2025

MODULAR MASS TIMBER UNITS ARE BEING INSTALLED FOR WORKFORCE HOUSING IN BIG SKY, MONTANA.

INTERNATIONAL MASS TIMBER REPORT

INTERNATIONAL MassTimber CONFERENCE

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LEFT — INTERIOR OF THE KALESNIKOFF MANUFACTURED MODULAR UNITS
Source: IDcubed

RIGHT — MODULAR UNIT ON THE FACTORY FLOOR
Source: Kalesnikoff

ON THE COVER

THE KNIGHT BUILDING, LOCATED WITHIN the famous Buck's T-4 campus in Big Sky, Montana, is the first large-scale modular mass timber building in the United States. The owner, Lone Mountain Land Company, embarked on the project with the goal of creating better-quality housing for their community. Faced with the challenge of construction labor shortages, the company embraced innovation via modular mass timber.

Composed of 120 Cross-Laminated Timber (CLT) modules, the building will provide high-quality workforce housing for 96 workers. Integrated Design Cubed (IDCUBED), a company that had worked for more than a decade to bring modular mass timber to North America, developed the strategies for module assembly, using processes established by its Austrian and German partners.

Produced and assembled by Kalesnikoff Mass Timber in a factory in Castlegar, British Columbia, the modules were delivered to the site with mechanical, electrical, plumbing (MEP) systems, finishes, and fixtures preinstalled to reduce the overall construction timeline. The CLT, exposed on most walls, provided for a beautiful and durable natural finish. IDCUBED designed the building and the modules, utilizing Virtual Design and Construction (VDC)/Building Information Modeling (BIM) technologies to plan and document all building systems in full detail, from structural connectors to plumbing subassembly components.

Mass timber's inherent precision, dramatically simplified assembly, and the integrated planning, from foundation to finish, contributed to the project's on-track delivery. Highline Partners completed all work on-site, including laying foundations, setting the modules, and finishing the building. The collaborative effort of all involved has been the key to the success of the project, which is scheduled to be completed in April 2025.


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Douglas Fir | Alaskan Cedar | Southern Yellow Pine
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PUBLISHER'S MESSAGE

IF YOU ARE AT THE INTERNATIONAL MASS Timber Conference in 2025, you are likely holding in your hands a printed copy of the *International Mass Timber Report*. Obviously, we are very excited to distribute hard copies once again at this year's conference. Digital and additional print copies will be available afterward.

As always, we continue to look for ways to improve the report.

The Mass Timber Performance Index is newly updated with capacity, production, and price estimates for glulam products in addition to the Cross-Laminated Timber (CLT) information we have provided for the past few years.

We have a tremendous variety of great case studies to share again this year. Thank you to those who submitted case study proposals; we are sorry we didn't have the space to include them all.

You may notice we have tapped a variety of new contributors to assist with keeping the core material (chapters 1–10) up to date. This allows us to share some new perspectives and make sure the information is the latest and most accurate we can make it.

Finally, if you haven't visited recently, make sure you check out our updated digital presence at MassTimberReport.com. Quite a bit of our archival material from past reports has been posted. We are working on some new ideas as well, so check back often.

As always, we welcome your feedback at MassTimberReport.com, or contact me directly at dparcell@masstimberconference.com.

David Parcell

Dave

Publisher

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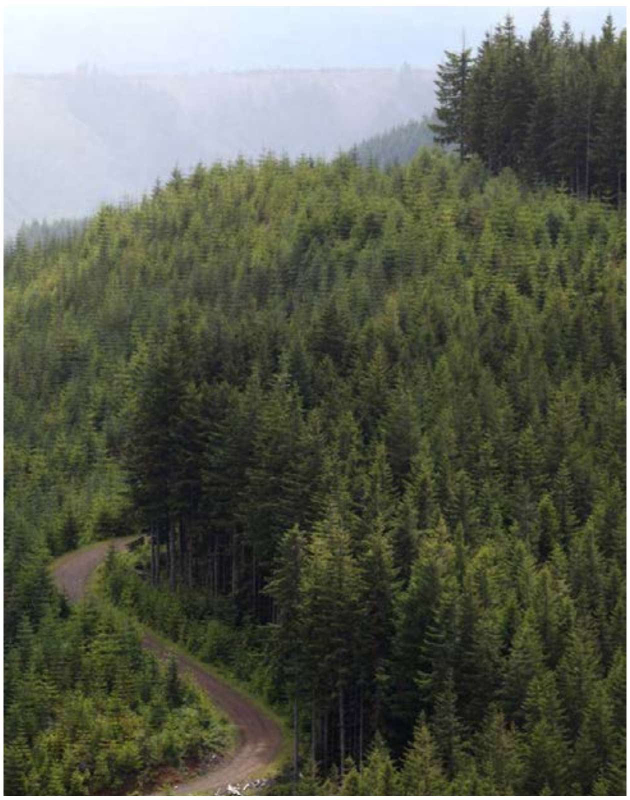
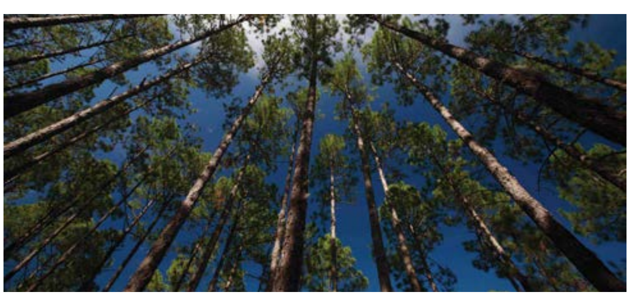




WEYERHAEUSER

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.

ARE WE THERE YET?

CLOSING THE GAP, REMOVING BARRIERS: THE ROLE OF AI AND AEC SOFTWARE

Our ambition is to change the industry,
not just build cool tools that make people 5% faster.

—Matt Campbell, Hypar[1]

WILL HILDESLEY
+coordinates strategy

CLOSING THE GAP

Three strategies have emerged as the mass timber ecosystem seeks to resolve product-market fit, level the playing field, and "close the gap"—real or perceived—with traditional construction pricing and risk management: standardization, productization and customization.

1. **Standardization:** Limit choice, maximize predictability
2. **Productization**: Buildings as products and platforms
3. **Customization**: Exploit mass timber's unique Computer Numerical Control (CNC) efficiencies

Each route has the potential to address persistent barriers to adoption. Each also has benefitted tremendously from developments in automation; machine learning; and Architecture, Engineering, and Construction (AEC) design tech. And each will find ways to exploit the rapid evolution of artificial intelligence (AI).

Whether helping to remove friction, improve predictability, reduce risk, or facilitate collaboration, advances in these technologies have made significant headway, chipping away at legacy dynamics that restrict innovation in AEC.

These advances are impressive, but in isolation they remain essentially incremental. The AEC sector is the poster-child tortoise in Aesop's fable, not least because plenty of wise "tortoises" throughout the industry can readily point to early-adopter hares who met their untimely ends by jumping on new technologies.

Emerging leaders who have successfully navigated the roller-coaster ride of mass timber's adoption curve to date may be best served by blending these animals' character traits. Addressing the significant remaining barriers to scaling mass timber will continue to demand the bold embrace of new approaches and technological innovation. But those at the coalface challenging the legacy habits of a highly conservative, risk-averse construction sector are also forced to accept its realities: if there's a revolution coming in AEC, it won't be happening overnight.

1 Hypar is a cloud-based design platform aimed at streamlining design and construction workflows founded in 2018 by Ian Keough and Anthony Hauck.

Will mass timber's unique properties as a construction material play a role in unlocking the ingenuity necessary to reshape an entire industry?

The question summons a tantalizing 2-part prospect: (1) Will rapid advances in AI and AEC tech themselves help remove remaining barriers to mass timber's adoption, closing the gap on the actual or perceived benefits and pricing of traditional construction? (2) In doing so, will an evolving combination of these emerging technologies and mass timber's unique characteristics help unleash a wholesale reimagining of how the AEC community envisions, designs, constructs, and collaborates?

TACKLE THE MONKEY FIRST

Some of the constraints on mass timber's uptake represent generic challenges typical of any new technology or innovation, others are more specific to the AEC and forest sectors, and the remainder are unique to the properties and evolution of mass timber and Cross-Laminated Timber (CLT) as a product.

Closing the gap with traditional construction methods and accelerating adoption of mass timber requires accurately identifying these barriers, grappling with their practical implications effectively, and assuring consumers that they have been tackled comprehensively.

In broad terms, 3 interventions have emerged to take on the barriers: (1) early adopters prepared to assume a degree of risk while pushing the envelope, (2) "accelerator" organizations convening or coordinating efforts across the value chain, and (3) AEC tech developers exploiting rapid advances in robotics, machine learning, design tech, and AI that introduce new efficiencies, improve collaboration, remove friction, or tackle legacy approaches.

Alphabet's Moonshot Factory X was intentionally designed from the ground up to systemize innovation within its culture and business practices; it is essentially a constraint removal machine.[2] To that end, team members are frequently admonished to stay relentlessly focused on the hardest challenges inherent to any project by "tackling the monkey first."[3]

As X's CEO Astro Teller says, when tasked with teaching a monkey to stand on a pedestal and recite Shakespeare, it might feel productive to start by building the pedestal: demonstrate progress to your peers and enjoy the dopamine hit of checking a task off the to-do list. Meanwhile, the riskiest, most critical challenge remains precisely as hard as it was on day one. You still have to teach a monkey to recite *Hamlet*, and that didn't get any easier while you spent valuable time and resources building your pedestal.

The rank order may vary according to budget, building typology, or client, but the key barriers to adoption for mass timber appear to maintain considerable fidelity across geographies. Ask any developer, insurer, architect, or general contractor to play "barrier bingo," and you'll see remarkable consistency: the mass timber community still has a troop of recalcitrant monkeys to deal with, barriers demanding focused attention and collaborative effort to resolve.

2 For a fascinating look under the hood of what this approach implies, see "The Gimbal" at https://storage.googleapis.com/x-prod.appspot.com/files/the_x_gimbal_v2.10_web.pdf.

3 Medium, "Tackle the Monkey First," https://blog.x.company/tackle-the-monkey-first-90fd6223e04d.

Dealing with these barriers may not be as hard as teaching monkeys to recite Shakespeare, but dealing with the practical implications and ensuring consumers perceive that they have been addressed remains an ongoing task.

ARE WE THERE YET? IDENTIFYING THE BARRIERS.

With the support of the US Forest Service, the Mass Timber Tipping Point, a 2-year endeavor led by Pilot Projects and Architecture 2030, convened North American architecture, engineering, construction, and planning firms to explore and better understand the full range of views, visions, and challenges of the use and uptake of mass timber projects. The project involved 43 firms representing over 409 North American offices, providing a snapshot of North America's mass timber landscape.

Asked to list reasons behind a client requesting or agreeing to use mass timber in their projects, factors such as aesthetics, environmental goals, and carbon reduction led responses. Asked which factors prevent consideration, the firms pointed to cost for the firm and the client, and/or a lack of available and suitable material. Asked what major challenges they face in utilizing mass timber, they highlighted factors such as cost, material availability, risk-averse clients and partners, design knowledge gaps, and a lack of experience.

