of that product. Mass timber's structural strength qualities result in a lower embodied fossil energy content than concrete or steel because it requires significantly less fossil energy to produce (see **Figure**

9.4). We frequently compare wood with these two other materials because the structural system of a building comprises up to 80 percent of its embodied carbon. Mass timber products are an effective replacement for these widely used, high-embodied-energy structural materials. In fact, wood products are often produced substantially with renewable energy, including the combustion of manufacturing by-products for power generation.

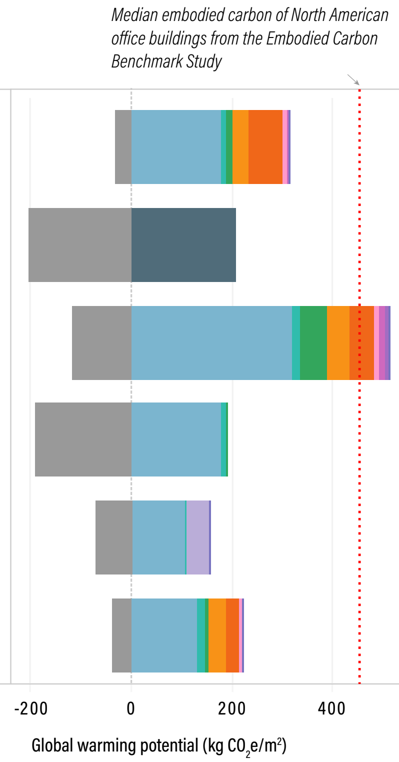
Architecture 2030 has determined that "embodied carbon will be responsible for almost half of total new construction emissions between now and 2050."[16] The crucial climate benefits of reduced embodied carbon are achieved while a building is under construction and thus have immediate impacts. Biobased products also stand apart from other materials in that they store carbon as well, potentially offsetting carbon impacts from other materials.

Life Cycle Analyses (LCAs)

LCAs are a process for documenting embodied carbon in building materials and comparing similar products. An LCA might focus on a single component or product, or it might capture an entire building. As discussed above, when calculating the LCA of a timber building, biogenic carbon

16 "Actions for a Zero Carbon Built Environment: Embodied Carbon," *Architecture 2030*, https://architecture2030.org/new-buildings-embodied/.

Building name, type, location	Building scope*	LCA tool and data source	Life cycle scope	Study period (years)
Brock Commons[1] Residential, Vancouver BC	S, F, E, I	Athena, USLCI, ecoInvent, EPDs	A1-A5, B2-B4, B6-B7, C1-C4	100
Catalyst[2] Mixed-use, Spokane WA	S, F, E	Athena, EPDs, SimaPro	A1-A5, B6	60
Design Building at UMASS[3] Mixed-use, Amherst, MA	S, F, E, I	Athena, USLCI, ecoInvent	A1-A5, B2-B4, B6-B7, C1-C4	60
Framework[4] Mixed-use, Portland, OR	S, F, E, I	Athena, USLCI, ecoInvent, journal articles	A1-A5	100
T3[5] Office, Minneapolis, MN	S, F	Tally, GaBi	A1-A4, B2-B5, C2-C4, D	60
Wood Innovation & Design Center[6] Education, Prince George, BC	S, F, E, I	Athena, USLCI, ecoInvent	A1-A5, B2-B4, B6-B7, C1-C4	50



***Building scope abbreviation**
S = Structure
F = Foundation
E = Enclosure
I = Interiors

Life cycle module
A1-A5
A1-A3 Product
A4 Transport
A5 Construction
Biogenic carbon storage
B2 Maintenance
B3 Repair
B4 Replacement
Impacts for B1, B5-B7 not shown
C2-C4
C1 Demolition
C2 Transport
C3 Waste processing
C4 Disposal

FIGURE 9.5: MASS TIMBER BUILDING GWP COMPARISONS

Several LCA studies of mass timber buildings in North America show that mass timber buildings (1) can have low embodied carbon compared to a benchmark value, which in this figure is represented by the vertical red dotted line, and (2) can have a significant potential to store biogenic carbon. Note that this figure does not aim to compare the buildings, but instead shows the general range in global warming potential results and the variation in LCA methods and tools. Direct comparison of environmental impacts between projects is challenging due to variation in model scope, building elements, background data, and underlying methods.

Source: Carbon Leadership Forum

1 M. Bowick, *Brock Commons Tallwood House, University of British Columbia: An Environmental Building Declaration according to EN 15978 Standard* (Athena Sustainable Materials Institute, 2018), http://www.athenasmi.org/wp-content/uploads/2018/08/Tallwood_House_Environmental_Declaration_ 20180608.pdf.

2 M. Huang, C. X. Chen, F. Pierobon, I. Ganguly, and K. Simonen, *Life Cycle Assessment of Katerra's Cross-Laminated Timber (CLT) and Catalyst Building: Final Report* (Carbon Leadership Forum, 2019), https://carbonleadershipforum.org/download/5173/.

3 M. Bowick, *Design Building, University of Massachusetts, Amherst: An Environmental Building Declaration according to EN 15978 Standard* (Athena Sustainable Materials Institute, 2017), http://www.athenasmi.org/wp-content/uploads/2017/04/ UMass_Environmental_Declaration_ 31_January_ 2017.pdf.

4 S. Liang, S. Gu, R. Bergman, and S. Kelley, *Comparative Life-Cycle Assessment of a Mass Timber Building and Concrete Alternative* (USDA Forest Products Lab, 2020), https://www.fpl.fs.fed.us/documnts/pdf2020/fpl_2020_liang001.pdf.

5 Based on Tally output files received from Magnusson Klemencic Associates (MKA), March 2021.

6 M. Bowick, *Design Building, University of Massachusetts, Amherst: An Environmental Building Declaration according to EN 15978 Standard* (Athena Sustainable Materials Institute, 2015), http://www.athenasmi.org/wp-content/uploads/2015/06/ WIDC_Environmental_Declaration_final.pdf.

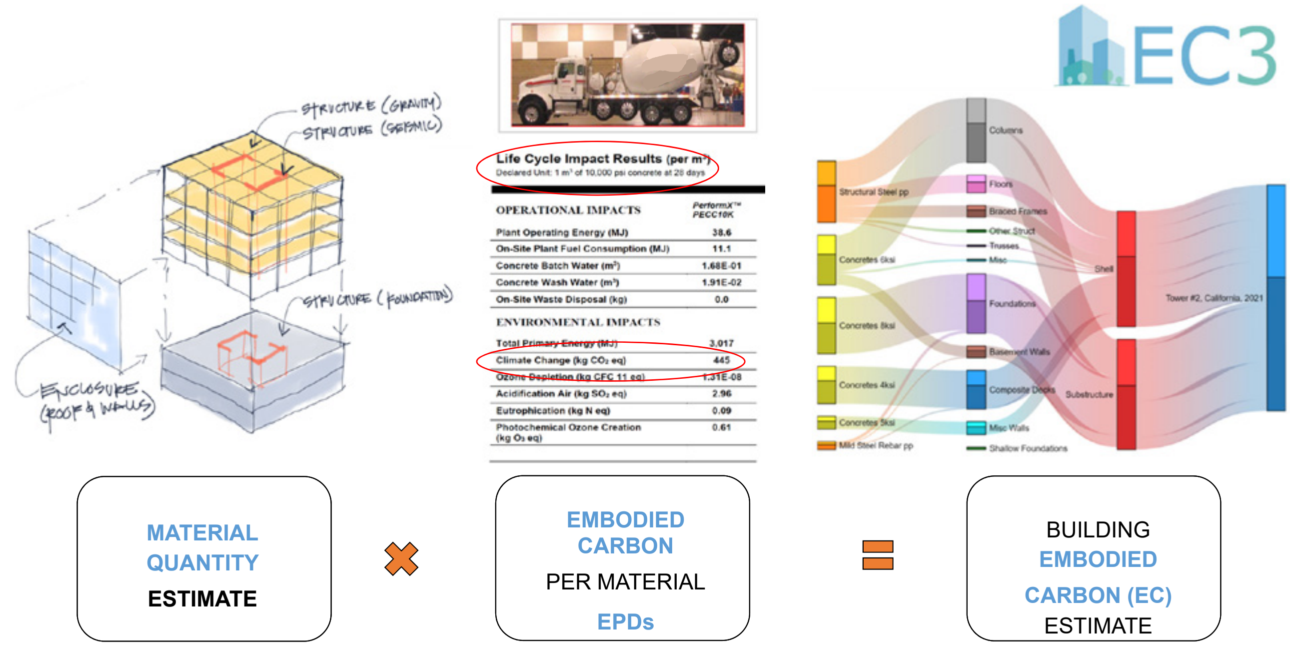


FIGURE 9.6: EC3 LIFE CYCLE ASSESSMENT TOOL

Source: Embodied Carbon in Construction Calculator Carbon Leadership Forum

can be assessed by considering a decomposition or industrial reuse cycle.

The Consortium for Research on Renewable Industrial Materials (CORRIM) and the Athena Sustainable Materials Institute are leading resources on LCAs for a variety of wood products and forest management. Embodied carbon and Global Warming Potential (GWP) have been researched and calculated for several North American mass timber products, yielding a range of results because of variations in wood sources and manufacturing processes. Recent research and data continue to confirm that, depending on the source, wood products can more than offset the carbon required to produce and install them. Because new methods of manufacturing, forest management, and energy sources are being developed, Life Cycle Inventories (LCIs) and LCAs will need to be updated continually.

The CLF is widely trusted for producing best-practice Whole Building LCAs (WBLCAs) for timber structures. In a 2019 study for Katerra, CLF compiled information from several mass timber buildings to compare their GWPs from a WBLCA standpoint. **Figure 9.5** shows the buildings' GWPs with and without biogenic carbon included, and in relationship to similar buildings with primary structural systems of concrete or steel.

LCA tools available to designers include Tally,[17] popular for its ability to plug in to Revit; Athena; Building for Environmental and Economic Sustainability (BEES); and the Embodied Carbon in Construction Calculator (EC3), illustrated in **Figure 9.6**. EC3 is a free, open-source LCA tool

17 https://kierantimberlake.com/page/tally

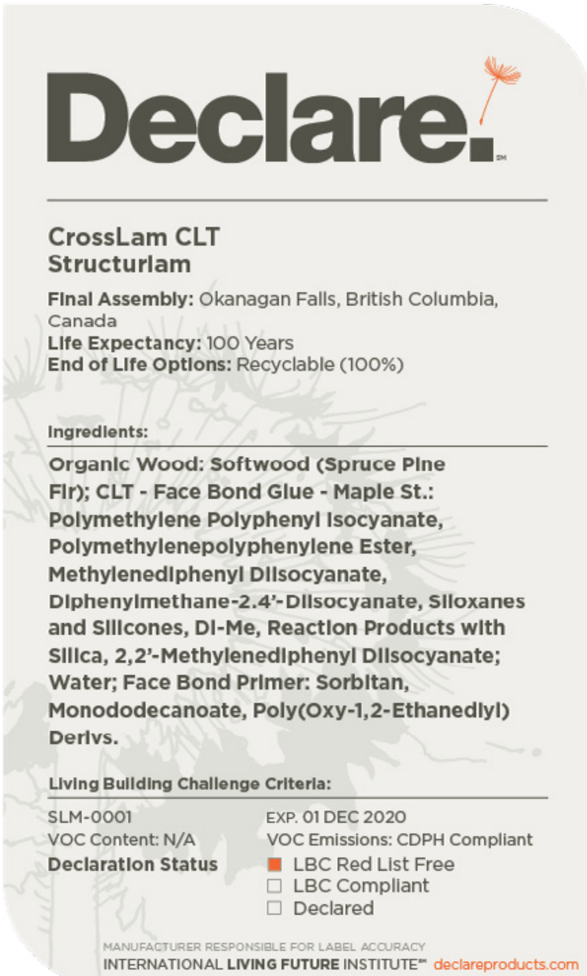


FIGURE 9.7: ENVIRONMENTAL PRODUCT DECLARATION FOR CROSS-LAM CLT

Source: https://declare.living-future.org/

that was developed by a multidisciplinary team led by the CLF and released in late 2019.[18] Each tool varies somewhat in end-of-life options and assumptions, and users of these tools will find that these factors contribute greatly to the output of LCAs.

Environmental Product Declarations (EPDs)

Reducing embodied carbon in building products reduces their GWPs. Designers can reference the information for products where GWP is measured and published, along with other disclosures such as toxicity or land conversion, by reviewing the product's EPD. EPDs report on 5 categories of environmental effects: GWP, ozone depletion potential, acidification potential, smog potential, and eutrophication potential. EPDs completed in compliance with the International Organization for Standardization (ISO) 14025 Type III are prepared and reviewed by an independent third party.

EPDs allow a specifier to compare different materials that provide the same function in a construction project. Though manufacturers may choose to pursue EPDs specific to their products—especially if they have exceptionally good reports—general EPDs for wood products are available through the American Wood Council (AWC) and the Canadian Wood Council (CWC). One of the most demanding EPD labels is "Declare" (see **Figure 9.7**); it identifies the most dangerous "Red List" ingredients and clearly states when products are free of them (see Adhesives, section 5.2.3).

EPDs are complex to interpret and time-consuming to track down, but they are becoming more accessible as building owners and industry professionals demand nontoxic and low-carbon materials. Some excellent and rapidly expanding resources for designers include the databases mindfulMATERIALS[19] and Carbon Smart Ma-

18 https://carbonleadershipforum.org/ec3-tool/
19 https://specmatters.com/mindful-materials/

FIGURE 9.8: ILFI'S ZERO CARBON CERTIFICATION REQUIRES EMBODIED CARBON DISCLOSURES

terials Palette,[20] and the organizational tool EPD Quicksheet.[21]

Green Building Certification Programs

The pursuit of environmental certifications is optional for most projects, but these programs and their supporters believe there are financial and nonfinancial benefits. These benefits include recognition/prestige, tax incentives, reduced ongoing operating costs, faster lease-up times, increased property values, increased energy efficiency, reduced waste, and more healthful and enjoyable working/living conditions. Certification systems have promoted the development and use of new products, procedures, and construction techniques.