Erica Spiritos, a contributor to the project (and to this report) and Director of the Washington State Mass Timber Accelerator (Masstac), shares her summary of key barriers to accelerated adoption of mass timber, below:

1. **Cost premium:** Mass timber is still often believed to be a more expensive option than concrete and steel construction.
2. **Learning curve**: It takes time and commitment to learn a new structural system and a new process to deliver it to market.
3. **Carbon accounting:** We lack standard approaches to assessing the carbon impacts of mass timber construction.
4. **Insurance coverage:** A scarcity of affordable insurance coverage prevents owners from choosing mass timber.
5. **Supply stalemate:** The perception of limited supply, paired with low utilization of operating manufacturing facilities, thwarts progress.
6. **Market forces:** Tariffs, subsidies, exchange rates, and relative industry maturity result in a higher cost of regional mass timber relative to imported products.

We can debate the contents of the list, its ranking, or the relative weight of one barrier versus another, but it provides a simple, practical framework to ask the relevant follow-up question: What part will the growing investment in and rapid evolution of AI and AEC tech play in removing these barriers, accelerating adoption, and helping close the gap on traditional construction?

THE GOALPOSTS: WHAT CAN AI AND AEC TECH BRING TO THE TABLE?

Rapid escalation in the development of AEC software reflects 5 trends relevant to mass timber's adoption:

1. **Global construction spending is projected to grow from $13 trillion in 2023 to $22 trillion in 2040.[4] Production efficiencies are essential to meet this demand.**
2. An estimated $50 billion was invested in AEC tech from 2020 to 2022, an 85 percent increase over the previous 3 years.[5]
3. AEC software that is either "mass timber enabled" or, in a couple of cases, "mass timber specific" is finally emerging to enable the standardization, productization, and customization pathways.
4. Generative AI and related technologies, including large language and diffusion models, are rapidly evolving.
5. Recognition of the potential to reduce carbon emissions by looking for ways to improve carbon accounting throughout construction's value chain is growing.

Stjepan Mikulić, founder of AEC AI Hub, tracks the growth of AEC-related AI applications. As of December 2024, his database includes 1,500 sector-specific entries. He notes that many companies he currently works with face a common dilemma: getting lost in the plethora of options, choosing not to engage with AI at all, or going all in and taking on too many initial projects to handle.

His advice? Start with one problem central to a firm's priorities that will benefit from these technologies' primary capacities:

- Enhancing project delivery
- Reducing repetitive tasks
- Improving analysis of large datasets

Asked to summarize how advances in AEC tech are revolutionizing mass timber, a basic prompt to Anthropic's Claude 3.5 provides the following list:

1. Improved interoperability, integrated design, and collaboration
2. Parametric design optimization
3. Using diffusion models for form finding and rapid prototyping
4. Advanced finite element analysis and machine learning
5. Digital fabrication and robotic assembly
6. Project management and supply chain optimization

In an October 2023 ArchDaily article,[6] Marília Matoso lists 11 categories in which AI can complement and enhance the work of architects more specifically: "Just as Revit and 3D Software did not replace architects but only transformed their workflows, the same principle holds for AI tools. AI is poised to bring about new tasks, such as AI management, alongside existing responsibilities, signaling a shift in how architects work."

1. Design options based on specific criteria

4 McKinsey & Company, "Delivering on Construction Productivity Is No Longer Optional," August 9, 2024, https://www.mckinsey.com/capabilities/operations/our-insights/delivering-on-construction-productivity-is-no-longer-optional.

5 McKinsey & Company, "From Start-Up to Scale-Up: Accelerating Growth in Construction Technology," May 3, 2023, https://www.mckinsey.com/industries/private-capital/our-insights/from-start-up-to-scale-up-accelerating-growth-in-construction-technology.

6 Marília Matoso, "Will Artificial Intelligence Replace Architects?" ["A inteligência artificial vai substituir os arquitetos?"] ArchDaily, (Trans. Simões, Diogo), October 18, 2023.

2. Site analysis and mass studies
3. Generative design
4. Pattern recognition
5. Coding (custom apps, programs, and plug-ins)
6. Energy efficiency and sustainability
7. Data summarization
8. Building maintenance
9. Building Information Modeling (BIM) and project management
10. Virtual reality and augmented reality
11. Cost estimation and material selection

With this basic introduction to the breadth of possibilities being explored, we can turn to current-use cases and make a relatively superficial examination of the emerging Venn diagram. Given the state of advances in these technologies, who is breaking new ground as relevant providers to the mass timber value chain, and how are their products being employed to reduce barriers to adoption?

ON DECK: CURRENT APPLICATIONS OF AEC TECH AND AI

The landscape of technology in construction is evolving rapidly, with AI-informed solutions filling out the roster of applications in project software, field solutions, building tech, reconstruction, and robotics.[7]

Although the transformation of all of these disciplines will continue to impact mass timber projects, perhaps the most transformative impacts will be those that either address specific barriers to adoption or are built from the ground up to service mass timber's value chain. While it is beyond the scope of this article to address the potential to overcome every barrier, we can sample the playing field by looking at how AI is breaking ground in carbon accounting and cover emerging mass timber applications for pointers.

Sourcing and Carbon Accounting

Tangible's offering streamlines data collection to provide real-time carbon data, smart recommendations to help users find opportunities to cut carbon and cost at different construction stages, and real-time data on specific buildings and portfolios to meet regulatory requirements and sync up with other sustainability data.

Pathways has set out to "build the data layer needed to decarbonize manufacturing." Using proprietary AI to parse, extract, and transform customer data, Pathways takes raw data about raw materials, transportation, and manufacturing processes and creates real-time Environmental Product Declarations (EPDs) and Life Cycle Analyses (LCAs).

Cove is a full-service sustainability consultancy leveraging a simulation engine and AI that has been used across 60,000 projects worldwide, providing services such as analysis of embodied carbon, sustainability analysis, and certification and compliance services.

7 BuiltWorlds, "25 AI-Powered Solutions Transforming the Built World," https://builtworlds.com/news/25-ai-powered-solutions-transforming-the-built-world/.

Mass Timber-Specific Tech

Given the risk and switching costs of changing design tech and the limited availability of applications that incorporate CLT-specific models and data, practitioners across the board are still turning to tools originally designed for steel and concrete applications. Providers such as **Dlubal** have made inroads with tools such as **Rfem** by making sure they include CLT-specific data and models. Others have gone a step further—building out tools designed from the ground up to fully integrate mass timber construction.

Founded in 2021 by a cross-disciplinary team at Massachusetts Institute of Technology (MIT), **Generate** has assembled a team of architects, engineers, and computer scientists to deliver a platform that allows project teams to design and iterate in a “code, cost and carbon-aware space.”

Generate promises to streamline mass timber design by rapidly generating design options and then identifying suitable systems for a specific project. The platform will automatically compile a quoting package using an automated digital workflow and then connect clients with suppliers for competitive bids. Generate will also analyze suppliers’ bids, providing comparisons and highlighting differences in scope.

Branch, a software start-up nested directly within StructureCraft’s engineering team, may represent the most ambitious attempt yet to create an end-to-end design tool that blends real-time structural analysis with fabrication, seamlessly integrating design and construction in one cohesive platform.

Branch's development has benefitted tremendously from its development "in house" and real-time feedback from StructureCraft's project teams.

The Branch platform has already been used to deliver more than 1 million square feet of timber construction. The platform aims to allow all stakeholders—from owners and architects to engineers and fabrication experts—to collaborate in a unified design space, enabling real-time cost and carbon feedback on design changes, and exploring high-level design concepts like building massing while instantly understanding the impacts of those changes on shop drawings, bills of materials, and CNC files.

Marne Zahner, Branch's director since 2022, has had a front-row seat to see how new AI models impact these developments and the work of his team. He notes that the degree to which AI is changing different aspects of the development game in mass timber applications parallels its use in other scenarios and domains. Just as many engineers, insurers, or general contractors have limited experience working with CLT, training datasets for AI have extremely limited access to mass timber case studies. Accordingly, when the Branch team is working on aspects of development that are CLT-specific, AI doesn't tend to bring its A game. In contrast, for aspects of development where coding problems are more generic, such as user interface design or queries, AI is already proving to be a game changer.

Where Zahner sees the greatest leaps in current applications of AI is customization. Although customizing AEC software to perform specific operations used to require deep domain knowledge and wizard-level coding skills, AI is making customization plausible for more general users. He highlights **CLT Toolbox** as doing extraordinary work filling gaps in mass timber-specific models and points to the data-wrangling capacities of programs such as **Speckle** as a great example of the potential to impact AEC tech and its development.

PULLING ON THE AEC TECH THREAD

Aaron Willette, now director of digital fabrication for Fabric Workshop Mass Timber, has worked with the likes of Intelligent City, WeWork, and Apple. He specializes in the integration of design, technology, and advanced manufacturing but proved in our interview that his real superpower is explaining the implications of AEC tech to those of us peering naively into that world from the outside.

His response to the question of how AEC tech will help mass timber close the gap with traditional construction was eloquent:

"In the long run, AEC tech is the thread by which all of this gets pulled together and we solve these remaining barriers. We're getting there, but it's a long and necessarily incremental process. In the short run, the implications should be equally clear: we all need to take hold of that thread and keep pulling."

Links

Branch: https://www.branch3d.com/

CLT Toolbox: https://clttoolbox.com/

Cove: https://cove.inc/

Fabric: https://fabricmasstimber.com/

Generate: https://www.generate.design/

Pathways: https://pathwaysai.co/

Rfem (Dlubal): https:// dlubal.com

Speckle: https://www.speckle.systems/

Tangible: https://tangiblematerials.com/

PARTNER **SPOTLIGHT**

The Urban Land Institute (ULI) Northwest and the Randall Lewis Center for Sustainability have partnered with the International Mass Timber Conference to curate a developer-focused educational track for the second consecutive year. This collaboration highlights the growing importance of sustainable practices in the built environment and the role of mass timber in driving innovation within the real estate industry.

ULI Northwest, serving the Oregon and Washington regions, is dedicated to advancing the adoption of mass timber as a cornerstone of a more sustainable and innovative built environment. With Cascadia's rich history of timber production and export, the region is uniquely positioned to lead in the development of this renewable and efficient building material, supporting both environmental goals and economic growth.

The ULI Randall Lewis Center for Sustainability in Real Estate leads the real estate industry in creating places and buildings where people and the environment thrive. In collaboration with ULI members and partners, the center drives industry transformation, cultivates leaders and champions, and helps foster solutions for sustainable, resilient, healthy, and equitable cities and communities. The center pursues these goals via cutting-edge research, global convenings, community technical assistance, and other strategies.

The center's core programs are:

- Decarbonization: Accelerating progress toward net zero with operational and embodied carbon real estate solutions.
- Healthy Places: Advancing health and social equity in real estate practice, and helping cities and communities foster inclusive well-being.
- Urban Resilience: Ensuring that buildings, cities, and communities are better prepared for the impacts of climate change.

The center is also home to ULI Greenprint, a global alliance of real estate companies dedicated to improving the environmental performance of buildings and enhancing real estate value.

EVERYTHING BUT THE SHADE

EMILY DAWSON, AIA
OWNER, Single Widget | Field Edge

I'M NOT ALONE IN HAVING MADE DUBIOUS social media-driven purchases. A tree-free toilet paper subscription seemed like a great idea during the pandemic. But researching this article put that small choice in a different light. The foresters I spoke with all had the same thing to say: markets for low-grade fiber (which can go into making paper products, for example) create the opportunity to practice better forestry. Without these markets, foresters lose a crucial tool. Just as chefs aim to "use the whole cow" to minimize waste, the forest products industry strives to use every part of a tree.