Options for certification programs include Leadership in Energy and Environmental Design (LEED), Green Globes, Passive House, and International Living Future Institute's (ILFI) suite of living building approaches. Each of these programs has different criteria for certifications. All, however, are on a mission to construct buildings with reduced environmental impacts. The use of wood as a building material is seen as positive in the context of the evaluation processes, though they vary in how wood certifications are viewed and accepted.

Zero-carbon certifications have emerged over the past several years in response to the growing realization of the importance of neutralizing embodied carbon. Internationally, projects can register with ILFI's Zero Carbon Certification program (**Figure 9.8**), which requires that 100 percent of the embodied carbon emissions impacts associated with the construction and materials of the project be disclosed and offset. The Canada Green Building Council (CaGBC) has a Zero Carbon Building (ZCB) Standard that recognizes embodied energy as well as operational energy. To date, 166 ZCB Standard projects have been completed, and 591 are emerging.[22] The US Green Building Council's (USGBC) LEED Zero program tracks operational energy only, but LEED's newest version, 4.1, awards credits for embodied carbon accounting.

These certification programs, where wood products are concerned, often tie back into forest management certifications, solidifying the connection between sustainably managed forests and the use of wood in new and creative approaches. These systems continually extend the goal of creating human habitats with ever-smaller environmental footprints, and increasingly recognize that using wood is a significant component of that goal.

20 https://materialspalette.org/palette/
21 https://architecture2030.org/epd-quicksheet/
22 "Getting to Zero Buildings Database," *New Buildings Institute*, July 20, 2022, https://newbuildings.org/resource/getting-to-zero-database/.

9.5 BALANCING WOOD, CARBON, AND OTHER VALUES

For decades, the Intergovernmental Panel on Climate Change (IPCC) has stated that the roles of sustainable forests and wood products are some of the greatest solutions to the climate crisis. Much has been published around the loss of biodiversity and the importance of natural habitats. Forested watersheds provide most of the US population with their drinking water. They are also the headwaters for much of the irrigation water for agriculture and the transportation of materials on barges. People love to hike, ski, bird-watch, achieve spiritual renewal, and more in forests.

But forests are at risk from more severe wildfires and infestations of insects and disease. Are all of these compatible? How does the building sector resolve these issues as it moves forward with providing human habitats?

The integration of *sinks* through forest sequestration of carbon from the atmosphere in forests, the *storage* of carbon in our built environment, and the *substitution* of low-/no-fossil carbon materials is the challenge of managing forests for all of the other values they provide in addition to carbon and climate benefits.

As identified in the CSFEP's 3S Framework,[23] some gaps in knowledge exist around feedback between forests and the climate, the built environment and the end-of-life fates of building materials, the increased demand for wood, and the need for forest management practices. But a recently published paper[24] concluded that "with a high level of confidence, we can say that the substitution of timber for mineral-based construction materials has a significant potential to draw down atmospheric carbon and mitigate greenhouse gas emissions from the construction sector. This transition therefore has a high potential to rebalance the global carbon cycle."

As we continue to expand the use of wood, we also need to continue to monitor progress, research areas of uncertainty, and refine policies to encourage the development of a climate-smarter world.

CSFEP has 15 breakthrough initiatives that use the model developed from the 3S Framework. Monitoring is being done to identify the barriers and enabling elements of moving forward, with the goal of enhancing replication of this new CSF economy. The 3S Framework model is simpler to use than a full-blown LCA, and it helps developers, government decision-makers, and others to compare the benefits of different construction materials. Tools like these can help the thinking and evaluation processes to achieve better forest management, more efficient use of trees, better construction, and better connection of links in the whole supply chain.

23 https://www.csfep.org/_files/ugd/5b4908_0d3165e0b9d343ee8e288956dbfd3a6a.pdf
24 Galina Churkina and Alan Organschi, "Will a Transition to Timber Construction Cool the Climate?", *Sustainability* 14, no. 7 (2022), https://www.mdpi.com/2071-1050/14/7/4271.

MCDONALD'S — AVENIDA PAULISTA
Source: Arcos Dorados; Credit: Fernando Ctenas

CASE STUDY: MCDONALD'S — AVENIDA PAULISTA

NEW MCDONALD'S IS AT FOREFRONT OF SUSTAINABLE CONSTRUCTION IN BRAZIL

PROJECT OWNER: ARCOS DORADOS

PROJECT LOCATION: AVENIDA BERNARDINO DE CAMPOS, 307, PARAíSO, SÃO PAULO, SP, 04004-040, BRAZIL

COMPLETION DATE: AUGUST 30, 2023

ARCHITECT/DESIGNER: SUPERLIMÃO

MASS TIMBER ENGINEER/MANUFACTURER: URBEM

GENERAL CONTRACTOR/STRUCTURAL ENGINEER: NOAH TECH BRASIL

THE CONSTRUCTION OF a McDonald's on Avenida Paulista in São Paulo features mass timber, a pioneering initiative in a country where the use of this material is still largely unexplored. In Brazil, the culture of construction with mass timber is progressing slowly compared to in other countries that have widely adopted this sustainable approach. That one of McDonald's most iconic stores embraces this practice is a significant step toward scaling up in Brazil.

MCDONALD'S — AVENIDA PAULISTA
Source: Arcos Dorados; Credit: Fernando Ctenas

In its first year of operation, Noah identified Arcos Dorados (McDonald's) as a potential partner for spreading the culture of mass timber in Brazil. As Arcos Dorados had initiatives in place in other countries, the challenge to introduce this construction method was accepted and implemented with dedication from the McDonald's engineering team and key partners in the technical team in Brazil.

Mass timber construction is sustainable, as the technique uses materials from reforestation that are renewable sources. In addition, mass timber has the remarkable ability to absorb carbon dioxide (CO2), helping mitigate greenhouse gas emissions. In the case of this McDonald's unit, it's estimated that the structure can capture and store up to 136 tons of CO2, representing a positive environmental impact—the equivalent of a 12 percent reduction in CO2 emissions when considering the entire construction.

The significance of this project goes beyond direct environmental benefits. The construction of a McDonald's store on Avenida Paulista, a location of great visibility and importance in Brazil, makes the adoption of mass timber more tangible for society. McDonald's is a globally recognized brand, and this initiative serves as a practical example for the general public, demonstrating that it's possible to build large-scale structures with sustainable materials.

This project can raise awareness about the importance of sustainable construction in Brazil and influence future projects. Moreover, it demonstrates the feasibility of the approach, contributing to cultural and educational shifts in the country. The unit boasts over 60 sustainability attributes, with 25 of them already mandatory in other McDonald's units. This innovation also extends to operational and management practices adopted in the unit.

CHAPTER 10: THE GLOBAL MASS TIMBER PANEL INDUSTRY IN 2023

LECH MUSZYNSKI
PROFESSOR, OREGON STATE UNIVERSITY

In 2024, the mass timber panel (MTP) industry, exemplified by Cross-Laminated Timber (CLT), does not feel all that new anymore. Not even in the US. And yet the industry continues throwing surprises and posing baffling puzzles. Among these are the uneven pace of developing production capacity and the uneven rate of attrition across the main MTP-producing regions. Although the root causes of both deserve thorough analysis beyond the scope of this paper, the purpose of this chapter is to put recent developments in a broader context. From this broader perspective, the MTP industry is integrating elements of mass timber design, manufacturing technologies, and construction. But the industry must still be recognized as a radically new concept challenging commodity-oriented forest products, industry models, and the linear models of construction project development.

It is also much smaller and more diverse than the volume of information and noise around it would suggest. Organic development of the global mass timber industry since the first commercial applications in the late 1990s has produced substantial diversity in manufacturing processes, levels of automation, scales of operation, and products and services options, as well as in market strategies and modes of interaction with its extensive supply chain. The industry is still young and is still finding its sweet spot at the intersection of the businesses along its complicated supply and value chains. Existing global mass timber operations offer a living laboratory that provides an understanding of both the current state of the industry and its future development.

10.1 SOURCES OF INFORMATION

The information on the MTP industry presented here is derived from three major sources:

- Industry surveys [1][2][3]
- Targeted site tours of mass timber manufacturing lines, related businesses, and research centers
- Review of trade journals tracking the development of the industry, trade association reports, and public web profiles of MTP companies and hardware manufacturers

Wherever possible, when data was obtained from different sources, the sources were verified against each other.

To ensure confidentiality of collected information, strictly required by some of the contacted companies, the information is presented in aggregate format. When discussing regional differences, the data is parsed by large regions that are defined in a way that prevents exposing information from individual manufacturers (**Figure 10.1**). The regions were designed based on geographic locations and concentration of companies, leading to the division of Europe into 2 MTP-producing regions: Central Europe (sometimes referred to as the Alpine region, which includes Austria, Switzerland, Germany, Italy, and Czechia); and Other European countries (rarely covered in trade literature summaries). Outside Europe, the MTP-pro-

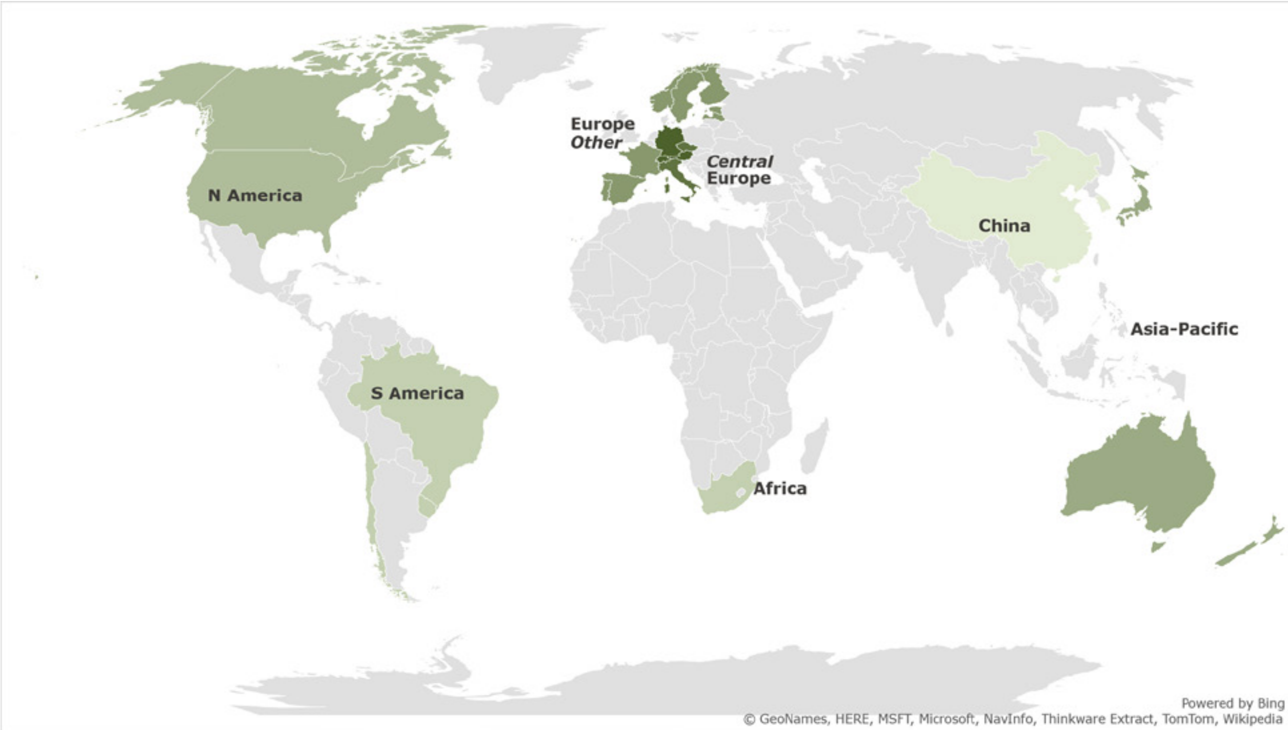


FIGURE 10.1: MTP-PRODUCING REGIONS.

ducing countries are divided into 4 large regions: North America (including the US and Canada); South America (including Chile, Brazil, and Uruguay); Asia-Pacific (including Japan, South Korea, China, Australia, and New Zealand); and Africa, which is represented by 2 plants in South Africa [4]. At present, we do not have enough data on commercial MTP production in South Korea to include it in the tally.

Some aspects of the content of this section have been previously communicated to professional audiences in journal papers, conference presentations, and proceedings publications [5][6][7][8][9][10][11][12].

10.2 CLT AND OTHER EMERGING MTP TECHNOLOGIES[1]

This report is primarily concerned with CLT, adhesive-bonded cross-laminated panel, because it is the most widely known MTP product. ANSI/APA PRG 320-2019, the North American product standard published by the American National Standards Institute (ANSI) and Engineered Wood Association (also known as APA), defines CLT as "prefabricated engineered wood product made of at least three orthogonal layers of graded sawn lumber or structural composite lumber (SCL) that are laminated by gluing with structural adhesives." This definition qualifies veneer products like Mass Plywood Panels (MPP) [15] or panels built from Laminated Veneer Lumber (LVL) as structural CLT under PRG 320. Although,

1 Based on author's contribution to [5] (updated).

in principle, this general definition agrees with that proposed in the European standard EN 16351:2021 [16], some European products might not qualify as structural CLT under PRG 320 due to restrictions on the thickness of laminations and discrepancies in structural lumber grading rules.

One of the interesting developments in the MTP industry is the emergence of similar cross-laminated panels made of dimension lumber but bonded with nails or hardwood dowels, so that the whole panel acts as a single load-bearing wall or floor, even though glueless, mechanically bonded panels are not covered by the respective CLT standards, PRG 320 and EN 16351:2021. Although the most obvious distinction among these 3 is the way the layers are bonded, they also differ substantially in raw material sourcing; manufacturing technologies; load-bearing capacities; and, consequently, the scope of potential uses. The similarities and differences are briefly discussed in the sections below.