USING THE WHOLE COW

It turns out that it is easy to find uses for every part of the "cow," but harder to find customers for some of the parts. A 2012 report by Dovetail Partners Inc. notes that, in North American forestry,[1] "waste" is largely obsolete, with just 0.14 percent to 1.5 percent of harvested wood incinerated or landfilled (see **Figure 1**). Over the past century, a steady procession of technological advances turned previously discarded fiber into valuable products. A partial list includes particle board, structural I-beams, Laminated Veneer Lumber (LVL), medium-density fiberboard (MDF), Oriented Strand Board (OSB), Parallel Strand Lumber (PSL), wood fiber insulation, and biomass energy. Innovations in post-WWII engineered wood products (EWPs) directly enabled foresters to harvest more material—not just the best, straightest, most lumber-ready trees.

New Hampshire State Forester Andy Fast explains, "Without those markets, we're limited to cutting only high-value trees, a poor forestry practice." Vermont forester and author Ethan Tapper says having commercial outlets is crucial to forest ecology, in that it "allows us to totally explode our capacity to do restoration work."[2] Thinning small, less valuable trees is important for restoration projects and working forests alike. Thinning is necessary to sustain-

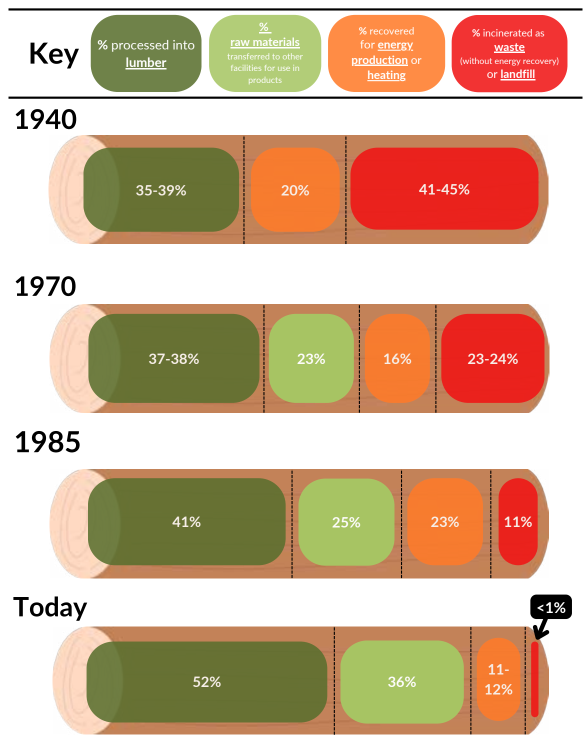


FIGURE 1: UTILIZATION OF HARVESTED WOOD BY THE NORTH AMERICAN FOREST PRODUCTS INDUSTRY, 1940–TODAY

Source: Dovetail Partners Inc., 2024

1 Dovetail Partners Inc., "Utilization of Harvested Wood by the North American Forest Products Industry," https://www.dovetailinc.org/upload/tmp/1580241837.pdf.

2 Ethan Tapper, "What Is 'Low-Grade' Wood? Why Markets for Low-Grade Wood Are Essential to Healthy Forests," https://www.youtube.com/watch?v=x8X_mBf_nII.

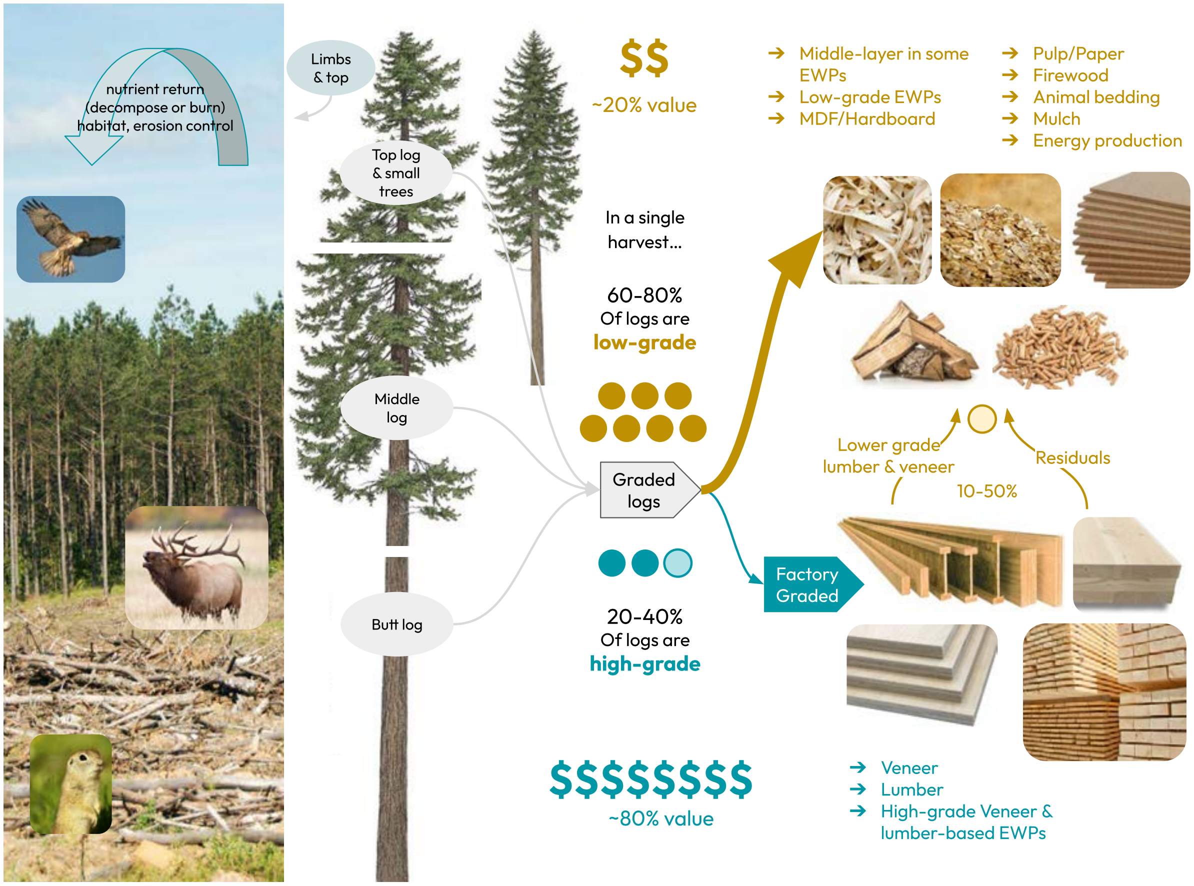


FIGURE 2: FOREST FIBER VOLUME-TO-VALUE FLOW

Source: Field Edge

ably produce higher-value fiber, and it's crucial for creating healthy forest ecosystems that are resilient to fire, pests, and disease. The focus of restoration work is on removing the low-grade volume so that the remaining higher-grade material has room to grow and increases in vigor. Without markets for low-value trees that can wholly or partially offset the cost, the restoration work is cost-prohibitive. Because logs from small trees lack strong commercial value, the challenge lies in finding the highest price for a harvest's lowest-value wood.

VALUING AND GRADING FIBER: IT'S NOT ALL TENDERLOIN

In a typical timber sale, about 20 percent to 40 percent of harvested trees are "high value," and 10 percent to 50 percent of that high-value material will be regraded for lower-value uses or become residual waste. The highest-grade fiber that remains after processing represents about 80 percent of the value of the forest products market (see **Figure 2**). The other 20 percent of overall market value is coaxed from the 60 percent to 80 percent of harvest volume that is midgrade to low grade, where the margin between the harvesting, processing, and transport costs and the market value is either very limited, or the value is well below the costs.

The business end of a mature tree is the section of the log closest to the ground. The value of the fiber tends to go down as you move up the tree because there are more knots and bark and fewer clear, strong lengths. The crown and top stem are often left in the forest as “slash” to decompose and regenerate soil, sometimes accelerated by a controlled burn to reduce wildfire risk. Slash is also used for erosion control, moisture retention, wildlife habitat, and/or to buffer equipment movement through sensitive areas.

Companies can successfully position themselves in the lowest-value fiber streams by acquiring “harvest residuals” for the cost of delivery. But, as Matt King, vice president of sales and innovation at Heartwood Biomass, explains, making that work requires a robust local ecosystem of diverse facilities. Heartwood has no competition for the slash and low-grade “cull logs” they use as feedstock for firewood and poles because they do the kind of sorting that doesn’t pencil for loggers. King says, “It’s not all going to be tenderloins! We’re seeing that 80 percent of optional removal biomass that would normally be slash is stuff that we can take.” Even so, Heartwood’s residuals constitute up to 30 percent of the volume they receive, which they sell at a loss for a variety of other uses: hog fuel for biomass plants, “beauty bark” for landscaping, and chips for paper. The opportunities to upcycle waste streams are crucial for the business to work, and they need to be hyperlocal. As King puts it, “it can’t even leave the county.”

The built environment, on the other hand, is one of the highest-value places wood fiber can land. Veneer products, followed by lumber, require the strongest, straightest trees. Generally, peeler logs and sawlogs (for veneer and lumber, respectively) are sorted at the site of harvest. These logs then move to the manufacturing facility, where a second round of grading separates clear from anomalous material. In some cases, the lower-grade material can be used at the same facility by strategically placing it in middle layers of EWPs, or it can be transformed into an entirely new product. In other cases, the lowest-grade material is sold to secondary manufacturers who remanufacture it into products such as pallets and crates.

MAKING AND SELLING EWPS: BALANCING ECOLOGY AND ECONOMY

Forest product companies of any size must decide how to purchase, sort, add value, distribute, and manage waste streams. Whether they’re harvesting from company-managed lands or purchasing logs on the open market, manufacturers can diversify by making multiple products that maximize their investment.

Oregon-based land manager and EWP manufacturer Roseburg Forest Products has a product portfolio that includes lumber and plywood. They also produce MDF made from sawdust from their mill’s by-products and LVL from specialty veneer grades sorted from their plywood mills. Any unused logs or residuals are used in their own facilities as energy or chipped for export. Another company operating primarily in the Pacific Northwest, RedBuilt, buys material to make and sell I-joists, LVL, and open-web joists as kit-of-parts building systems. “It’s really a suite of products that are delivering these projects,” says Jason Weber, vice president of sales. Although they prefer to produce with Douglas-fir, RedBuilt builds certainty and flexibility into their offerings by having Southern Yellow Pine (SYP) product certifications as well, in the event that local material is not available or is too expensive. “Inventing truss joists in the ’70s was kind of the precursor to the sustainability movement," says Weber. Because there's always a mix of quality in the fiber they get, making EWPs gives them the flexibility to make the best use of the resource as they receive it.

Large companies create efficiencies across multiple regions and markets. Manufacturing giant Georgia-Pacific operates in 30 US states, sourcing raw materials from a range of suppliers across the country. The largest parts of the trees they purchase are used for lumber and plywood, while residuals and thinnings are incorporated into EWPs like OSB or transformed into cellulose for paper, packaging, and pulp—all managed within the same company.