Nail-Bonded Solid Wood Wall

A nail-bonded Solid Wood Wall, or as it is known in Central European markets, Massiv-Holz-Mauer (or MHM), which translates literally to "massive wood wall," is a massive, prefabricated CLT panel with layers made of rough-sawn boards that are bonded with nails [17]. This product should not be confused with one described as Nail-Laminated Timber (NLT), commonly used as beams and floor panels in timber structures in North America, where all layers are oriented parallel to one another. The nail-bonded CLT panel technology might have predated the development of adhesive-bonded CLT, but the commercial breakthrough came with a Solid Wood Wall system patented in Germany in 2005 [17]. The Solid Wood Wall is fabricated on small-scale, turnkey 3-step Hundegger production lines. The lines consist of specialized molders to produce longitudinal grooves on 1 side of the laminations, an automated lay-up and nailing station, and a Computer Numerical Control (CNC) finishing center. Relatively short, fluted aluminum nails that penetrate 3 layers do not interfere with cutting tools. Panels may consist of 9, 11, 13, or 15 layers (each about 16.5 millimeters or 10/16 inch) with 1 thin bitumen layer for improved airtightness of the lay-ups. The intended use of this product is as load-bearing and division walls for low-rise buildings in moderate exposure to moisture (below 20 percent) and at low to moderate exposure to corrosion [17].

There are 30 licensed Solid Wood Wall plants across Europe [17], and in 2022, the latest assessment, the total output in Central Europe was about 55,000 cubic meters (or over 23,000,000 board feet [MMBF] of the North American dimension lumber equivalent) [18].

Dowel-Bonded CLT (Wood100)

Dowel-bonded CLT—marketed as Wood100, Nur-Holz (which means "only wood"), and various local brand names [19][20][21]—is a massive prefabricated cross-laminated panel with layers of rough-sawn boards bonded with hardwood dowels. It is still a relatively new cross-laminated product and should not be confused with one marketed in North America as Dowel-Laminated Timber (DLT), for use as beams and floor panels in timber structures, where all layers are oriented parallel to each other. The low moisture content and tight fitting of the dowels at the time of assembly assure a durable, tight connection once the dowels gain moisture in ambient conditions

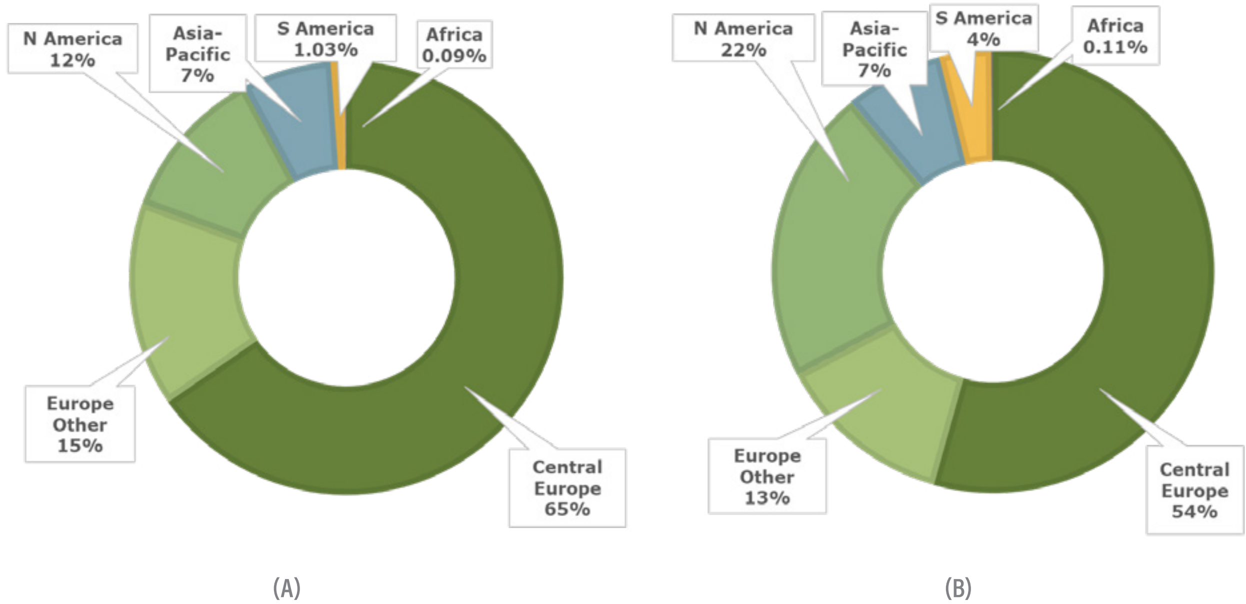


FIGURE 10.2: REGIONAL DISTRIBUTION OF THE TOTAL GLOBAL CLT OUTPUT VOLUME (A) AND PER-SHIFT CAPACITY (B) (BASED ON [2]).

and swell. The panels are assembled in highly automated lines. Only 3 commercially successful systems are known to date: (1) Wood100 (drawing attention to its 100 percent wood content), developed by Thoma company in Austria [19]; (2) a system developed by Swiss industrial hardware manufacturer TechnoWood AG [21][22][23]; and (3) Rombach Nur-Holz, which operates out of the Black Forest region in Germany and uses threaded hardwood dowels as connectors [24]. By 2022, Rombach was operating 1 manufacturing line; Thoma operated 2 lines, 1 in Austria and 1 in Germany; and TechnoWood AG had 12 highly automated lines in Europe [18].

Unlike other CLT products, some layers of the dowel-bonded CLT are arranged at 45 degrees or 60 degrees to the surface layer direction for increased in-plane shear stiffness (**Figure 10.3**). As in the Solid Wood Wall products, lay-ups typically incorporate 1 thin bitumen layer for improved airtightness. The dowel-laminated CLT panels are intended for use as load-bearing wall, floor, and roof panels in low-rise (up to 4 stories) timber structures [22].

10.3 SHIFTS IN GLOBAL PRODUCTION DISTRIBUTION

Since the publication of the first global survey [1][8], substantial production capacity has been added within and outside the core Alpine region of Europe, including new plants in China, South Africa, Chile, Brazil, and Uruguay; at least 3 in South Korea; and 2 short-lived ones in Indonesia.

In the same time, the North American MTP industry has seen significant closures, stormy takeovers, or quiet MTP production suspensions, reducing the total volume of structural MTPs [25][26][27].

FIGURE 10.3: THREE EXAMPLES OF CROSS-LAMINATED PANELS BONDED WITH NAILS AND DOWELS: (A) A SECTION OF SOLID WOOD WALL SHOWING LONGITUDINAL GROOVES IN LAMINATIONS INTENDED TO ENHANCE THE THERMAL-INSULATION PROPERTIES OF THE PANELS [17], (B) A DOWEL-LAMINATED WOOD100 PANEL SHOWING THE 60-DEGREE LAYER (SOURCE: L. MUSZYNSKI), AND (C) CONSTRUCTION OF ROMBACH NUR-HOLZ PRODUCT WITH THREADED HARDWOOD DOWELS AND A 45-DEGREE LAYER (SECOND FROM THE TOP) [24].

The annual global output of CLT in 2023, which we can attribute to 97 specific production lines, is just over 2 million cubic meters. The global annual per-shift capacity in 2023 is about 1.68 million cubic meters.

In January 2022, Gert Ebner of the Timber-Online.net trade journal compiled a list of pending and announced new and expanding CLT production projects for the years 2020 to 2024, predicting an increase of capacity in Europe by over 1.3 million cubic meters [28]. More than half of that volume was launched by the third quarter of 2023, and it's included in our tally. Considering known CLT operations in South Korea and other regions, for which the produced volumes/capacities are unavailable or outdated, and the number of high-capacity plants that should reach full capacity in 2023 to 2024, it is likely that, by the end of the first quarter of 2024, the global annual output will reach 2.6 million to 3 million cubic meters.

Manufacturers of mechanically bonded cross-laminated panels like Solid Wood Wall, Wood100, and Nur-Holz (45 lines, mainly in Central Europe, and not included in the distribution graphs in **Figure 10.2**), taken together, likely contributed another 76,000 cubic meters of structural panel products to the MTP market in 2022 (the time of the most recent tally [18]).

The steady addition of production capacity in Europe and the recent troubles in the North American CLT industry have combined to shift the global distribution of adhesive-bonded CLT production (**Figure 10.2**). The Alpine region in Central Europe still accounts for over 65 percent of the output (40 percent by Austria alone) and nearly 54 percent of the annual per-shift capacity. All European manufacturers combined contribute more than 80 percent of the adhesive-bonded CLT volume to the global construction market and 100 percent of the dowel- and nail-bonded cross-laminated panels. A difficult-to-assess portion of that volume is being exported to overseas markets, where European companies successfully compete with local CLT manufacturers.

In the same time frame, North American CLT production shrank from 17 percent of the global volume in 2020 [29] to 12 percent in the current tally, with equally substantial reduction to the per-shift capacity, down from 28 percent in 2020 to 22 percent in 2023. It should also be noted that, in 2022 in North America, at least 120,000 cubic meters of adhesive-bonded CLT (about half of the output reported here) was produced as nonstructural panels for the industrial (access and rig) mat market.

The global CLT industry has seen closures for a variety of reasons in countries like Austria, Australia, Czechia, France, Japan, Indonesia, New Zealand, and Norway. Although the recent attrition rate in the North American MTP production capacity is unprecedented, it is too early to blame it on the global pandemic or draw any general conclusions about underlying systemic factors or the state of the industry in the region. The MTP industry has a substantial degree of intrinsic flexibility as it is oriented toward custom-made products serving premium construction projects, allowing it to come through the global recession largely unscratched.

The impact of the global pandemic has been more difficult to assess. Anecdotal evidence based on brief, unstructured conversations with industry leaders in the US in 2020 suggested that the CLT industry in the Pacific Northwest was navigating the pandemic relatively well. This sentiment was later corroborated by news from Central Europe [30].

However, a global industry survey conducted in 2021 and 2022 [3] painted a more complex picture. Equal shares of respondents increased, maintained, or were forced to decrease production compared to their pre-COVID-19 levels. Increases in production were attributed to previously planned business expansions and increased demand for medium-scale public buildings and single-family residential housing. Production decreases (in some cases as sharp as 75 percent) were attributed to decreases in demand, increases in raw material costs, COVID workplace restrictions, and COVID-related absences. Although the response rate of 12 percent (15 out of 122 surveys sent out in 7 languages) is par for the course in industrywide surveys, it is lower than in our previous surveys [1][2] and too low to fairly represent the unprecedented diversity in the MTP industry [3].

10.4 RAW MATERIAL SOURCING

Raw material use has to be considered separately for the 3 types of MTPs defined above (CLT, Solid Wood Wall, and Wood100).

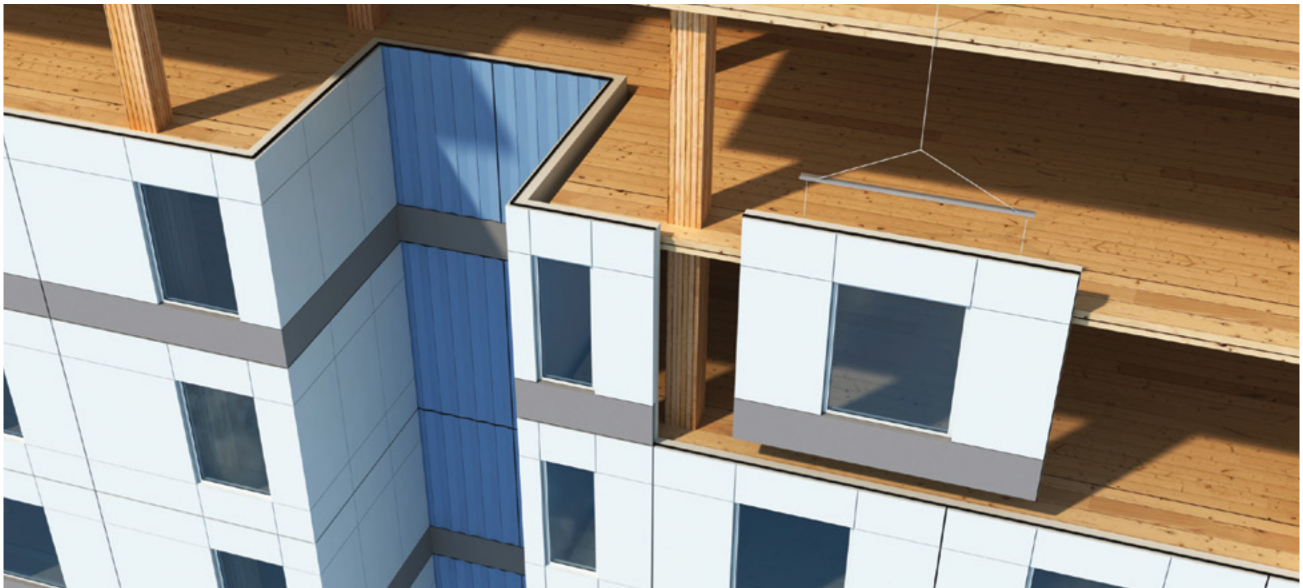
Laminations

CLT production in North America is regulated by a prescriptive ANSI/APA PRG 320 standard [14] that regulates the grades and dimensions of lumber used in structural panels. The minimum requirement for the layers aligned with the principal loading direction is visual grade No. 2 or better; and for the transverse pieces, it is No. 3 or better (see Chapter 3: Raw Materials for additional details). Although both grades allow a certain amount of wane, and PRG 320 allows gaps between adjacent lamination edges (up to ¼ inch, or 6.4 millimeters), manufacturers tend to use square pieces and eliminate all gaps because wane pockets and gaps in the panels form water catchment wells at construction sites. It follows that logs with diameters too small to produce a substantial volume of lumber free of wane may not be favored unless laminations are finger-jointed from square sections of lumber produced from small logs.