Even with their diverse portfolios, large companies must make improvements in utilization to stay nimble in rapidly changing markets. Boise Cascade recently developed a mass timber product using only the lowest-graded veneers, and the company's innovation team is exploring the viability of biochar and insulation as higher-value alternatives for their waste material even though they currently use it to produce 70 percent of their manufacturing energy.

Small and large companies alike are highly dependent on strong local forest and wood product economies. As Canfor's general manager of specialty products Kim Henze explains, "The density of the network matters." Operating across Canada and the US, Canfor purchases stands wholesale from landowners, then harvests and sorts logs for use in making products. Their mills are focused on running volume, and EWP lines are focused on utilization and creating value. By volume, lumber production creates about 50 percent residuals: chips, shavings, and dust. Ideally, this material can be sold or delivered to companies that use it for pulp, energy, or animal bedding. "Everything is utilized, but the opportunity is to increase the value of products that are being created from residuals. There is a huge drive to extract more value from that 50 percent." Like King, she stresses that if there aren't value-added producers nearby, transport will be too costly, and that value cannot be captured. More interconnection opens greater opportunities for utilization.[3]

Katie Cava, who oversees sustainability certification of forests and mills at Weyerhaeuser, agrees with Henze. She says that, right now, markets for thinnings are mostly pulp or pellets, but they'd like to see higher-value markets. Products like the company's proprietary TimberStrand are one way to capture value from smaller trees, in turn supporting the landowners with whom Weyerhaeuser works. Cava notes, "Strong EWP markets help our smaller-scale landowners make the decision [to thin]. It's really hard for someone who owns just 40 acres to [spend money to] thin their forests if they don't have anywhere to sell that wood."

Vertically integrated companies that manage forests and manufacture diverse products have greater fiber utilization flexibility than more specialized ones, but specializing has its advantages too. The majority of the industry in North America is dispersed, with business models relying on well-established systems. Sterling, the highest-volume CLT manufacturer in the US, has focused on commodity feedstock since the company was founded 75 years ago. Michaela Harms, senior director of mass timber, explains how Sterling built its equipment line to maximize the existing supply chain by using standard dimensions and processes. This al-

3 See Lech Muszyński's chapter 10 in this report for more on manufacturing and geographic distances.

lows the company to purchase raw materials that, along the production line, require the least amount of modification, thereby reducing waste (and cost). Harms focuses her work on efficiency at the project level because most of the waste from these products occurs during design and construction.

BEYOND 100 PERCENT

EWPs made from high-value lumber or veneers are marvels of engineering and achieve incredible things in the built environment, but those made from chips and strands also have an important role in a building's sustainable procurement story. OSB was invented in the late '70s as a way to use surplus aspen in the Lake States region. It now represents almost 6 percent of all wood fiber consumption in the US (see **Figure 3**),[4] a market double that of plywood that equates to about $6 billion in annual sales. The same data shows that 53 percent of wood fiber consumption is pulpwood, which makes me wonder, what will the next breakout product be, and how can we use more of the suite of products already at our fingertips?

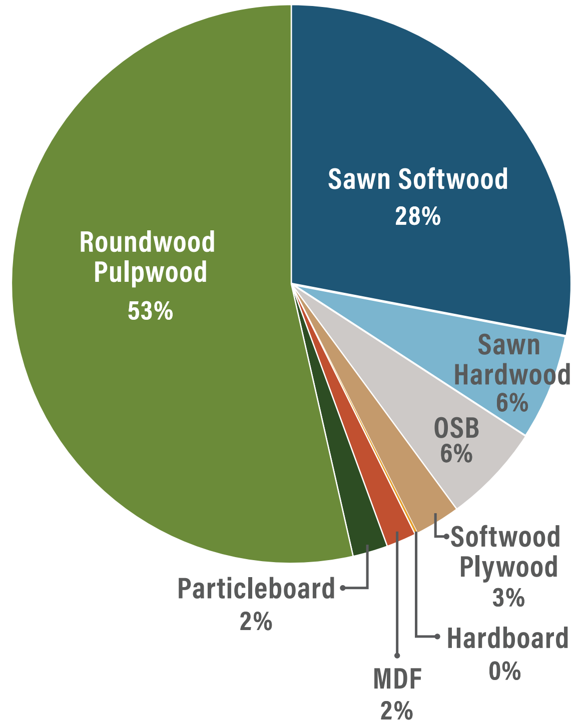


FIGURE 3: FOREST AND WOOD PRODUCTS BY VOLUME

2023

Source: USDA

Which turns our attention toward construction, which discards 15 percent of the wood products it purchases—before they are even put to use;[5] 8.3 percent of all landfilled municipal solid waste is wood.[6] With this in mind, designers could better optimize our designs to minimize postmanufacturing waste. We could also look for opportunities to use lower-grade EWPs, knowing that this is the longest-lasting place in the market for this carbon to be stored. During our conversation, forester Fast noted that only 16 percent of a tree can be used for clear lumber as specified by architects. He implores architects to rethink their finish specifications to reduce pressure on clear-grain wood. To achieve a full circular economy, end users have work to do.

THE CASE FOR INDUSTRIAL DIVERSITY

The expanding suite of wood products—and the facilities that produce and support them—is an intricate ecosystem that needs diverse markets to thrive. When any part of that system goes away, as in the precipitous disappearance of pulp mills over the

4 United Nations Economic Commission for Europe, "United States Forest Products Annual Market Review and Prospects: Country Market Report, 2021-2025," https://unece.org/sites/default/files/2023-11/US_FPMAR_2023-2024_Nov3.pdf.

5 https://www.nationalwaste.com/blog/wood-recycling-for-the-construction-industry-dont-let-your-money-get-hauled-away/

6 https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/wood-material-specific-data

past few years[7] the impacts ripple immediately into other wood products businesses and forest thinning projects. Mass timber is relatively new on the scene, and it's a fantastic example of how innovations in the supply chain continue to develop,[8] with new products and utilization improvements that inspire designers and foresters alike. The best and highest value of a harvested stand of trees, however, is rarely going to be captured at one facility. We miss a lot of the story if we just look at one product type at a time.

In the end, I did change my toilet paper subscription (you were dying to know, right?), and I'll continue to seek more durable pulpwood products. As the highest-value market outlet for wood products, the construction industry is in a truly remarkable position to help improve forest health outcomes. If using paper products improves forest health while helping bring down the cost of lumber, I'm sure that innovators in the building industry can find many other ways to use this fiber in a much more durable way.

7 Forisk Consulting, "Pulpmill Slowdown: What Is Going On?" https://forisk.com/blog/2023/05/26/pulpmill-slowdown-what-is-going-on/.

8 See 'Eat the Problem' by Lech Muszynski in the *2023 International Mass Timber Report*.

REVOLUTIONIZING NAIL-LAMINATED TIMBER (NLT) WITH SILVASPAN

STANDING OUT IN THE MASS TIMBER industry is no small feat. But reinventing age-old technology? That's an even greater challenge. SilvaSpan has successfully embraced both. Drawing from over a decade of experience, the Lowell, Ontario, company has redefined Nail-Laminated Timber (NLT), bringing this heritage construction material back to the mainstream.

With a focus on precision and beauty, SilvaSpan has modernized NLT, using off-site construction to create panels that combine stunning aesthetics with superior performance and low cost. According to Kevin McElhone, director, SilvaSpan is a small company that's achieving big things. The mission is clear: to revive the unique NLT heritage with big updates to product performance and make it cost-effective for today's mass timber market.

THE CURVED CEILINGS IN THE BRIGHTWATER BUILDING IN PORT CREDIT, ONTARIO, SHOWCASE THE DESIGN FLEXIBILITY OFFERED BY NLT PANELS

Source: SilvaSpan

AUTOMATED NLT MANUFACTURING

NLT has been used to construct our cities for over a century. Traditionally, NLT was assembled on-site because lumber was abundant and labor was inexpensive. In today's mass timber world, however, efficient off-site construction, with strict quality controls and precision manufacturing, are all crucial ingredients for success.

SilvaSpan has revolutionized this process by automating the manufacturing of NLT panels. The company developed an innovative 4-step process to ensure consistent quality:

1. Finger-jointing standard dimensional lumber 2x4 to 2x12 into lengths up to 60 feet
2. Planing the finger-jointed lumber on all sides to remove any blemishes and achieve uniform thickness
3. Coating each lamina with a clear sealant for moisture control
4. Using custom-made, patented automated press equipment to nail the boards together into panels varying from 4 inches to 12 inches thick by 8 feet to 12 feet wide and up to 60 feet long

THE COST ADVANTAGES OF NLT

SilvaSpan has been in operation for almost 2 years and has already secured a steady stream of orders. According to McElhone, the success of SilvaSpan's NLT lies in its distinct beauty, low cost, excellent product performance, and optimum wood use.

Regarding NLT's aesthetic appeal, architects frequently praise the vertical grain orientation, which creates a sleek, linear look that stands out compared with CLT panels.

There's also SilvaSpan's low start-up cost. Compared with Cross-Laminated Timber (CLT) plants, SilvaSpan's manufacturing equipment is significantly less expensive. SilvaSpan designed and built the automated nail press to provide precision control in the panel manufacturing.

Another advantage is enhanced product performance through patented design. SilvaSpan's NLT panels feature small gaps between the laminas.

THE CEILINGS IN THE ONE YOUNG MASS TIMBER BUILDING IN KITCHENER, ONTARIO, FEATURE NLT PANELS THAT HIGHLIGHT THE STRENGTH, SUSTAINABILITY, AND NATURAL BEAUTY OF ENGINEERED WOOD SOLUTIONS

Source: SilvaSpan

This patented manufacturing innovation allows the panels to accommodate the natural shrinking and swelling of wood due to changes in moisture, ensuring stable panel dimensions over time.

Finally, NLT's strength efficiency offers cost savings. Unlike CLT panels, which rely primarily on their longitudinal lamellas for strength, NLT panel strength comes from its entire profile, as all the wood fibers are oriented in the same direction. This results in a higher strength-to-volume ratio, meaning less wood is needed to achieve the same performance, translating into lower costs for builders.

A BRIGHT FUTURE FOR NLT

With their visual appeal, excellent performance, and cost advantages, NLT panels are well positioned to gain traction in the mass timber construction industry. However, McElhone acknowledges that awareness is a hurdle. Many architects, engineers, and developers are still unfamiliar with NLT and SilvaSpan. By highlighting its benefits, McElhone hopes to bring NLT into the spotlight and secure its place in the future of sustainable construction.

SPONSOR **SPOTLIGHT**

CREATIVE THINKING, PRACTICAL RESULTS

RJC Engineers is a national, employee-owned engineering firm that celebrates creative thinking, prompt service, and technical excellence in building structure and enclosure engineering. Bringing the best of RJC to every project for over 7 decades, the firm integrates multifaceted ingenuity and practicality to create success for its clients and their projects.

As a leader in mass timber design, RJC is at the forefront of delivering low-carbon, high-performance solutions that push the boundaries of sustainable construction. With a distinguished legacy of landmark projects and active roles on national wood design code committees, RJC is trusted by architects, developers, and fabricators to turn bold visions into resilient, efficient structures.

One such project is the University of British Columbia (UBC) Gateway building, currently under construction. This 6-story, mass timber structure exemplifies a commitment to Indigenous relationships, sustainability, and community health. The first project in North America to utilize the innovative CREE panel system, it is poised to become the UBC's first zero-carbon building, setting a new benchmark for sustainable wood design.