Solid Wood Wall and dowel-bonded CLT (like Wood100 and Rombach Nur-Holz), on the other hand, are not regulated by product standards concerned with structural CLT and (to our knowledge) are not regulated by any dedicated blanket standards for structural products. In some European countries, they can be used in low-rise structures based on European technical approval certificates issued to individual manufacturers (see, for instance, reference [31]). The panels are not nearly as airtight as adhesive-bonded CLT, so wane is not perceived as a substantial problem in Solid Wood Walls or in the core layers of dowel-laminated panels like Wood100 or Rombach Nur-Holz.

Solid Wood Wall panels use rough-sawn boards rather than nominal 2-by stock. The surface is not considered for visual quality. That means there should be greater potential to use lumber of lower quality than that required for adhesive-bonded CLT. However, the nailing patterns require laminations of a certain minimum width, making the use of lumber sawn from small-diameter logs unlikely with this technology. Laminations are grooved on 1 side along the grains to increase the thermal insulation of the panel (**Figure 10.3a**). The final thickness of grooved laminations is about 16.5 millimeters (10/16 inch). As mentioned before, Solid Wood Wall and Wood100 lay-ups typically incorporate 1 thin continuous bitumen sheet for improved airtightness. Rombach Nur-Holz does not mention such a solution.

Dowel-bonded CLT uses rough-sawn lumber in core layers, but dressed lumber is needed for the face layers that often are meant to be visible in structures. Also, bonding with dowels requires wide-face lumber (likely more than 200 millimeters, or 8 inches) to form 2 rows of successful dowel bonds in each surface layer. This likely limits the prospect of utilizing small logs (**Figures 10.3b** and **10.3c**). Besides, in their promotional materials, both Thoma and Rombach stress the top-quality lumber used in their products, likely appealing to the high end of the construction market.



ASSEMBLY WORK CONTINUES EVEN AT -17 DEGREES CELSIUS.
Source: Acetra; Credit: Johan Mathis Gaup

CASE STUDY: KAUTOKEINO SCHOOL

KAUTOKEINO SCHOOL UNDERWAY

PROJECT OWNER: KAUTOKEINO MUNICIPALITY

PROJECT LOCATION: BREDBUKTNESVEIEN 34
KAUTOKEINO, NORWAY

COMPLETION DATE: JANUARY 3, 2023

ARCHITECT/DESIGNER: OLA ROALD ARKITEKTUR

MASS TIMBER ENGINEER/MANUFACTURER: ACETRA/SKONTO

GENERAL CONTRACTOR: PEAB AS

STRUCTURAL ENGINEER: ACETRA

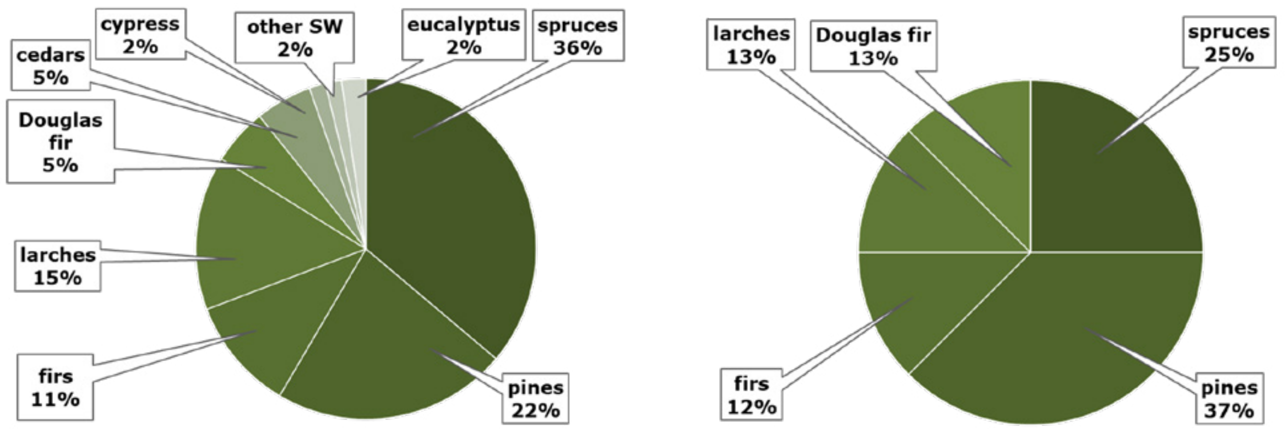
THE NEW SCHOOL in the center of Kautokeino was built on the site of the former primary and secondary schools, and it will accommodate students from the first to the tenth grades. The school was designed to support the Sami culture and its focus on experience-based learning. A circular outdoor space connects all parts of the school and provides direct access to the auditorium and the workrooms.

ABOVE — FINISHED WORK
Source: Acetra; Credit: Johan Mathis Gaup

RIGHT — WALLS GO UP DURING CONSTRUCTION OF KAUTOKEINO SCHOOL
Source: Acetra; Credit: Johan Mathis Gaup

The new, modern, environmentally friendly school, where the Sami language will be taught, will have a sports hall and pool.

The building is made of Cross-Laminated Timber (CLT), except for the pool building, retaining walls, and foundation. It has a total area of about 5,000 square meters in 2 stories, both built of CLT.



(A) (B)

FIGURE 10.4: PERCENTAGE OF COMPANIES REPORTING USING SPECIES GROUPS (E.G., SPRUCES, PINES, AND FIRS RATHER THAN SPECIFIC SPECIES) GLOBALLY (A) AND IN THE US (B). NOTE THAT NOT ALL COMPANIES REPORT SPECIES USED IN THEIR MTPS. "OTHER SW" STANDS FOR OTHER SOFTWOODS NOT GROUPED OTHERWISE.

No magic is involved in the species selection for mass timber production. Manufacturers tend to target structural-grade softwoods available in their regions, with some manufacturers occasionally importing lumber from external—and even faraway—markets if the prices are favorable. Although we do not have precise information on the volume of individual species used by the mass timber industry, it is possible to get a general idea of the diversity by examining the number of manufacturers that report use of general species groups, i.e., the use of spruces, pines, and firs in general, rather than specific species, as shown in **Figure 10.4**.

The dominant position of spruces in the chart summarizing global use (**Figure 10.4**) is easily understood if we recall that more than 80 percent of the global CLT output is produced in Europe (**Figure 10.2a**), where spruces are the most commercially available structural species. It should also be noted here that, in most countries outside the Alpine region, growth of the CLT industry has been encouraged by governments that want to find a stable, economically viable outlet for substantial volumes of lesser-quality domestic lumber. The incentive programs used in these campaigns vary by country in terms of scale, specific form, and duration; and not all are equally successful. An interesting example of such trends is pilot-scale operations in Tasmania and South Africa that successfully built cross-laminated lumber panels using plantation eucalyptus species.

Selection of Adhesives and Mechanical Binders

Companies consider many factors when selecting adhesives or binders for their production lines. These include (but are not limited to) cost, a volatile factor for a long-term investment; appeal to the local market, which may consider appearance, sustainability, emissions regulations, carbon dioxide footprint, etc.; performance, which may consider bond integrity and fire performance; and ease and cost of application, e.g., plant logistics, curing dynamics, and open time versus press time.

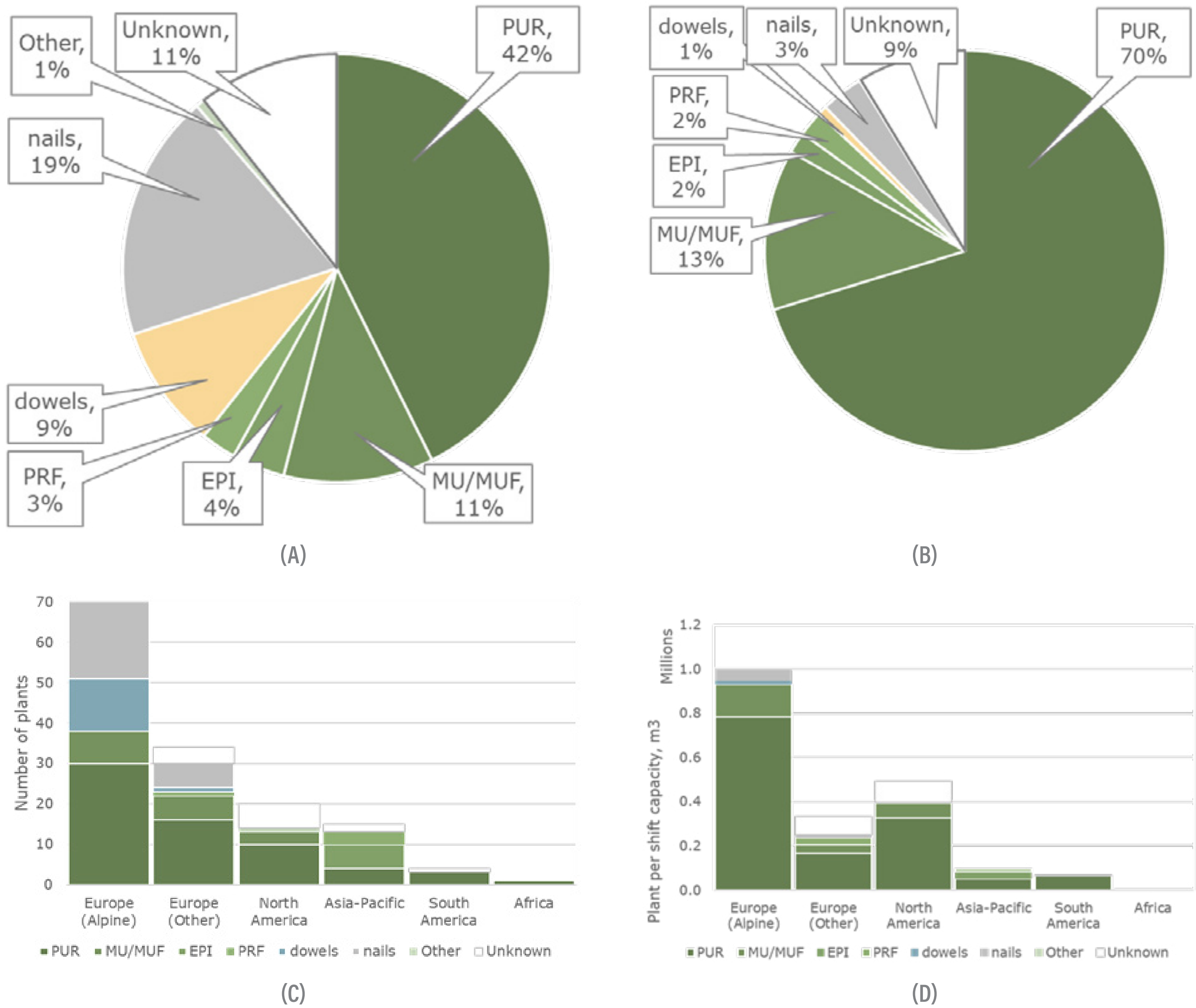


FIGURE 10.5: USE OF BINDERS IN GLOBAL MTP PRODUCTION: (A) USE OF GLOBAL BINDERS BY NUMBER OF PLANTS, (B) SHARES OF PRODUCT VOLUMES USING SPECIFIC BINDERS, (C) USE OF BINDERS BY NUMBER OF PLANTS IN MTP-PRODUCING REGIONS, AND (D) SHARES OF PRODUCT VOLUMES USING VARIOUS BINDER TYPES BY REGION.

The global image may be very different when considering the number of plants using specific types of binders (**Figure 10.5a**) versus the volume of materials with the same types of binders (**Figure 10.5b**). The difference is particularly striking when comparing the share of companies using mechanical binders (18 percent use nails and 9 percent use hardwood dowels) with the shares of products with mechanical binders produced and installed in buildings (combined 4 percent of the estimated annual global output volume). This apparent discrepancy may be explained by the large number of Hundegger-licensed Solid Wood Wall operations that produce a relatively small volume of panels. There are also substantial differences among the major MTP-producing regions. **Figure 10.5c** shows binder use in regions by the number of plants, while **Figure 10.5d** shows volume of MTPs produced with the major types of binders by region.

The graphs highlight the dominant position of the polyurethane (PUR) adhesive systems, which are used by more than 40 percent of companies around the globe and are found in nearly 70 percent of the cross-laminated MTPs produced. The share of melamine-based systems (melamine formaldehyde [MF] and melamine urea formaldehyde [MUF]) reached about 13 percent (by volume produced) due to late adopters in North America selecting binders at a time when the fire safety of the PUR systems had been challenged. Those concerns have been dispelled by a new generation of PUR systems with improved performance at elevated temperatures. The share of melamine systems is also spurred by a growing number of press systems capable of curing adhesives with radio frequency.

Phenol-resorcinol-formaldehyde (PRF) adhesives (widely used in glulam) and emulsion polymer isocyanate (EPI) form 4 percent of the global output of MTP produced and installed, reflecting the preferences of manufacturers operating in Japan.

Shares of companies or production volumes for which we do not have definite data on binder selection are marked in white. It may be safely assumed, however, that these companies use adhesives rather than mechanical binders, and so the global share of adhesive-bonded MTP volume produced and installed may be more than 95 percent.

In summary, even though there is substantial diversity in selection of binders (adhesives and mechanical) motivated by a variety of factors, the market is shaped by the choices of the biggest producers in Alpine Europe. Although most new developments happen in that region, trends are difficult to appreciate, given the long history and number of plants installed when PUR seemed to be the only option available. Newer markets, on the other hand, may reflect either actual trends or local preferences. Companies betting on ultimate green appeal (like zero emissions, 100 percent wood) are not in serious competition with adhesive-bonded MTPs. It should also be noted that new adhesive systems are being developed and offered to CLT manufacturers as we speak, and the scene is likely to change as the market continues its path to maturity.

10.5 THE SENSITIVE QUESTION OF COMMODITIZATION[2]

For anyone familiar with the forest products industry, the fundamental concept of structural MTPs must appear deceptively familiar and void of mystique. In fact, about two-thirds of the manufacturing is almost indistinguishable from that of preparing laminations for glulam. The concept of structural panel products consisting of cross-laminated layers of veneer is almost as old. Industrial manufacturing of plywood dates back to the 1860s [32]. Arguably, the first patent describing layered CLT composite bonded *with suitable cement* was issued to 2 residents of Tacoma, Washington, back in 1923 [33].

The expectation is that MTPs will sooner or later follow the familiar path from proof of concept toward maturity and join the broad family of wood-based commodities. The sentiment is often shared by manufacturers with solid pedigrees in the forest products sector. It seems a natural and logical course of events.

2 Based on author's contribution to [11].

The organic development of the global MTP industry since the early 1990s has produced substantial diversity in manufacturing processes, including in levels of automation, scales of operation, products and services options, and market strategies. But one thing remains in common: the development has not followed typical commodity-oriented forest products industry models. All structural CLT panels discussed in this section are specialty products, by which we understand that all panels are fabricated for specific projects.

General Discussion

Investopedia [34] defines "commodity" as "a basic good used in commerce that is interchangeable with other goods of the same type … most often used as inputs in the production of other goods or services," adding that "the quality of a given commodity may differ slightly, but it is essentially uniform across producers." Both conditions are possible only in goods that come in uniform units or in standardized series differentiated by dimensions, crucial properties, or quality grades—all regulated by relevant product standards.

Dimension lumber and wood-based composite panels like plywood, Oriented Strand Board (OSB), and medium-density fiberboard (MDF) are this kind of commodity, with prices determined by supply and demand in global or regional markets; they may be traded by manufacturers, final users, wholesalers, retailers, and speculators alike [34]. So defined commodities are produced in relatively small varieties and yet are used in a great variety of applications. The manufacturers need to know the broad types of applications, but they do not need to bother with how individual customers may use each individual 2-by-4 or sheet of plywood. The final user will decide if and how the individual pieces may be modified or customized to meet the demands of the intended use.

Although some mass timber elements, like the typical glulam sections of moderate spans or repeatable mass timber trusses, may be manufactured to stock as commodities for a broad construction market, offering custom products of particularly large dimensions or unusual shapes to meet the demands of special, one-of-a-kind projects is a reasonable alternative. In the latter case, prefabrication of all necessary details at the manufacturing line is more efficient than fabrication on-site, though, if necessary, custom cuts to beam or column elements at support points can be added at the construction site with hand tools or portable power equipment. Fundamentally, the concept is no different from working on a large log. Humans have been doing that for millennia.

The Necessity of Prefabrication

Structural MTPs, that is, elements with two large dimensions, change the game and move the concept into scantily charted territory. MTPs are area elements, used as load-carrying walls and floors, typically connected with other elements along edges. Adjustments to their external shape must be applied to these edges with a level of precision to ensure proper fit with other elements. With the technology available today, the sheer size (up to 20 meters by 4 meters), mass (up to 5.5 metric tons), and embedded value of individual panels preclude such adjustments on the construction site. The MTPs *must* arrive at the construction site prefabricated for assembly. For MTPs, prefabrication is not an option but a necessity, and that necessity has consequences for manufacturing practices.

The principle is corroborated by evidence collected in literature reviews, surveys, and site tours conducted at Oregon State university (e.g., [1][2][3][6][8][9][10]). Most manufacturers use modular presses that allow efficient production of elements of various external dimensions, and some use robotic lay-up to outline planned window and door openings. In all MTP production lines of which we are aware [10], prefabrication is an integral part of the manufacturing process and, with few exceptions, is performed on dedicated, large-frame, robotic CNC centers armed with a variety of tools. The process involves not only trimming the perimeter to required sizes, but also cutting necessary windows and doors, ducts for utilities, specialty connection nests, etc. That is possible only if the design is developed to the minute details before a panel is even pressed. This effectively makes all structural MTPs specialty products, made to meet the demands of each project. This is the first substantial barrier for commoditization: save for reasonable repetition of certain elements in an individual project, or even a level of modularity in large construction projects, custom-fabricated panels are not *interchangeable with other goods of the same type* [34].

If all production is customized, with a substantial margin of negotiable detail, there is little incentive to standardize the production process or final product dimensions. The industry maintains substantial diversity in terms of manufacturing processes, levels of automation, scales of operation, products and services options, and marketing strategies[10].

With most manufacturers either directly or indirectly involved in construction, it is legitimate to perceive buildings rather than panels as the final product of the industry, and panel production as a stage in a process that begins with project commission and ends with closing the shell of a building. That may further explain why panels are not being traded independently of specific projects.

Logistics and Storage

The large sizes of structural MTPs pose challenges to storing and transporting raw and finished panels. Even short-term buffer storage of panels within the manufacturing lines (before or after CNC finishing, at packaging and loading stations) poses a logistical challenge. The spaces must be within range of an overhead crane, and although flat-stacking panels is easy, it precludes quick access to all panels but the top one.

It is easy to imagine that the warehousing or mass storage of panels made to stock in a variety of standard sizes would require a crane and substantial area for buffering to access panels of desired characteristics, or specialized storage hardware enabling quick access. Although such hardware concepts are being offered by manufacturers serving the MTP industry [35], we are not aware of any unit planned for installation.

The existence of independent fabricators of MTPs is often pointed to as a trend for the future of the industry, allowing effective decoupling of panel production and fabrication. Although such off-site fabricators may assist manufacturers in handling overflow of production related to large projects, sending large, blank panels to another place for finishing complicates production logistics and increases costs. Such an arrangement is further complicated by the fact that there are fewer external fabricators than MTP manufacturers.

All panels sent to external fabricators are still pressed in quantities and sizes demanded by specific projects. Hypothetical use of stock panels in a range of standard sizes would necessitate trimming larger margins to comply with specific project demands, increasing the cost of production.

It simply does not make economic sense for anyone in the industry to carry the cost of intermittent storage and/or waste generated from remanufacturing *blank* panels.

These challenges provide additional incentives for integration of finishing and customizing panels within the production lines, and they prompt manufacturers to synchronize production and construction in such a way that prefabricated elements are being sent to the construction site on time in the sequence of assembly. In fact, manufacturers experiencing CNC finishing as a production bottleneck tend to add CNC nests to their existing production lines.

For the time being, the challenges and costs of moving panels between the manufacturing line and external finishing facilities, as well as the challenges and cost of storing MTPs in a raw or finished state, seem to preclude stocking or speculative trading and constitute an additional barrier to commoditization of panels.

Is Commoditization Possible?

The discussion thus far has focused exclusively on structural panels. In North America, however, a substantial volume of CLT panels (at least 120,000 cubic meters in 2022) is produced for nonstructural applications: access mats, rig mats, and temporary highway elements for construction and industrial activity in challenging terrains (sands, unstable soils) serving oil, gas and chemical, and general construction industries (e.g., [36]). These matting elements come in standard sizes and are being mass-produced, meeting most of the defining characteristics of a commodity. Notably, some CLT manufacturers in North America are serving both the construction and the matting markets.

As mentioned above, even within otherwise unusual buildings, a certain level of repetitiveness or even modularity is practiced to achieve design, production, and construction efficiencies. There is a great interest in modular design with MTPs [37]. A successful modular design template of an apartment building, commercial building, or utility structure that may be executed in large numbers may create incentives for some manufacturers to specialize in fabricating large numbers of kits-of-parts, or identical sets of elements, to match the demands of the market or even to fabricate a certain margin to stock. Although these kits-of-parts may be considered a commodity of sorts, individual MTPs would still be custom-made for such projects, and it is hard to imagine that they may be traded or stocked outside of that paradigm.

Summary

Custom cutting of massive panels at the construction site is next to impossible with current technology. Producing prefabricated panels finished for specific designs and just-in-time delivery to the construction site is, for the time being, the most efficient solution. Although companies do offer prefabrication services on raw panels, they seem to operate on the overflow of production dedicated to large projects rather than fabricating commodity panels. All these circumstances define the MTP industry as a specialty industry,

LEFT — KORE DURING THE FISKARS VILLAGE ART AND DESIGN BIENNALE, 2022

Source: Wood Program; Credit: Kimmo Räisänen

RIGHT — THE LARGE SKYLIGHT ADMITS PLENTY OF NATURAL LIGHT.

Source: Wood Program; Credit: Kimmo Räisänen

CASE STUDY: KORE

KORE OFFERS MODULAR MINIMAL LIVING SPACE

PROJECT OWNER: WOOD PROGRAM, AALTO UNIVERSITY

PROJECT LOCATION: METALLIMIEHENKUJA 4 ESPOO, FINLAND 02150

COMPLETION DATE: AUGUST 30, 2021

ARCHITECT/DESIGNER: WOOD PROGRAM 2020-2021

MASS TIMBER ENGINEER/MANUFACTURER: METSÄ WOOD

STRUCTURAL ENGINEER: MAURI KONTTILA

OTHER CONTRACTORS: ROTHOBLAAS

KORE, CONCEIVED DURING the pandemic years of 2020–2021, was designed to create a compact and flexible living space. The goal was to emphasize the importance of a comfortable interior habitat for mental and physical well-being, given the lessons learned from the pandemic. A key accomplishment was the design of a transportable and adaptable living unit suitable for various environments.

The project was conceived by a team of 15 students from 9 different countries and was constructed during the Wood Program, a yearlong course at Aalto University in Finland that focuses on wooden architecture and construction. This program emphasizes learning through drawings, models, and mock-ups in various scales, and the design process evolves through experiments, group discussions, and creating and building.

The Kore concept houses all essential living functions, including sleeping, eating, studying, bathing, and socializing. This core also serves as a technical space, supplying water, light, and electricity for self-sustaining house functions. To enhance the multifunctionality of the space, the sliding doors serve a dual purpose: they close off the wardrobe, for example, when the bathroom is open for circulation. In combination with a wooden ladder, these doors conceal and reveal the core functions. The living area and sleeping loft maintain a strong connection to the outdoors through a spacious opening and an impressive skylight.

The Laminated Veneer Lumber (LVL) roof structure is designed to be fully detachable from the Cross-Laminated Timber (CLT) walls for transportation purposes. It features preinstalled lifting hooks and a well-thought-out roof-wall connection for disassembly and transport, and reassembly in different locations. The exterior deck is detached and includes a wheelchair ramp, ensuring accessibility for everyone.

A selection of Finnish wood species was employed in the construction, such as spruce for the CLT walls and ceiling plywood, birch for countertops and the central core's plywood, and oak for wet areas and flooring. The cladding panels were prefabricated in a workshop and then hung and fixed on-site. The black exterior provides a contrast to the warm and welcoming interior space.

THE BLACK EXTERIOR CONTRASTS WITH THE INTERIOR.
Source: Wood Program; Credit: Kimmo Räisänen

The decision to employ sustainable and renewable materials such as solid wood and mass timber products like CLT, LVL, glulam, and plywood was driven by several compelling factors. These materials are recognized for their capacity to sequester carbon dioxide, their minimal environmental impact, and the positive impact they have on human well-being. In this case, they also enabled a swift construction process and a hands-on approach.

By opting to divide the house into 2 sections and leveraging the lightweight properties of these wooden materials, transportation costs were kept down. In addition, prefabrication capabilities afforded by these materials allowed for adaptability and enhanced precision in construction. Overall, the use of mass timber in such a small-scale project harmonizes with the project's sustainability objectives, accommodates design adaptability, and satisfies the need for efficient construction, making it a compelling choice for architects and builders alike.

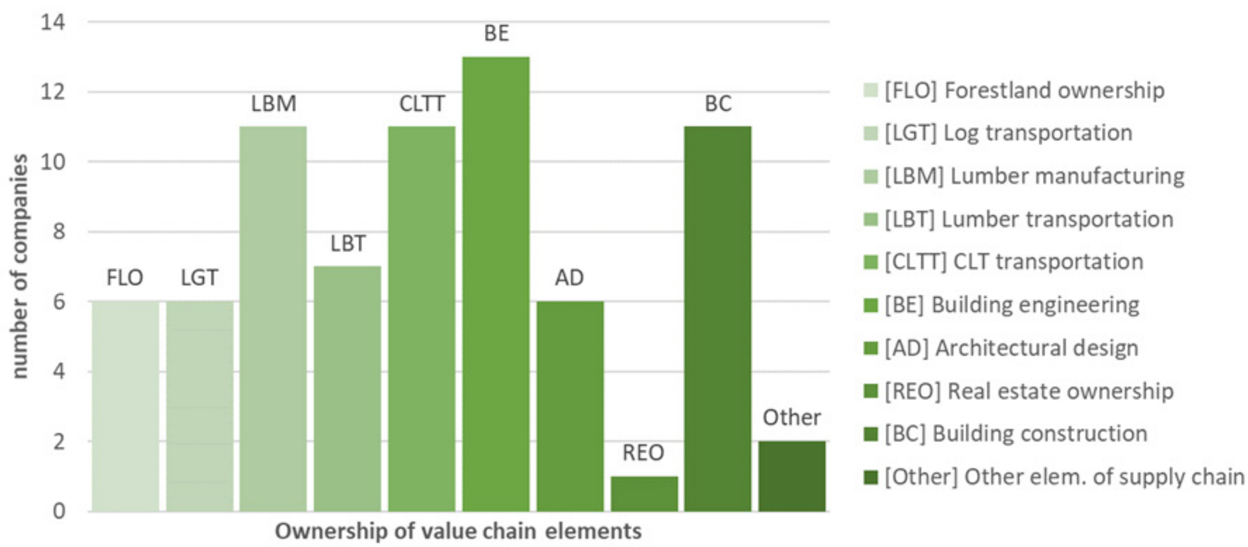


FIGURE 10.6: VERTICAL INTEGRATION: OWNERSHIP OF VALUE CHAIN ELEMENTS AS REFLECTED IN COMBINED RESPONSES FROM 2 SURVEYS CONDUCTED IN 2016 [1] AND 2019 [2] (29 RESPONDENTS WITH NO DUPLICATION BETWEEN THE 2 SURVEYS) [8].

with custom prefabricated products delivered as ready-to-assemble elements of building shells or even finished buildings. Panel production is but a stage in an integrated process that begins with project commission and ends with closing the shell of a building.