RJC's wood expertise spans a diverse range of projects worldwide, from residential to institutional buildings. By leveraging cutting-edge technology and a deep understanding of wood design, RJC consistently delivers projects that redefine what's possible in construction. Our talented teams are driven to challenge limits, ensuring every project achieves maximum value and performance.

We are committed to driving innovation in mass timber construction, transforming ideas into enduring landmarks that redefine possibilities in the built environment. Discover the full potential of mass timber—reach out to RJC today.

MASS TIMBER PERFORMANCE INDEX

ROY ANDERSON
VICE PRESIDENT, The Beck Group
ERICA SPIRITOS
Growing regional mass timber ecosystems

INTRODUCTION

The Mass Timber Performance Index serves two purposes. First, it estimates North American Cross-Laminated Timber (CLT) market prices. Unlike commodity lumber, CLT pricing is project-specific and is influenced by its own set of supply and demand factors. It is helpful to think of CLT as a custom building component rather than a commodity product. Second, the index describes the North American mass timber industry's scope in terms of number of buildings constructed, the corresponding volume of lumber consumed, and the 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 the custom-made nature of CLT production. Accordingly, the CLT price index provides a likely pricing range. Actual CLT panel market prices will reflect project-specific factors such as market conditions, a manufacturer's efficiency, and how strongly a manufacturer desires to win the work.

In **Figure 1**, we update the CLT price information with data for the period Q1 2016 to Q4 2024 (the blue line with units that correspond to the left axis). This information first appeared in the 2022 edition of the *International Mass Timber Report*. Prices have held fairly steady during the last 2 years at around $42 to $44 dollars per cubic foot. The CLT market prices shown here are derived from a financial model of a prototypical CLT manufacturing plant. The estimated CLT panel prices in the figure include estimates of the cost of producing CLT and a margin for the manufacturer's profit. In 2024, the model was refined to include a more accurate representation of administrative overhead costs; escalation and inflation for all labor and materials dating back to 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.

Also shown in the figure (the orange line with units that correspond to the right axis) is an estimated market price for lumber, derived from *Random Lengths*, a lumber price reporting service. Lumber pricing is discussed in greater detail in the next section.

LUMBER PRICE DISCUSSION

The composite lumber price (an average of more than 20 different lumber grades and species) in Q4 2024 is almost identical to the price in Q1 2023. There were a few modest peaks and valleys, but for the past two years, lumber prices in North America have been more stable than at any time since 2016. This stability provides some pre-

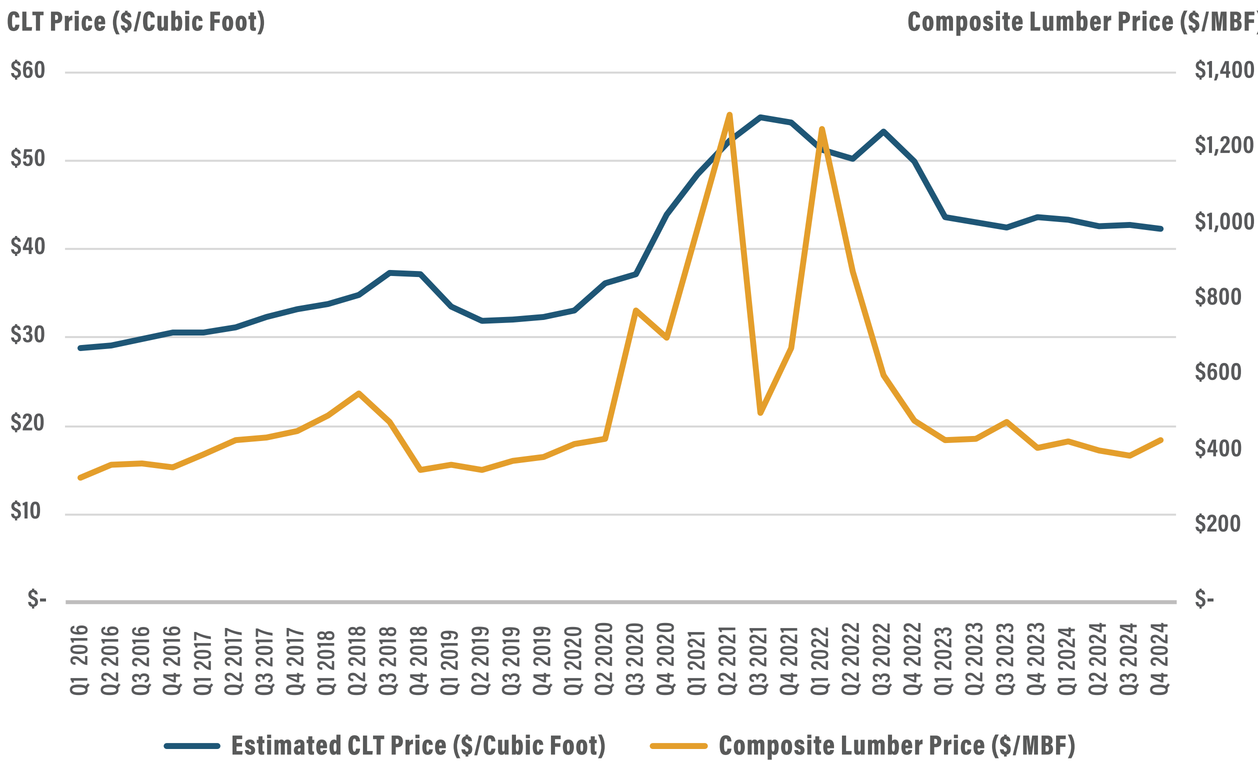


FIGURE 1: CLT PRODUCT PRICE INDEX

dictability to mass timber manufacturers and has dissipated the pandemic-era phenomenon of having higher-priced lumber inventory sitting in the yard waiting for manufacture. According to our financial model, the cost of purchasing lumber has been holding steady at around 40 percent of the total cost of manufacturing mass timber panels.

In early 2025, many economists are pointing to positive signs in the economy, which typically translate into rising wages, job growth, lower interest rates, and a higher rate of housing starts. All these factors increase lumber demand and strengthen prices. However, early 2025 is also a time of major uncertainty in lumber markets as it is unclear whether President Trump will impose a 25 percent tariff on all goods imported from Canada, including lumber. It is our belief that any tariffs that are implemented will quickly be resolved because they would have severe negative economic impacts for both countries.

Regardless of tariffs, the potential for a spike in lumber prices remains as a result of the log supply shortage described in last year's report. British Columbia, Oregon, and Washington have all enacted policies that constrain harvesting on public and private lands. Additionally, wildfires limit the ability to harvest trees during significant portions of the year. Fires also have the longer-term impact of reducing the standing inventory of timber available for harvest. The constrained ability to harvest timber translates into reduced lumber production. If lumber demand increases in 2025, the ability to turn on the spigot is hampered by raw material supply. Exacerbating this situation is the recent closure of a number of sawmills in the Pacific Northwest and British Columbia.

OTHER FACTORS AFFECTING CLT PRICE

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

- *Panel thickness:* Though panel pricing is often given on a volumetric basis, the price of a 5-ply might not be the same as the price of a 3-ply. The height of a press bed will govern how many panels of each thickness can be produced per press cycle, resulting in different pricing for panels of different thicknesses.
- *Strength grade:* Electronically rated (made from Machine Stress Rated [MSR] lumber) panels will be more expensive than visually graded (V-series) panels because they are manufactured with stronger and stiffer lumber that is more costly than visually graded lumber.
- *Species:* CLT is manufactured from a variety of tree species including Douglas-fir; Southern Yellow Pine (SYP); and spruce, pine, fir (SPF). Each species has its own supply and demand landscape that affects its market pricing.
- *Visual Quality:* Architectural or visual-grade CLT is more expensive to produce, given the added cost of sanding the exposed surface(s).
- *Billet utilization (waste):* Billet utilization will fluctuate depending on the geometry of a mass timber building and the efficiency of the panel layout. Waste material is generated 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 specific building project. Design assist and 3D modeling (detailing) costs rise as project complexity increases. Thus, buildings with complex designs are more expensive to produce.

GLULAM PRICE DISCUSSION

Let it be known that the price of CLT does not equal or correspond to the price of glulam on a volumetric basis! Glulam is manufactured from a special grade of lumber called lamstock, which is of higher quality than the #2 & Better and #3 & Better grades typically used to manufacture CLT. For example, the edges of all boards in a glulam beam are visible. This means that lamstock must be perfectly square (with no wane). This more restrictive specification reduces the available lamstock supply. Additionally, lamstock's maximum allowed moisture content is 15 percent(12% +/- 3%). That requirement drastically reduces the number of sawmills from which glulam manufacturers can source material because kiln capacity is often the limiting factor on production at sawmills. Also, drying to a lower moisture content often lowers the grade yield. The result is lamstock pricing that may be more than double that of lumber used to make CLT. And the story does not end there.

The width of a glulam beam and the corresponding width of the lamstock further impacts pricing. Wide boards (2x10, 2x12, 2x14) that meet the quality requirements are more limited in their availability. The result is significantly higher pricing compared to more readily available lamstock widths (2x4, 2x6, 2x8). The price of 2x12 lamstock, for example, could be $1400 per MBF, while 2x4 lamstock sells for $800 per MBF. Recall from Figure 1 that the composite softwood lumber price in 2024 was only about $410 per MBF.

Wide beams, and therefore wide boards, are increasingly common in mass timber construction—particularly in fire-rated buildings where the structure is designed with a sacrificial char layer of approximately 1.6 inches per hour on all exposed sides. This means that the average beam in a mass timber building may be 10.75 inches wide, produced from all 2x12 lamstock.

Although there is currently no publicly reported price index for lamstock or glulam, some price indicators exist. For SYP, one can look at the lumber price in *Random Lengths* for #1 Southern Pine, Kiln-Dried, East Region, and then assume further cost for additional planing and drying. For Douglas-fir, one can look at *Random Lengths* price for Structural Light Framing for Fir & Larch from Spokane, Grade 2400f as an indicator for lamstock pricing. Unfortunately, *Random Lengths* publishes prices only for standard board sizes. Assume wide boards are 1.5 to 2 times the published price.

Lastly, it is helpful to understand that there is no standardized approach to pricing glulam. Some manufacturers will price glulam based on an average cost of their lamstock inventory, while others will price the lamstock required for a specific order (project). We hope that this narrative sheds some light on the dynamics affecting glulam pricing and look forward to being able to provide corresponding data as the number of suppliers grows.

MASS TIMBER DEMAND

In 2024, the demand for mass timber decreased in line with the overall construction industry, as high interest rates made it challenging for developers to secure affordable funding. According to WoodWorks data, roughly 155 mass timber projects either began construction or were built in 2024, a 20 percent reduction from the 197 projects in 2023. Another 1,168 projects are in the design stage in the US as of December 2024, indicating that there is strong demand for mass timber construction once funding becomes more available and affordable.

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 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, Texas, Washington, Massachusetts, Georgia, Colorado, and New York all have more than 50 new mass timber projects in design and construction. Assembly, business, educational, and multifamily

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	309,000	51%
2020	177	148,000	174,000	395,000	44%
2021	185	169,000	207,000	339,000	61%
2022	163	201,000	256,000	564,000	46%
2023	197	214,000	268,000	575,000	47%
2024	155	187,000	231,000	589,000	39%

TABLE 1: ESTIMATED MASS TIMBER LUMBER USAGE AND PRODUCTION IN THE US AND CANADA (2019 TO 2024)

MBF = 1,000 board feet

buildings were the leading market sectors, accounting for over 80 percent of new mass timber construction in 2024.