Although intrinsic barriers prevent commoditization of structural MTPs even in the most developed markets, that does not mean that some form of commoditization is not possible in the future. It is more likely to focus on commoditization of certain types of highly modular designs than on blank panels.

10.6 SUPPLY CHAIN AND MARKET STRUCTURE[3]

The development of the structural MTP industry following a specialty rather than commodity model—and the newness of the panelized timber solutions in the construction market—gave companies a strong incentive to control the project acquisition process by integrating a certain level of architectural and engineering design services, project management, and, quite often, construction services or construction supervision. In this regard, buildings are the actual product, and panel production becomes just one stage in the process.

In reality, the level of vertical integration varies substantially, both among and within the 3 products discussed. **Figure 10.6** presents responses of 29 companies asked about the ownership of elements of their value chain in 2 separate surveys conducted in 2016 [1] and 2019 [2]. (The latest responses of the companies participating in both surveys were used.)

More than a third of the respondents owned sawmills (LBM on the graph), project transportation fleets (CLTT on the graph), building engineering

3 Based on author's contribution to [10].

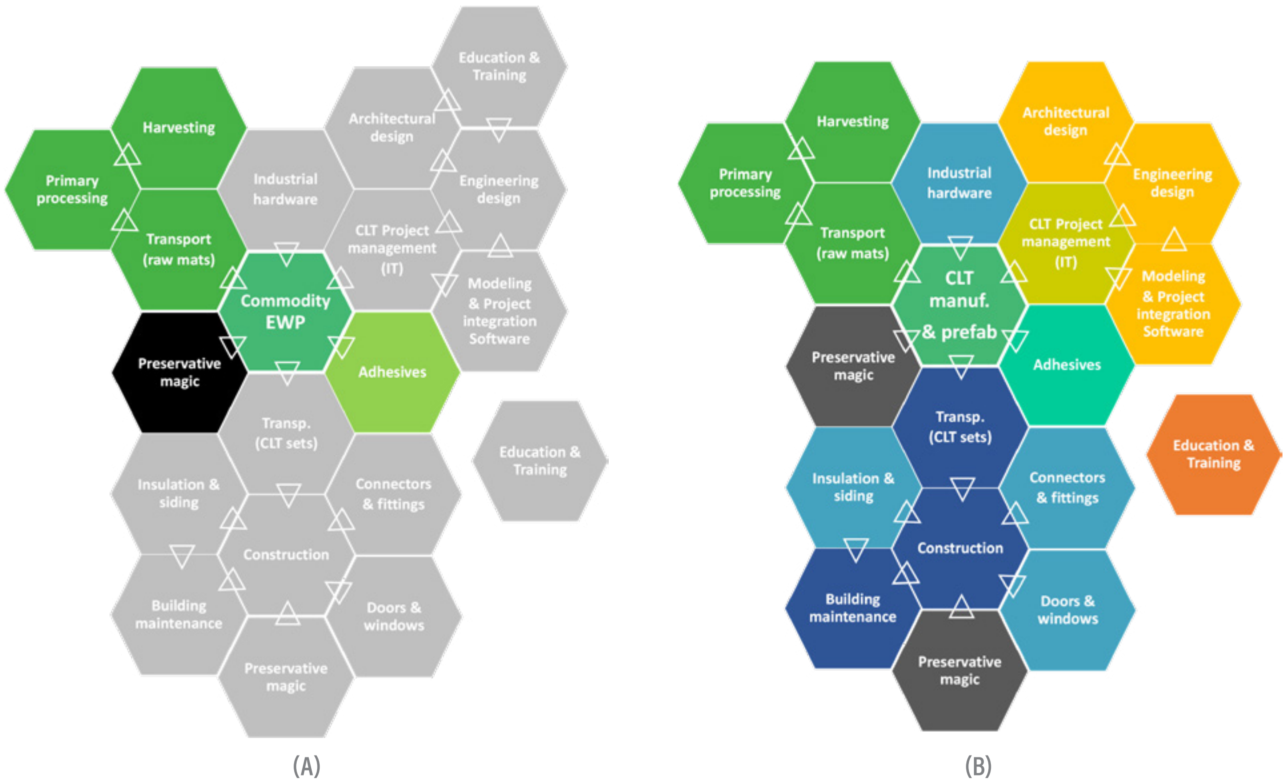


FIGURE 10.7: TYPICAL SUPPLY/VALUE CHAIN MODEL OF AN EWP COMPANY (A) COMPARED TO A POSSIBLE SUPPLY/VALUE CHAIN OF A CLT COMPANY WHERE THE FINAL PRODUCT IS A BUILDING (B).

offices, and/or construction crews (BE and BC on the graph, respectively).

As explained in the previous section, intrinsic barriers prevent commoditization of massive CLT panels and force the industry into a specialty model, even in the most developed markets. In this model, the products delivered to the market are not panels but building shells, or even finished buildings.

Compared to Engineered Wood Products (EWP), therefore, the value chain of MTP products is much more complex. It necessarily involves architectural firms that serve as sort of external project acquisition gates, civil engineering offices, and project management on one side; and specialized connectors manufacturers, insulation and siding products, and construction crews on the other (**Figure 10.7**).

As noted above, most structural adhesive-bonded and all dowel-bonded MTP-producing companies show some level of vertical integration in their complex value chains. The most common model is integrating the engineering detailing services and a level of project management, while other services are outsourced to closely allied partner companies familiar with the technology. There are companies, however, that offer architectural design offices; transportation; construction services (**Figure 10.8a**); customized connectors and preinstallation; and, in one case, custom manufacturing of their own windows/doors, floor finishes, insulation, and external siding [1][6]. Some companies own forestlands and sawmills [2]. On

FIGURE 10.8: A COMMON SCHEME OF VERTICAL INTEGRATION OF CLT COMPANIES (A) AND AN EXAMPLE OF A VERTICAL INTEGRATION OF COMPANIES SPECIALIZING IN BUILDING WITH CLT, THOUGH NOT PRODUCING PANELS, LIKE EURBAN [10] (B).

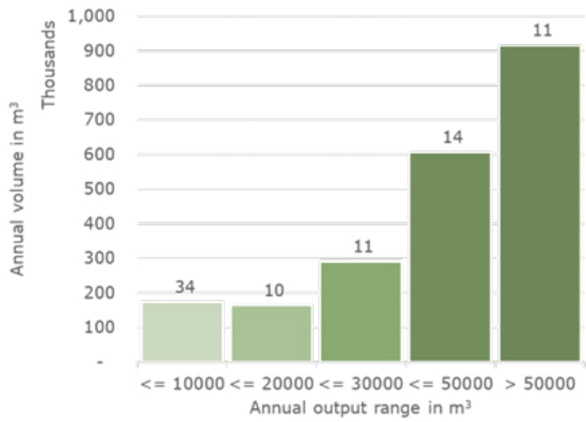
the other end of the spectrum, a few small-scale companies focus exclusively on fabricating panels for external orders, outsourcing all other functions to the parent companies. Examples may be found in Japan and Finland.

A well-known example of a vertically integrated company offering panelized construction services but outsourcing the production and fabrication of MTPs is the British company Eurban (**Figure 10.8b**). To date, Eurban boasts 321 mass timber/CLT projects realized in the United Kingdom, all from imported CLT prefabricated specifically for the projects [38]. Although this may indicate a future trend, it is not a common arrangement, and vertically integrated mass timber companies seem to benefit from their control of a range of aspects of project development.

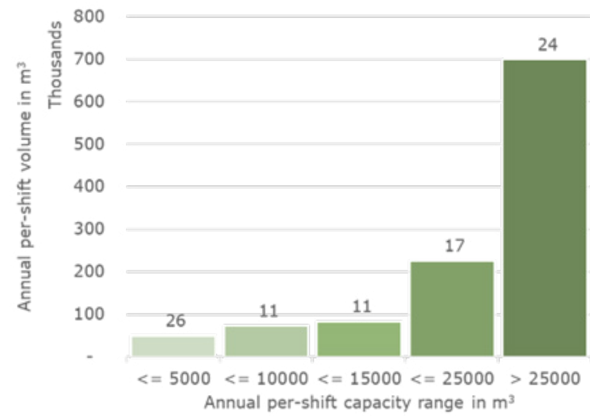
10.7 DIVERSITY IN TECHNOLOGY AND PRODUCTION LINES

Organic development of the global mass timber industry over almost 30 years since the inception of the first commercial production has produced substantial diversity in manufacturing processes, levels of automation, scales of operation, and products and services options, as well as in market strategies and modes of interaction with the extensive supply chain.

Ownership of CLT plants ranges from family enterprises to international holdings. The scales of operation and the levels of automation vary. Annual production volumes of CLT plants across the globe vary from less than 500 cubic meters to over 125,000 cubic meters (**Figure 10.9a**), while



(A)



(B)

FIGURE 10.9: ANNUAL PRODUCTION VOLUMES (A) AND ANNUAL PER-SHIFT CAPACITY (B) ALLOCATED TO CLT LINES REPRESENTING A RANGE OF PRODUCTION CAPACITY REPRESENTED BY BARS. THE NUMBER OF PRODUCTION LINES IN EACH CATEGORY IS PROVIDED ABOVE EACH BAR (BASED ON [6], UPDATED).

the annual per-shift capacities vary from less than 500 cubic meters to 110,000 cubic meters (**Figure 10.9b**). Over the past 6 years, however, an increasing number of new CLT plants have opted for specialized off-the-shelf equipment solutions, characterized by a high capacity, a high level of automation, and an option for full integration of entire lines.

The graphs in **Figure 10.9** indicate that not all companies use their production capacity to the same degree. This is consistent with the noncommodity character of the industry. In a particular sense, this is also true for a number of high-capacity plants launched in 2022 and 2023 that have not yet reached their full production potential.

Two out of three of all presses installed are fabricated by one of four specialized European manufacturers (**Figure 10.10a**). A similar proportion of all installed CNC centers we know about are fabricated by just two leading European manufacturers (**Figure 10.10b**). As a result, many of the production lines launched since 2017 are rather similar. That trend applies to the oldest and largest CLT companies as they upgrade their lines to meet the demand for increased capacity.

Even though some companies operate more than 1 line under the same roof, few decide to build another plant in a different location, and even fewer build new production lines in foreign markets. This is true even for the major Alpine region players that are very successful in pursuing projects in foreign markets. Almost proverbial examples are the activities of leading Austrian companies in the Australian market, almost exactly halfway around the world.

10.8 GAUGING MTP POTENTIAL IN REGIONS

Gauging the current and future CLT markets in individual regions or countries is notoriously difficult because of the substantial differences among regions in terms of the strength of their economies, robustness of their construction markets, and the size and level of sophistication of

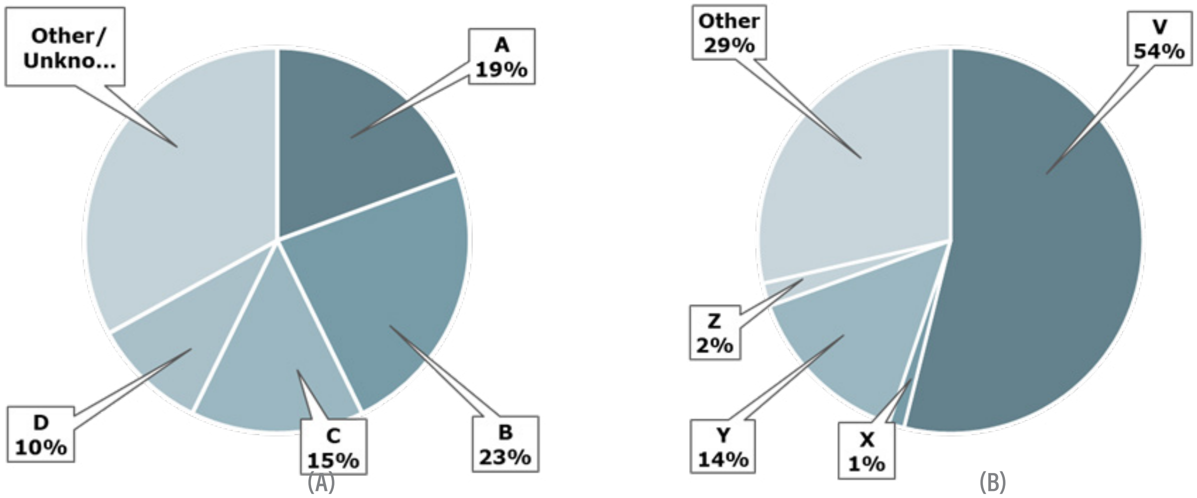


FIGURE 10.10: SHARES OF KNOWN CLT LINES EQUIPPED WITH PRESSES (A) AND CNC FINISHING CENTERS (B) MANUFACTURED BY THE 4 LEADING PROVIDERS OF PRESS LINES AND COMPLETE TURNKEY INTEGRATED PRODUCTION LINES.

their forest products industries. The density of the population and myriad other factors also could be considered. A rough estimate may be arrived at, however, by using a set of substitute gross indicator metrics widely available for individual countries that are possible to summarize for regions. For instance, GDP per capita is a readily available measure of a country's economic output that accounts for the size of its population, but it must be combined with another metric indicative of that country's access to structural forest products and its ability to process them to get meaningful estimates of CLT industry potential [29].

When metrics are normalized by values seen in Central Europe, the most mature and most saturated market, the small region outweighs all others in the number of installed CLT manufacturing lines and has no equal in terms of the total annual CLT output volume or per-shift production capacity. These gaps may be interpreted as an indirect indicator of the potential for regions that seem to be otherwise similar to the Alpine region in other gross metrics scaled per capita [29].