WoodWorks/Wood Products Council provides free project support to the Architecture, Engineering, Construction and Design (AEC+D) community on multifamily, institutional, and commercial buildings. Growing the mass timber market is the objective of the organization, and it has 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 see details about most of the projects at https://www.woodworksinnovationnetwork.org/

STATE OF THE INDUSTRY IN NORTH AMERICA

Though 2024 was a slow year for the construction industry as a whole, with a reduced number of mass timber projects relative to 2023, we witnessed the mass timber industry take strides toward increased capacity in preparation for anticipated increased demand.

Smartlam opened a state-of-the-art glulam manufacturing facility in Dothan, Alabama, in a brand-new building adjacent to its CLT manufacturing facility. The $50 million glulam manufacturing facility, equipped with machinery from Ledinek, can produce as much as 84,000,000 board feet annually of large glulam beams and columns required to properly serve the mass timber market. Previously, glulam and CLT production had been housed under one roof in Dothan. Dothan is strategically located to serve the Southeast, one of the fastest-growing mass timber markets in the United States. SmartLam North America has 1.5 billion board feet of available SYP lumber annually between its 4 southern sawmill shareholders.

SmartLam North America also spent an additional $24 million to fully automate the existing CLT facilities in Dothan and Columbia Falls, Montana. This additional investment will allow each facility to produce 2,000,000 cubic feet (more than 55,000 cubic meters) annually.

On the west coast, Timberlab took major strides toward becoming a manufacturer when it acquired American Laminators' glulam production facilities in Swisshome, Oregon, and Drain, Oregon. The Swisshome and Drain locations have been operating for over 60 years, utilizing Douglas-fir, SYP, and Alaskan Yellow Cedar, accounting for an annual capacity of 20 million board feet. Each facility will undergo operational upgrades to continue enhancing product optimization and continuing the legacy of manufacturing in the 2 communities.

Timberlab's acquisition of American Laminators followed soon after the announcement that the company would construct and operate a state-of-the-art CLT manufacturing facility in Oregon's mid-Willamette region. The facility broke ground in Millersburg, Oregon, in February 2025 and is expected to commence operation in 2027.

LUMBER USAGE

In this report, we used a different data source for the number of mass timber buildings constructed in Canada: the Interactive State of Mass Timber in Canada Dashboard, produced by Natural Resources Canada. Thus, the lumber usage and capacity utilization figures have changed from what was reported in prior years. The new data has fewer buildings constructed than what we previously estimated. This means that the estimated total annual lumber usage in the mass timber market has dropped slightly. As **Table 1** indicates, it is estimated that lumber usage peaked in 2023 at 214 million board feet. In 2024, lumber usage in the mass timber sector is estimated at 187 million board feet. That usage volume is roughly equivalent to the total annual output of a single modern, large-scale softwood sawmill.

Aside from the update in source data for the number of buildings, the reduced lumber consumption is a result of the year-over-year drop in the number of mass timber buildings completed in North America, declining from the peak of 197 in 2023 to 155 in 2024. All other things being equal, it is estimated that 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 nearly 60 billion board feet of lumber annually for the last several years.

For sawmills interested in the emerging mass timber market, one opportunity is to produce lumber of nonstandard thicknesses to enable the manufacture of thinner and more efficient panels. The availability of thinner lumber provides greater flexibility in panel design and allows for more efficient use of fiber in applications where a thinner 3-layer panel is adequate, such as in the sizable residential housing market. The use of 10-millimeter and 20-millimeter-thick lumber is a hallmark of European CLT and makes it challenging for North American manufacturers to compete on projects. Currently, sawmills face challenges in producing thinner lumber, as smaller piece size reduces productivity and increases cost. Also, when dimension lumber is tallied, it is counted as being 2 inches thick, even though the actual thickness is only 1.5 inches. The difference between nominal size and actual size, on a percentage basis, is smaller when lumber is sawed to a 1-inch thickness. This means the sawmill does not realize as much of a tally advantage when producing 1-inch lumber. Despite these challenges, efforts are underway to identify a solution for making a wider range of thicknesses available to the mass timber industry.

MANUFACTURING CAPACITY

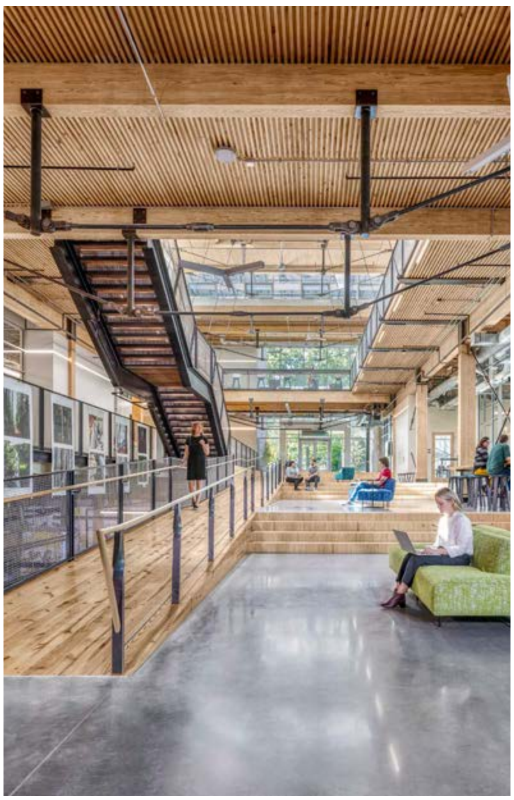
This year's analysis of mass timber panel manufacturing capacity shows a slight increase from 2023 to 2024, as we've added SilvaSpan in New Lowell, Ontario, to the tabulation. Although the data used to calculate the capacities shown in **Table 1** is representative only of manufacturers that produce 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.

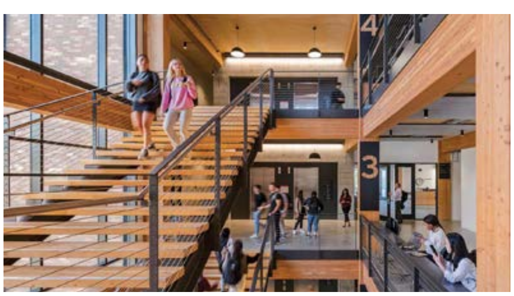
CONCLUSION

Often, when the market is at a low point in the cycle, it can be beneficial to undertake transformational steps to prepare for the future. Though demand was significantly lower in 2024 than in 2023, the mass timber industry hunkered down to get ready for the floodgates to open in the future. We hope that the commercial real estate industry will recognize and appreciate the efforts to increase capacity, answering a concern the industry has long had about material availability and procurement risk. As panel manufacturers are operating at less than 40 percent of their capacity, there is room for major players in both the public and private sector to integrate mass timber into future plans.

PARTNER **SPOTLIGHT**

WOODWORKS WPC WOOD PRODUCTS COUNCIL™





WOOD PRODUCTS COUNCIL

At WoodWorks, our mission is to help developers, designers, and construction professionals bring mass timber and light-frame wood projects to life. Our team of experts provides support across disciplines for the code-compliant design, engineering, and construction of commercial and multifamily wood buildings in the U.S.

Our services include free one-on-one project support, a nationwide education program, and a wide range of published technical resources. Topics we can assist with include:

- Allowable heights and areas, construction types
- Structural detailing, lateral and gravity systems
- Fire resistance and acoustic-rated assemblies
- Code paths, alternate means of code compliance
- Mass timber construction management
- Carbon impacts, Whole Building Life Cycle Analysis (WBLCA) education

As a nonprofit, our work is made possible with support from partner organizations representing all facets of the industry, with major funding from the Softwood Lumber Board and US Forest Service.

WoodWorks also hosts the WoodWorks Innovation Network (WIN), a user-generated database that lets you explore projects on an interactive map, connect with industry professionals, and contribute your own work.

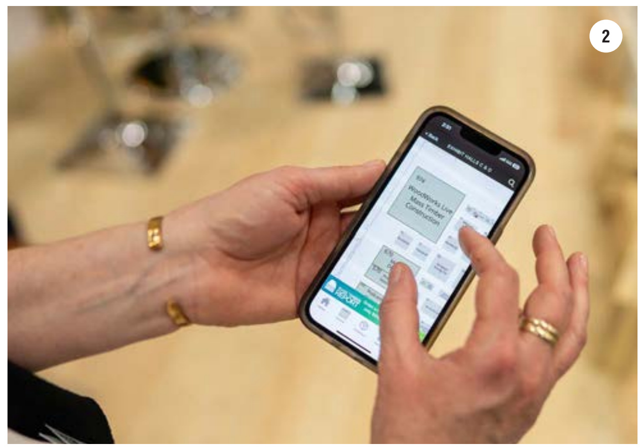
From 1 story to 18, we're here to support the success of your commercial and multi-family wood building projects. Get in touch at www.woodworks.org/project-assistance

2024 INTERNATIONAL MASS TIMBER CONFERENCE

THE 2024 INTERNATIONAL MASS TIMBER Conference (IMTC) was bigger and better than ever with more attendees, a larger exhibit hall, and the great content and industry-leading speakers that are the trademark of the IMTC. We have gathered a variety of images from the conference and tours to share with all of you, whether you are a veteran, a first-time attendee, or just wondering what you might be missing.

1. CRAIG AND ARNIE ARE THE FIRST TO TRY OUT THE NEW SELFIE SIGN AT IMTC

2. OUR APP NOW FEATURES THE EXHIBIT HALL FLOOR PLAN



BUILDING AND FACILITY TOURS

3. OUR FIRST-EVER FORESTRY TOUR WAS VERY POPULAR

4. TAKING A CLOSE LOOK

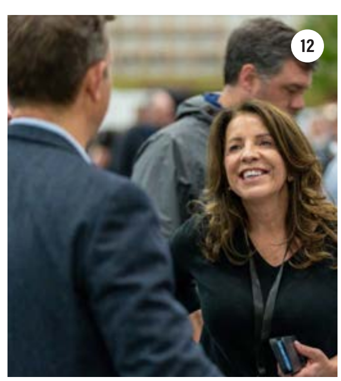
5. ONE OF SEVERAL PROJECT TOUR STOPS

6. ANOTHER PROJECT TOUR STOP

7. A PLANT TOUR

8. ANOTHER PLANT TOUR

THE EXHIBIT HALL

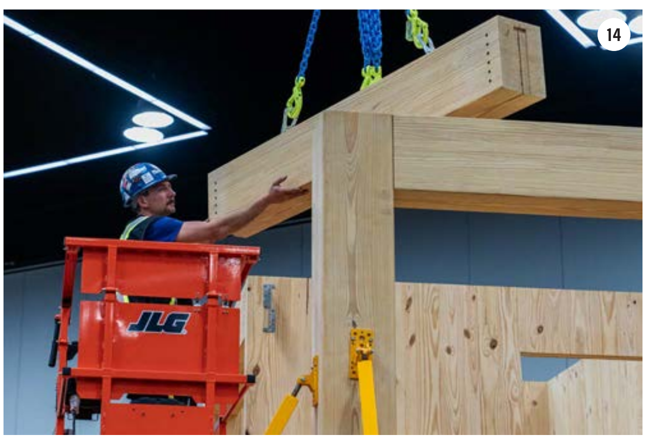


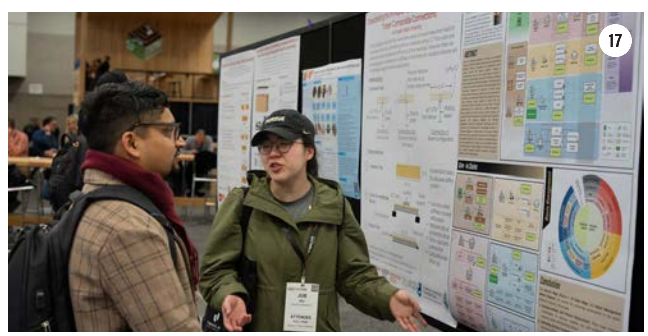
9. THE ALWAYS POPULAR OPENING RECEPTION ON THE EXHIBIT HALL FLOOR

10. MEETING OLD FRIENDS AND MAKING NEW ONES

11. ONE OF THE IMPRESSIVE STRUCTURES ON THE SHOW FLOOR

12. BUSINESS GETTING DONE





13. A CLOSE-UP DEMONSTRATION

14. THE WOODWORKS LIVE BUILD ON THE SHOW FLOOR

15. DEEP IN DISCUSSION

16. AN IMPRESSIVE SCALE MODEL

17. THE POSTER SESSION

SPEAKERS

18. KEYNOTE SPEAKER: EMILY PILLOTON-LAM, FOUNDER AND EXECUTIVE DIRECTOR OF GIRLS GARAGE, DISCUSSING OPPORTUNITIES FOR GIRLS AND WOMEN IN THE WORKPLACE

19. OPENING KEYNOTE: “WILL MASS TIMBER RESHUFFLE OUR ECONOM” WITH KEY INDUSTRY LEADERS

20. FIRESIDE CHAT HOSTED BY THE URBAN LAND INSTITUTE FOCUSED ON THE OPPORTUNITIES IN MASS TIMBER FOR DEVELOPERS AND INVESTORS

21. ONE OF THE SIXTEEN INDIVIDUAL PRESENTATION SESSIONS WITH INDUSTRY EXPERTS

PARTNER **SPOTLIGHT**

FOREST SERVICE

TOP — FS first mass timber hybrid, Nez Perce-Clearwater National Forest, Kamiah, ID.

MIDDLE — Ascent during construction, with Brian Brashaw and Steve Kuennen.

BOTTOM — PDC PDX

The United States Forest Service has spearheaded mass timber development, creating momentum for mass timber construction in the United States. Since 2014, we've emphasized education, technical assistance, code revision, research, and special projects to spur a new industry.

The Forest Service and our public and private partners are at the forefront of using mass timber in construction and changing the way America builds. This work supports the crucial connection between the markets for forest products and resilient forests for all landowners—federal, state, tribal, and private. This construction growth has resulted in 13 new mass timber panel plants across the United States, with 6 large-scale producers.

KEY INITIATIVES INCLUDE:

- The Forest Service's annual investments in WoodWorks are supporting new commercial, institutional and multifamily construction.
- The Forest Service delivers the Wood Innovations, Community Wood, and Wood Products Infrastructure Assistance grants. These programs are delivering market development and expanded manufacturing capacity for lumber and mass timber.
- Scientists and engineers with the US Department of Agriculture Forest Products Laboratory (FPL) provide scientific and engineering credibility to the development and acceptance of mass timber in building codes.
- Our Wood Innovations program is influencing other federal government agencies for mass timber and net-carbon zero construction with the USDA Rural Development, Department of Defense, Government Services Administration, and Department of State.

ID 356354801 | Timber © Oleksandra Osadcha | Dreamstime.com

2024 MASS TIMBER NEWS HIGHLIGHTS

FOR OVER 22 YEARS, I'VE SHARED the latest forestry and forest products news through the free Forest Business Network (FBN) weekly e-newsletter. In 2014, we introduced a "Mass Timber" category that has consistently been our most popular topic. You may also recognize me from my active presence on LinkedIn and other social media platforms where I share insights into the industry.

A common question I receive is: "What was the biggest news of the year?" Well, this past year, the mass timber headlines were truly dominated by the state of Oregon. Take a dive into some of the biggest stories from the Beaver State.

FOR EVEN MORE NEWS, HEAD OVER TO THE NEWLY UPDATED WEBSITE

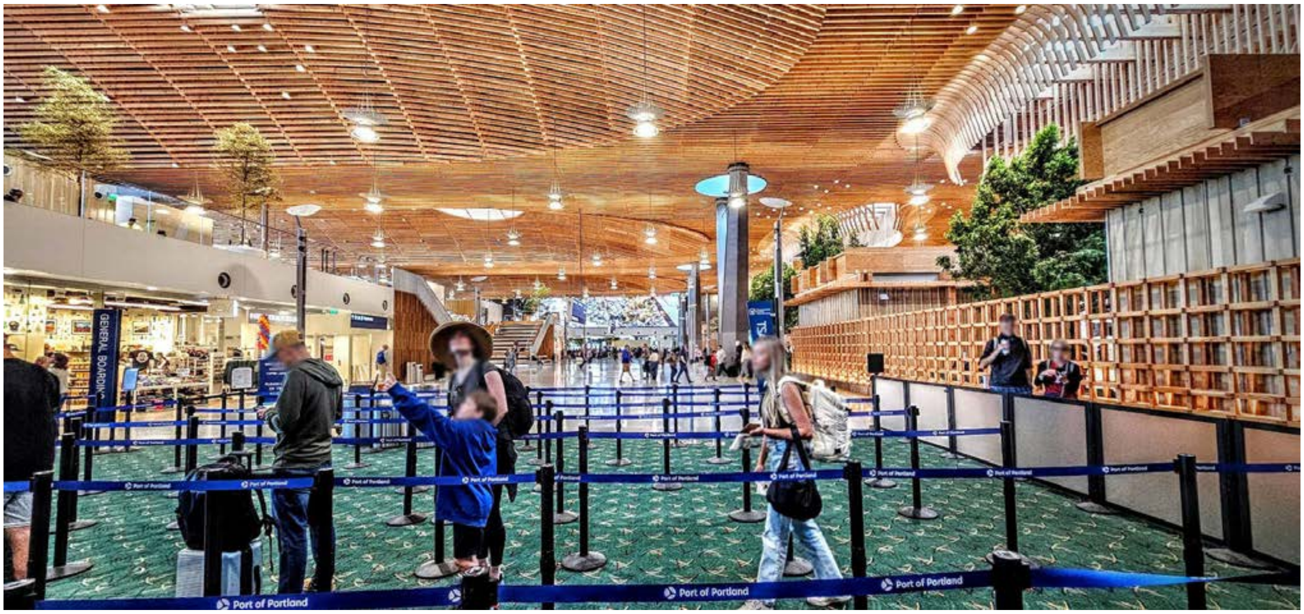
https://masstimberconference.com

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



PORTLAND INTERNATIONAL AIRPORT'S MASS TIMBER TERMINAL
Credit: Craig Rawlings

Portland's Stunning Timber Terminal
The grand opening of Portland's brand-new mass timber airport terminal in August 2024 captured global attention.

Timberlab Inc.'s Expansion
Timberlab Inc. announced a new 100,000 cubic meter plant, further solidifying America's Cross-Laminated Timber (CLT) market.

Rosboro Timber Company's Growth
Springfield-based Rosboro Timber Company announced a significant $120 million expansion, showcasing Oregon's commitment to the industry.

Oregon Mass Timber Coalition Gains Funding
The Oregon Mass Timber Coalition received a substantial $41.4 million grant, solidifying Oregon's leadership in mass timber development.

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Mass Timber

Timber Circular Economy

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Learn about the mass timber industry and sustainable practices, policies and tools in the wood sector.

Apply your certificate toward a future online master's degree.

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TALLWOODINSTITUTE.ORG

Oregon State University | TALLWOOD DESIGN INSTITUTE | UNIVERSITY OF OREGON

CHAPTER 1: INTRODUCTION

ROY ANDERSON
VICE PRESIDENT, THE BECK GROUP

As AI keeps extending further into the fabric of society, we thought it would be a good time to ask AI, "*What's the most exciting thing about mass timber building construction?*" Below is a summary of the responses from ChatGPT, Copilot, and Google AI:

The most exciting thing about mass timber construction is its potential to transform the building industry through sustainability, efficiency, and beauty. Here are some key highlights:

1. ***Sustainability:*** *Mass timber is a renewable resource and stores carbon, helping reduce the carbon footprint of buildings. It can be a carbon-negative material, offsetting emissions in a way that traditional concrete and steel cannot.*
2. ***Speed and Efficiency:*** *Mass timber panels are prefabricated off-site, allowing for faster on-site assembly and reducing overall construction time as compared to traditional nonresidential construction materials like steel and concrete. This efficiency also minimizes labor costs and lessens disruption in urban areas during construction.*
3. ***Strength, Durability, and Performance:*** *Engineered wood products like Cross-Laminated Timber (CLT) and glulam are incredibly strong, making them viable for tall buildings while providing flexibility and resilience. Mass timber is not only strong but also performs well in seismic conditions and has good fire resistance.*
4. ***Aesthetics and Well-Being:*** *The natural beauty of exposed timber offers a unique, warm aesthetic that is often difficult to achieve with other materials.*
5. ***Versatility and Innovation Potential:*** *Mass timber can be used in a wide range of building types, including hospitality, commercial, schools, health-care facilities, and laboratories. It also enables more creative design possibilities that allow architects and engineers to push the boundaries of design in ways that were once thought impossible.*

Overall, mass timber brings the potential for a greener, faster, and more beautiful way to build, appealing to developers, architects, and communities alike.

This report provides readers with a broad, yet deep, understanding of the North American mass timber industry in 2024. 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. In 2023 more than 3,000 people attended the conference. 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. To provide attendees with a lasting reference tool covering the whole mass timber supply and value chains, conference organizers are providing every attendee with a printed copy of the report.

Another purpose of the report is to provide an annual description of the state of the industry. The changes and growth in the mass timber space 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 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 2024.

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, but rather a family of products that have the common feature of having large dimensions. The original mass timber product is solid wood (i.e., timber and lumber) sawn to large dimensions. It 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

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

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

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 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 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 ca-

FIGURE 1.3: MASS PLYWOOD PANEL (MPP)
Source: Oregon Department of Forestry

bles 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.

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 many layers of wood veneer in various combinations of grain orientation (see **Figure 1.3**). 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 1.4**). Glulam, a well-established product that has been used in residential and nonresidential construction for 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 equivalent-size solid-sawn beams 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.

FIGURE 1.4: GLULAM TIMBERS
Source: APA

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 1.5**). 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

FIGURE 1.5: POST AND BEAM

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.

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 panel, 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 1.6**). 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.

FIGURE 1.6: NAIL-LAMINATED TIMBER (NLT) PANEL
Source: StructureCraft

FIGURE: 1.7 DOWEL-LAMINATED TIMBER (DLT) PANEL
Source: StructureCraft

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. However, if the NLT panels do require machining, a drawback is that the metal nails used in NLT can dull or damage woodworking tools such as saws, drills, and routers. 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 1.7**). 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 contain more moisture. The result is a tight-fitting connection that holds the boards together. The panel sizes for DLT are typically 8 feet to 12 feet wide and up to 60 feet long. The panel 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, also uses it in vertical applications.