10.9 SUMMARY AND CONCLUSIONS

Overall, the CLT industry continued its exponential growth across the globe. The number of new high-capacity lines in regions outside Central Europe has grown substantially and is likely to expand further by the first quarter of 2024. By comparison, in the years 2021 to 2023, the North American region experienced a series of setbacks that led to closures, suspensions, or reorganizations of 3 major CLT-producing companies. It is not known if this attrition process was related to the global pandemic or had other common roots. The industry still seems to be far from maturity, and the actual impact lags behind the outsized hype in the excited communities along its supply chain. Tectonic shifts in global economies triggered by the global pandemic, war in Ukraine, and other disruptions increased the sense of volatility that touches the complex supply and value chains of the global MTP industry.

ACKNOWLEDGMENTS

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REFERENCES

[1] Albee, R. R. "Global Overview of the Cross-Laminated Timber Industry." MS thesis, Oregon State University (Corvallis, Oregon), 2019. 114 pp.

[2] Larasatie, P., R. R. Albee, L. Muszyński, J. E. Martinez Guerrero, and E. N. Hansen. "Second Survey of the Global CLT Industry." World Conference on Timber Engineering, WCTE 2020, Santiago, Chile, January 11–14, 2021. 8 pp.

[3] Larasatie, P., L. Muszynski, and E. Hansen. "Global Mass Timber Panel (MTP) Industry during the COVID-19 Pandemic: Initial Findings." Proceedings of the XV World Forestry Congress: Building a Green, Healthy, and Resilient Future with Forests, Seoul, Republic of Korea, May 2–6, 2022. 5 pp.

[4] Smily, J. XLam ZA, personal contact. October 5, 2023.

[5] Sanchez, D. L., T. Zimring, C. Mater, K. Harrell, S. Keley, L. Muszyński, B. Edwards, S. Smith, K. Monper, A. C. Marley, and M. Russer. "Literature Review and Evaluation of Research Gaps to Support Wood Products Innovation." Technical report of the Board of Forestry and Fire Protection Joint Institute for Wood Products Innovation, submitted to the California Board of Forestry and Fire Protection: Agreement #9CA04450. 2020. 116 pp.

[6] Muszyński, L., E. Hansen, B. M. S. Fernando, G. Schwarzman, and J. Rainer. "Insights into the Global Cross-Laminated Timber Industry." *BioProducts Business* 2 (8): 77–92.

[7] Albee, R. R., L. Muszyński, E. N. Hansen, C. D. Knowles, P. Larasatie, and J. E. Guerrero. "Recent Developments in Global Cross-Laminated Timber (CLT) Market." World Conference on Timber Engineering, proceedings of the WCTE, Seoul, Korea, August 20–24, 2018. 6 pp.

[8] Muszyński, L., P. Larasatie, J. E. Martinez Guerrero, R. Albee, and E.N. Hansen. "Global CLT Industry in 2020: Growth beyond the Alpine Region." Proceedings of the 63rd International Convention of Society of Wood Science and Technology, July 12–17, 2020, virtual conference. 8 pp.

[9] Muszyński, L., P. Larasatie, E. N. Hansen, E. Bright, T. Barnett, J. E. Martinez Guerrero, and R. Albee. "Global CLT Industry in 2021: Binder Selections." FPS International Conference on Wood Adhesives, Portland, Oregon, April 11–13, 2022.

[10] Muszyński, L., P. Larasatie, E. N. Hansen, J. E. Martinez Guerrero, and R. Albee. “Mass-Timber Panel MTP Industry and Its Supply/Value Chain.” Proceedings of the 64th 2021 International Convention, Flagstaff, Arizona, August 1–7, 2021. 29–43.

[11] Muszyński, L., E. N. Hansen, and P. Larasatie. “The Sensitive Question of Commoditization in the Mass Timber Panel Industry.” Proceedings of the 65th 2022 International SWST Convention, Kingscliff, Australia, July 10–15, 2022. 6 pp.

[12] Muszyński, L., M. Riggio, M. Puettmann, A. Dodoo, L. Schimleck, and N. Ahn. “Conceptualizing the End of Life for Mass Timber Panel Buildings towards Circularity: Mapping the Gaps in Knowledge.” In Shahnoori S., and Mohammadi M., eds. “The State of Circularity.” The content of the 2nd International Conference on Circular Systems for the Built Environment, Eindhoven, Technische Universiteit Eindhoven, 2022. pp. 55–62.

[13] Ahn, N., C. Bjarvin, M. Riggio, L. Muszyński, L. Schimleck, C. Pestana, A. Dodoo, and M. Puettmann. “Envisioning Mass Timber Buildings for Circularity: Life Cycle Assessment of a Mass Timber Building with Different End-Of-Life (EOL) and Post-EOL Options.” Proceedings of World Conference on Timber Engineering, WCTE 2023, Oslo, Norway, June 19–23, 2023. 7 pp.

[14] ANSI/APA. *ANSI/APA PRG 320-2018 Standard for Performance-Rated Cross-Laminated Timber.* 2018. APA, The Engineered Wood Association, Tacoma, Washington. p. 46.

[15] *Freres Wood*. 2023. Accessed October 1. https://frereswood.com/products-and-services/mass-ply-products/mass-ply-panel/.

[16] CEN EN. *16351:2021: Timber Structures: Cross Laminated Timber: Requirements*. p. 11.

[17] *MHM*. 2023. Accessed October 1. https://www.massivholzmauer.de/en/about-us/sales-offices/locations/mhm-producers.html.

[18] Jauk, G. 2022. “Sustained Strong Growth: Production of Cross-Laminated Timber to Set a New Record: +17% to 1.3 million m³.” *Timber-Online*. Accessed October 1, 2023.

[19] Thoma, E., et al. 2020. Accessed October 1, 2023. “Wood100 Is 100% Wood.” https://www.thoma.at/100-percent-wood/?lang=en.

[20] Nägeli, A., and G. Webstobe. 2019. “APPENZELLERHOLZ.” Accessed October 1, 2023. https://www.naegeli-holzbau.ch/appenzellerholz.html#technische-daten.

[21] *TechnoWood AG*. 2023. Accessed October 1, 2023. https://www.technowood.swiss/en/?jet_download=2187.

[22] *TechnoWood AG*. 2023. “A. and Web-D-Vision: TWOODS: The Solid Wood System.” Accessed October 1, 2023. https://www.technowood.ch/en/solutions/twoods.

[23] *TechnoWood AG*. 2023. Accessed October 1, 2023. https://www.technowood.swiss/en/?jet_download=305.

[24] *Rombach Nur-Holz*. 2023. “Oberharmersbach/DE.” Accessed September 30, 2023. https://www.nur-holz.com/en/.

[25] Weinberg, C. 2021. “Soft-Bank Backed Katerra to Shut Down.” *The Information.com*, June 1.

[26] Guzely, E. 2021. “Mercer Acquires Katerra’s CLT Production Site.” *Timber-Online.net*, August 5.

[27] O’Brien, F. 2023. “Structurlam Mass Timber Company Files for Bankruptcy.” *Western Investor*, April 26.

[28] Ebner, G. 2022 “Sustained CLT Boom Demand for Softwood Lumber Will Pass the 2 Million m³ Mark in 2023.” *Timber-Online.net*, January 18. Accessed February 10, 2022. https://www.timber-online.net/wood_products/2022/01/sustained-clt-boom.html.

[29] Muszyński, L. 2021. “The Global Mass Timber Panel Industry in 2020.” In Anderson R., E. Dawson, L. Muszyński, B. Beck, H. Hammond, B. Kaiser, and C. Rawlings. 2021. *2021 International Mass Timber Report*.

[30] Jauk, G., and E. Guzely. 2020. “Corona Is Not Going to Stop CLT.” *Timber-Online*, May/June. Accessed October 6, 2020. https://www.timber-online.net/wood_products/2020/05/corona-is-not-going-not-stop-clt.html.

[31] OIB. “MHM Wall Element.” European Technical Assessment, ETA-15/0760, by Austrian Institute of Construction Engineering (OIB), Austria, 2017. 24 pp.

[32] Accessed June 4, 2022. https://en.wikipedia.org/wiki/Plywood.

[33] Walsh, F. J., and R. L Watts. Composite lumber. US Patent 1,465,383, patented August 21, 1923.

[34] Ferdinando, J. 2022. “Commodity.” Accessed May 29, 2022. https://www.investopedia.com/terms/c/commodity.asp.

[35] Accessed May 30, 2022. https://www.minda.com/en/solid-wood-industry/high-bay-warehouse.

[36] Accessed May 30, 2022. https://www.sterlingsolutions.com/sterling-locations/.

[37] Bhandari, S., M. Riggio, S. Jahedi, E. Fischer, L. Muszynski, and Z. Luo. “A Review of Modular Cross Laminated Timber Construction.” *Journal of Building Engineering* 68(A), January 2023: 105485.

[38] *EUrban*. 2020. Accessed October 1, 2023. http://www.eurban.co.uk/.

WATCHMAKING WORKSHOP
Credit: Didier Boy de la Tour

CASE STUDY: OMEGA FACTORY

THE OMEGA FACTORY: PROMOTING CRAFTSMANSHIP AND EMPLOYEE HEALTH

PROJECT OWNER: OMEGA S.A.

PROJECT LOCATION: JAKOB-STÄMPFLI-STRASSE 96 BIEL/BIENNE, SWITZERLAND 2502

COMPLETION DATE: FEBRUARY 1, 2017

ARCHITECT/DESIGNER: SHIGERU BAN ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: CRÉATION HOLZ AG , SJB KEMPTER FITZE AG (TIMBER STRUCTURAL ENGINEER)

STRUCTURAL ENGINEER: SCHNETZER PUSKAS INGENIEURE (GENERAL/CONCRETE STRUCTURAL ENGINEER)

MECHANICAL, ELECTRICAL, AND PLUMBING: GRUNER, KIWI, ROSCHI+PARTNERS, HKG ENGINEERING

OMEGA WATCHMAKING DEMANDS specific performance criteria from a building for the sake of craftsmanship as well as employee health. To support the precision of the watchmakers' work, their facilities must be evenly lit and dust-free, with minimal vibration.

The 6-story Omega Factory is a hybrid structure composed of a rigid concrete core running the length of the middle third of the building, flanked by timber-framed watchmaking workshops and offices that are 10.5 meters deep. The core contains stairs, elevators, and restrooms, as well as an automated storage system known as the Central Stock. Two vertical lifts retrieve watchmaking components from an inventory of 30,000 boxes and deliver them directly to the watchmakers via conveyors.

Spruce glulam columns are spaced every 5.4 meters along the perimeter, and they're connected to spruce glulam girders by two circular beech Laminated Veneer Lumber (LVL) dowels. The column-and-beam joints have no metal hardware, a feat that requires a high level of engineering and fabrication accuracy. The joints are similar to the elliptical beech dowel joints used at the Tamedia Headquarters (Shigeru Ban Architects, Zurich, Switzerland, 2013), but simpler because circular dowels are more industrial and less expensive to fabricate. In both buildings, beech—a hardwood—was selected for its superior rigidity.

The floor slabs have a hybrid approach as well. A 100 millimeter-thick, in situ, reinforced concrete topping was added to the Cross-Laminated Timber (CLT) structure to increase its weight, thereby reducing building vibrations. Pursuing a heavier building is counterintuitive—typically, it is less expensive and more efficient to design structures to be as light as possible—but watchmakers are highly sensitive to movement, warranting the addition.

Within a workshop, it is important to balance technical requirements with the employees' comfort. Cleanliness is paramount for this type of production facility, and its clean room construction is unprecedented for a timber building. A significant volume of air exchange is needed to maintain a dust-free environment.

Increasing a ventilation system's speed of supply and exhaust is known to cause health concerns, such as those resulting from dryness. It also creates a noisy environment.

FACTORY CONSTRUCTION
Credit: Philipp Zinniker / Itten+Brechbühl

SOUTHEAST FACADE WITH LOADING DOCK
Credit: Didier Boy de la Tour

Perforated drop ceiling panels were designed to supply a great volume of air across a broad surface area at a slower speed. The air exhausts out at the floor level, creating one-way airflow to further minimize the circulation of dust.

The Omega Factory has a bright and open interior with ample daylight. The floor-to-ceiling glazing boasts stunning views of the town and landscape, a visual reprieve from the detailed tasks of watchmaking. To facilitate this work, the facade needed to be as clear as possible, with low-iron glass permitting unpolarized natural light. The glazing's lack of color distortion has the added benefit of improving the timber structure's visibility from the exterior.

DLT CRAFTED WITH RECLAIMED LUMBER
Credit: Paul Mayencourt

CASE STUDY: RECLAIMED WOOD IN DLT

HERITAGE AND INNOVATION FOR DLT

PROJECT OWNER: URBAN MACHINE

PROJECT LOCATION: 1070 40TH ST, OAKLAND, CA 94608

COMPLETION DATE: OCTOBER 15, 2023

ARCHITECT/DESIGNER: PAUL MAYENCOURT

MASS TIMBER ENGINEER/MANUFACTURER: ALL BAY LUMBER

URBAN MACHINE'S COLLABORATION with the University of California, Berkeley, and All Bay Lumber is reshaping sustainable building materials by focusing on integrating reclaimed wood into Dowel Laminated Timber (DLT).

DLT is renowned for its sustainability, relying on minimal glue usage. Introducing reclaimed wood further amplifies this eco-friendly mass timber solution.

Using reclaimed lumber reduces waste and minimizes the need for tapping into new resources. By reusing old-growth wood, Urban Machine honors forests and extends trees' life spans in the built environment. This practice not only champions ecological responsibility but also preserves the natural beauty of the wood.

Old-growth wood is durable and resilient. Incorporating reclaimed old-growth wood into DLT

DLT MADE WITH RECLAIMED WOOD, READY FOR ASSEMBLY

Source: All Bay Lumber's warehouse
Credit: Jorie Wisnefski

RECLAIMED OLD-GROWTH WOOD IN DLT

Credit: Paul Mayencourt

panels ensures that these qualities are retained in the final product. This is a crucial aspect of mass timber construction, as the strength and reliability of the materials used are paramount to the success and safety of the structures.

By using reclaimed lumber, Urban Machine, UC Berkeley, and All Bay Lumber are championing a circular economy. Wood that is typically bound for landfills or other, less sustainable fates now can live another life in construction projects as premium lumber.

By combining innovative technology and sustainable design, Urban Machine, UC Berkeley, and All Bay Lumber are reclaiming wood as just one step in a broader mission to build more responsibly and ensure good lumber is not wasted.

The evolving collaboration between Urban Machine and UC Berkeley underscores the importance of sustainable materials and innovative techniques in the construction field. Reclaimed wood in DLT isn't just a building material; it's a symbol of the profound potential for change, for reimagining the ways we construct our world.

GLOSSARY

Introducing the Mass Timber Terminology Glossary.

Consistent with the educational focus of the International Mass Timber Report and recognizing that not all readers are mass timber experts (yet), we think that it is important to identify and define the many unusual terms that are used in this report and that can also be useful in understanding the mass timber movement. For each term included, we offer a short definition and a note as to the chapters of the report where you will find more detail. In future iterations, we are considering offering a complete index of all locations within the report where each term is referenced.

While we hope that you find this Glossary informative and helpful, it does have some limitations. First, this is our initial effort, and we anticipate it growing over time. We focused on specific terminology used in the report and are sharing our understanding of the terms as they are used here. There may very well be other, more accurate or comprehensive definitions of these terms out there, and we have no argument with that.

Second, this is not (yet) presented as a complete list of all the important terminology as it pertains to mass timber. We had to deal with limitations of time and the allocation of space and chose to address what we feel are the most important terms used in this report. Going forward, we invite your input on what additional terms should be added and how the definitions we offer might be expanded. Please share your feedback at masstimberreport.com.

Thank you for your continued support of the International Mass Timber Conference and the International Mass Timber Report. We hope you find this new tool useful and look forward to its continued development—with your help.

actual lumber size — actual sizes for lumber. For example, a 2-by-4's actual thickness is 1.5 inches and actual width is 4 inches. Refer to chapters 1 and 3 for more details.

bio-based — term describing materials primarily derived from living matter that have grown via photosynthesis. Refer to chapters 5, 9, and the essay "Urban Carbon Sinks" for more details.

biogenic carbon — nonfossil carbon that is part of the carbon cycle from the atmosphere to plants and back. Refer to chapter 9 for more details.

biophilia/biophilic — the innate human love for natural forms. Refer to chapters 7 and 8, and the essay "Urban Carbon Sinks," for more details.

biophilic design — a concept used within the building industry to increase occupant connectivity to the natural environment through the use of direct nature, indirect nature, and space and place conditions. Refer to chapters 1, 7, and 8 for more details.

board foot — common unit of measurement for lumber; 1 board foot equals 1 inch thick by 12 inches wide by 12 inches long. Refer to chapter 1 for more details.

carbon footprint — an informal term used to describe the net greenhouse gas emissions associated with an entity or event (a building, a trip, etc.) over a given time period. Refer to chapters 5, 9, and 10, and the essay "Urban Carbon Sinks," for more details.

carbon sinks or sequestration — the natural or artificial absorption and storage of carbon for a period of time. Refer to chapter 9 and the essay "Urban Carbon Sinks" for more details.

carbon storage — the carbon stored in wood as it's used in a building. Refer to chapter 9 and the essay "Urban Carbon Sinks" for more details.

carbon substitution — the carbon avoided by using a product with a lower embodied carbon content instead of a more carbon-intensive product. Refer to chapter 9 for more details.

circular economy — a system where a waste material from one process or product is a viable nutrient for another, natural or industrial. Refer to chapters 8 and 9, and the essay "Urban Carbon Sinks," for more details.

Computer Numerical Control (CNC) — a digital process that translates component designs directly into automated instructions for manufacturing equipment. Refer to chapters 4, 6, and 10 for more details.

cubic foot — common unit of measurement for mass timber product volume. Refer to chapter 1 for more details.

cubic meter — common unit of measurement for mass timber product volume. Refer to chapter 1 for more details.

cunit — a method of log measurement; 1 cunit equals 100 cubic feet of log volume. Refer to chapter 1 for more details.

decarbonization — the process of reducing net carbon dioxide emissions created by a process or product. Refer to chapters 8 and 9 for more details.

Design for Disassembly (DfD) — a method employed during the design of a building to improve the salvage potential of the building's materials at the end of the building's life. Refer to chapter 8 for more details.

Design for Manufacture and Assembly (DfMA) — a method employed during the design of a building to improve the efficiency of manufacturing the building components in a factory, and in turn, assembling those components on-site. Refer to chapter 10 for more details.

design-phase forward planning — creating a building by putting more resources (time, money, collaboration) into the planning and design process (the lowest-risk time of the project) to minimize changes during construction (the highest-risk time of the project). Refer to chapters 5, 6, and 8 for more details.

dimension lumber — the standard predimensioned wood used in wood-frame construction, including walls, floors, and roofs. One and a half inches thick and of various lengths and widths, it is the structural softwood lumber used in most wood-based housing construction in North America. Refer to chapters 1, 3, and 10 for more details.

dimensional stability — in reference to mass timber structural elements, the ability to resist dimensional changes due to changing moisture content. Refer to chapters 1, 5, and 6 for more details.

embedded carbon — the carbon stored in a product or building. Refer to chapters 5, 6, 8, and 9 for more details.

embodied energy/carbon — the greenhouse gas emissions from upstream stages of a product's life, such as extraction, production, transport, and construction. Refer to chapters 5, 6, 8, and 9 for more details.

encapsulation — a complete, undisrupted barrier between a building component and an integral threat, such as fire or water. Refer to chapters 5 and 8 for more details.

end-of-life value — the potential of an asset to retain value or become a liability at the time it is no longer useful in its current form. Refer to chapters 8 and 9 for more details.

Engineered Wood Products (EWP) — a class of wood-based composites that can be used for fabrication of structural (load-bearing) elements in buildings. Refer to chapters 1, 4, 5, and 10 for more details.

forest certification — a process that assures the public that the benefits and functions of the forest, including clean air and water, wildlife and plant habitats, soil health, and recreation, are maintained or protected during management and harvest. Forest certification identifies land that is managed with a goal of sustainability. Refer to chapters 2 and 9 for more details.

forestland — forests that are less well-stocked with trees (i.e., tree cover accounts for only 5 percent to 10 percent of the area) and where timber harvesting is prohibited (wilderness, roadless, national park, etc.). Refer to chapter 2 for more details.

growth-to-drain — a ratio of the amount of wood fiber a given area of forest can grow annually to the amount that is removed annually from the combination of natural mortality (insect, disease, fire) and timber harvesting. Refer to chapter 2 for more details.

hygroscopic — able to absorb moisture from the environment. Refer to chapters 5 and 7 for more details.

International Building Code (IBC) — the International Building Code (IBC) establishes minimum requirements for building systems using prescriptive and performance-related provisions. It is founded on broad-based principles that make possible the use of new materials and new building designs. Refer to chapters 1 and 5 for more details.

just-in-time delivery — materials delivered to a site immediately prior to installation to reduce or eliminate on-site materials storage and handling. Refer to chapters 6, 8, and 10 for more details.

kit-of-parts construction — a precision building component system designed to be assembled quickly on-site. Refer to chapters 5, 6, and 8 for more details.

lamination — piece of sawn lumber or structural composite lumber, including stress-rated boards, remanufactured lumber, or end-joined lumber, prepared and qualified for production of glulam or mass timber panels. Refer to chapter 10 for more details.

lamstock — a special grade of lumber manufactured for use in glulam beams that has been selected for minimal defects and high strength/stiffness and that is dried to a lower moisture content.

Life Cycle Analysis (LCA) — the methodology for assessing the environmental impacts of making a product. Refer to chapters 5, 8, and 9 for more details.

light frame construction — a type of building construction that uses dimension lumber and engineered wood that is regularly spaced and fastened together with nails to create floor, wall, stair, and roof assemblies. As they are fastened together, the wood components form the structure of a building, much like a skeleton. Refer to chapters 3 and 10 for more details.

microbiome — the collective of a group of microorganisms in any given place, for example, on the surface of a material or in the air of a space. Refer to chapters 5, 7, and 8 for more details.

modular construction/design/modularity — the design and construction of large, complex, multitrade building components that maximize prefabrication techniques. Refer to chapters 5, 6, 8, and 10 for more details.

moisture content — amount of water contained in a sample of a material expressed as a mass fraction of either oven-dry mass of the material (oven-dry base) or the mass of the material with water (green-base). Refer to chapters 5 and 10 for more details.

multifamily — a classification of housing where multiple separate housing units for residential inhabitants are contained within one building. Refer to chapter 3 for more details.

multitrade components — components that arrive on-site with preassembled materials or systems that would require multiple specialized skills or subcontractors to assemble on-site. Refer to chapters 5 and 6 for more details.

nominal lumber size — lumber's size in name only. For example, a 2-by-4 is not really 2 inches thick by 4 inches wide. Refer to chapters 1 and 3 for more details.

nonresidential — any commercial, industrial, institutional, public, or other building not occupied as a dwelling, including hotels and motels. Refer to chapter 3 for more details.

off-site construction/prefabrication — the fabrication of building components at a location other than the construction site, usually with more controlled installation conditions and not contingent on the sequencing of other trades. Refer to chapters 5, 6, 8, and 10 for more details.

panelized construction — large, planar building components, sometimes multitrade. Refer to chapters 5, 6, 8, and 10 for more details.

renewable material — material made of resources that can be replenished at a pace equal to or greater than the pace of harvesting. Refer to chapters 5 and 9, and the essay "Urban Carbon Sinks" for more details.

resilience/resiliency — a building's ability to recover from a disaster such as an earthquake, fire, hurricane, or flood; uncompromised recovery, retrofit, or repair after a disaster. Refer to chapters 6, 7, 8, and 9, and the essay "Urban Carbon Sinks," for more details.

tall timber/tall wood buildings/high-rise construction — a structure over 6 stories (the top occupied floor is more than 75 feet above the fire department access point). Refer to chapters 5, 6, 8, and 10 for more details.

timberland — forests that are well-stocked with trees and capable of producing at least 20 cubic feet of wood fiber per acre per year, and where timber harvest is not restricted. Refer to chapter 2 for more details.

volumetric modular — three-dimensional building components large enough to inhabit. The size of volumetric modular building components is dictated by transportation limitations. Refer to chapters 5 and 6 for more details.

Whole Building LCA (WBLCA) — the methodology for assessing the environmental impacts of constructing a building. Refer to chapters 8 and 9 for more details.

MEET THE AUTHORS

ROY ANDERSON

VICE PRESIDENT
THE BECK GROUP

Dr. Roy Anderson has more than 30 years of forestry and forest products experience. He has helped hundreds of clients plan, develop, and improve forest-based businesses, including mass timber and glulam manufacturing. Roy spoke about the mass timber supply chain at the 2016, 2022, and 2023 International Mass Timber Conferences, and he has been part of the report's author team since its inception.

EMILY DAWSON

ARCHITECT | OWNER
SINGLE WIDGET

Emily is a licensed architect and implementer of bio-based structural solutions with over 20 years of experience in the construction industry. She has been promoting mass timber topics since 2013, after designing the first Cross-Laminated Timber structure built in Oregon. Inspired by her studies of European mass timber, Emily increasingly applies off-site fabrication approaches in her work. Successfully leading design teams to innovate in multiple sectors has given her a broad view of the industry, as well as a passion for breaking boundaries in the profession.

DAVE ATKINS

SUSTAINABILIST,
FORESTER,
ECOLOGIST, WRITER

Dave introduced US Forest Service leaders to Cross-Laminated Timber in 2010 and helped launch their participation in its development. He retired from the USFS in 2014 but continues to work at the nexus of forest management and wood products to help create the balance of social, economic, and environmental needs of a carbon-neutral society—from biochar to mass timber to resilient, sustainable forests.

LECH MUSZYNSKI

PROFESSOR
OREGON STATE UNIVERSITY

Dr. Lech Muszynski is a professor in the Department of Wood Science and Engineering at Oregon State University. A native of Poland, he received his MS in wood technology and PhD in forestry and wood technology from the University of Life Sciences in Poznań, Poland. Lech joined OSU in 2004. Since 2010, one of the focus areas of his research has been the Cross-Laminated Timber (CLT) technology and other mass timber panel (MTP) products. Lech has toured MTP manufacturing plants, construction sites, MTP-focused research centers, and related businesses across the globe.

ERICA SPIRITOS

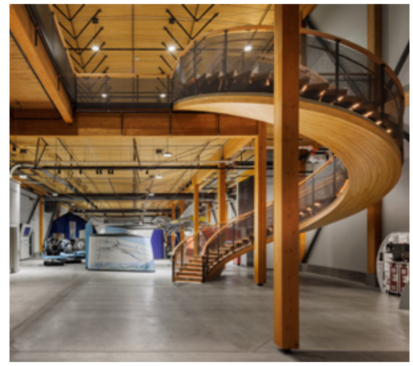
GROWING REGIONAL MASS TIMBER ECOSYSTEMS

Erica Spiritos has been working to advance the use of mass timber in commercial construction for a decade and is focused on the development of regional mass timber ecosystems across the United States. Erica was cofounder and vice president of Timberlab, where she helped to deliver precedent-setting projects including the PDX International Airport expansion, Ascent, and Heartwood.

BRYAN BECK

PRESIDENT
THE BECK GROUP

Since graduating with a forest products degree from Oregon State University, Bryan has been working in the forest products industry for more than 25 years. As president of The Beck Group for the last 10 years, Bryan leads the firm's benchmarking, merger and acquisition, business valuation, and capital project planning services. He has also led several Cross-Laminated Timber and glulam feasibility studies.



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ADVERTISERS INDEX

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