With no metal fasteners, DLT panels can be processed with CNC machinery without the possibility of nails 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 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 Holz100 (or Wood 100) 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.

FIGURE 1.8: HEAVY TIMBER DECKING
Source: Southern Wood Specialties

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.

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,

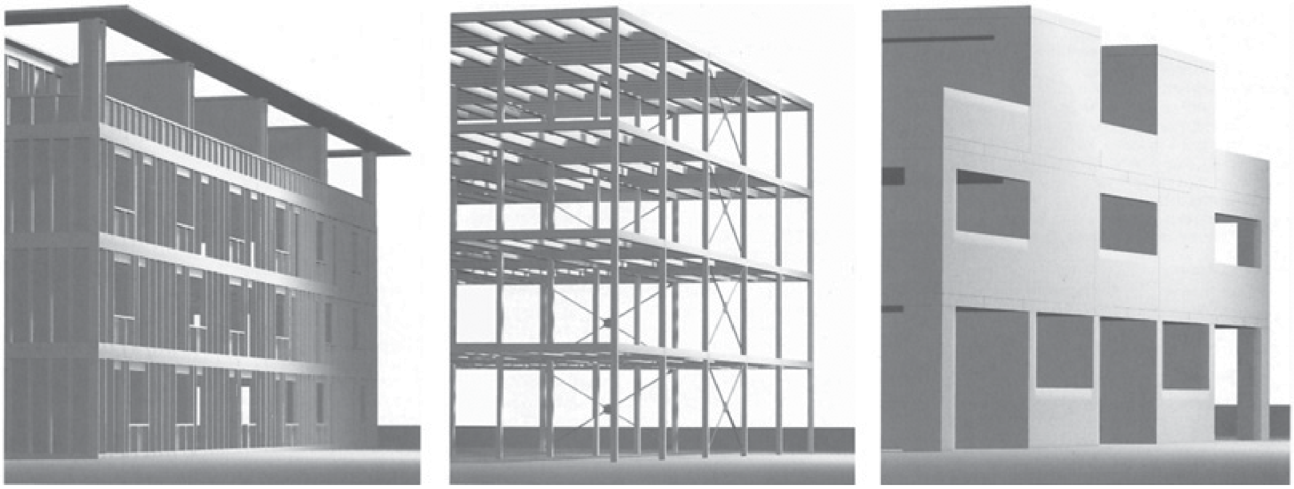


FIGURE 1.9: WOOD-BASE BUILDING CONSTRUCTION SYSTEMS
Source: Fast and Epp

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

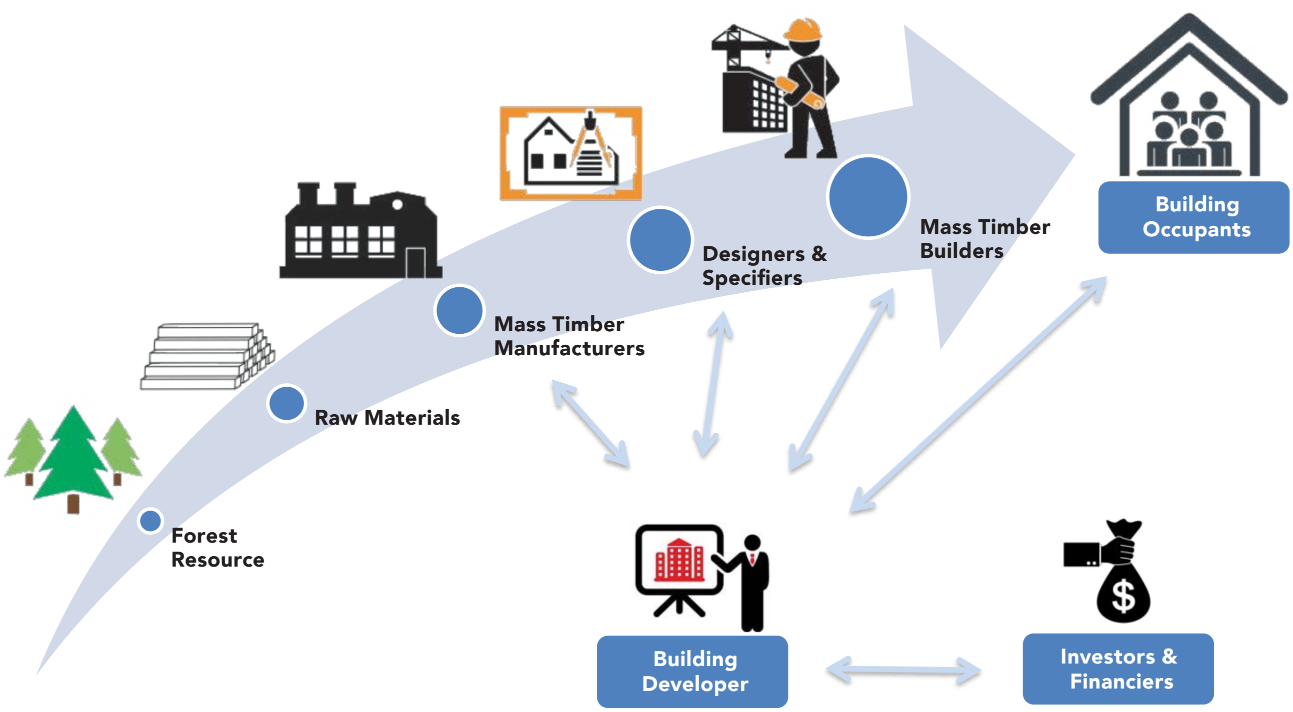


FIGURE 1.10 MASS TIMBER SUPPLY CHAIN


MAXIMIZE
Carbon Storage
with all-wood assemblies
Introducing TimberHP:
High-Performance Wood Fiber Insulation
Made in America
Project Credit: OPAL Architecture
TIMBERFILL
TIMBERBATT
TIMBERBOARD
to learn more, visit www.TimberHP.com

BALTIC POINTE, IN DRAPER, UTAH, WAS BUILT IN THE FOOTHILLS OF THE SILICON SLOPES*Source: Oakland Construction; Credit: Scott Zimmerman*

CASE STUDY: BALTIC POINTE

BALTIC POINTE: PIONEERING MASS TIMBER IN UTAH

PROJECT OWNER: THE GARDNER GROUP AND PELION VENTURE PARTNERS

PROJECT LOCATION: 14761 FUTURE WAY, SUITE 500, DRAPER, UT 84020

COMPLETION DATE: JUNE 26, 2024

ARCHITECT/DESIGNER: METHOD STUDIO

MASS TIMBER ENGINEER/MANUFACTURER: KALESNIKOFF

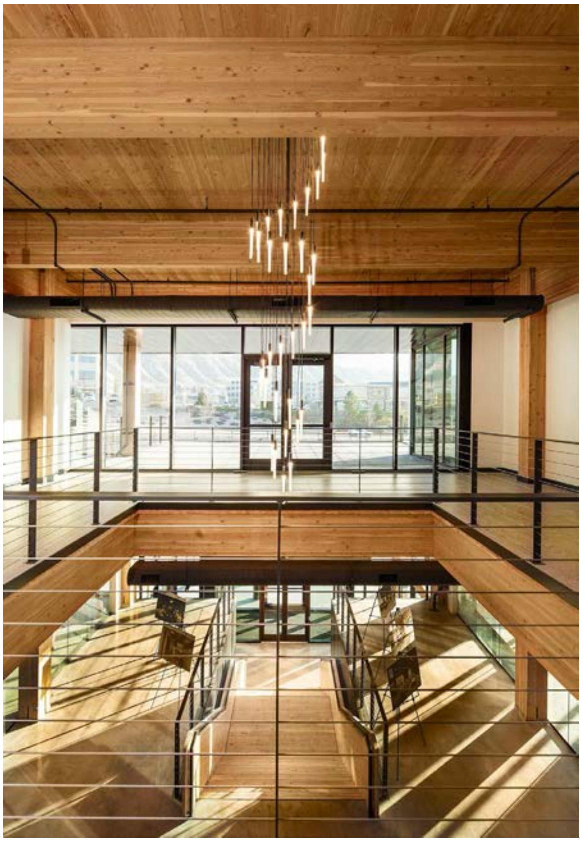
GENERAL CONTRACTOR: OAKLAND CONSTRUCTION

STRUCTURAL ENGINEER: BHB ENGINEERS

MECHANICAL, ELECTRICAL, AND PLUMBING: PVE CONSULTING ENGINEERS AND SPECTRUM ENGINEERS

OTHER CONTRACTORS: TIMBER WORKS (TIMBER ERECTOR)

BALTIC POINTE IS the first large-scale commercial mass timber building in the state of Utah, and it is featured prominently in the foothills of Utah's Silicon Slopes. A 5-story, 136,000-square-foot, mixed-use commercial office building, Baltic Pointe is the result of the shared vision between The Gardner Group, Pelion Venture Partners, and Method Studio. "Progress doesn't happen by accident; it is a purposeful act," said Ryan Bevan, president of construction for The Gardner Group. "In lieu of giving lip service to green building, we want to live what we're preaching. This project is a testament to our efforts."



THE ATRIUM AND MASS TIMBER STAIRWAY IN BLATIC POINTE

Source: Oakland Construction; Credit: Scott Zimmerman

Baltic Pointe sits on a challenging sloping site, which required a strategic site development approach. The architecture of the project was conceived in 3 distinct parts: the "plinth," a solid base that grounds the project in the hillside; the "veil," a punctured building skin that drapes itself over a thin glass facade; and the "jewel box," a warm, rich timber skeleton that embraces and enlivens the occupiable interior.

Due to the dramatic grade on the site, multiple building entrances and access points were needed. To meet jurisdictional parking requirements, Baltic Pointe rests on a 2-story (58,000 square feet) cast-in-place, reinforced concrete parking garage that serves as a podium for the mass timber construction above.

The core and shell construction of Baltic Pointe was completed in January 2024 at a total construction cost of $33,165,278. The erection of the mass timber structural frame accounts for nearly 17 percent of the total core and shell construction costs ($5,620,164). Subsequent tenant improvements have been completed, with other spaces planned for future build-out.

"We think the benefits of the prefabrication process of mass timber—compared to traditional steel and concrete construction methods—will see an offset of cost from the rising rates of labor, making mass timber more cost-effective," Bevan said. "Our hope is that Baltic Pointe sets a new precedent in Utah (and beyond) for prioritizing the use of renewable natural resources in construction."

Baltic Pointe uses Douglas-fir Cross-Laminated Timber (CLT) (3-ply) for all floors and the roof. The over 211,000 cubic feet of CLT panels and glulam columns/beams were sourced from forests in the southern interior of British Columbia, Canada. The project sequesters over 5,300 metric tons of CO_2 and helps keep over 2,000 metric tons of CO_2 from entering the atmosphere. Based on the growth rates of US and Canadian forests, the amount of wood fiber used on the project is regenerated in 16 minutes.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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

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[1] 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 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.

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

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 be sawn either 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 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 consider the nominal versus the cubic size of the lumber feedstock (see **Table 1.1**), as well as any

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

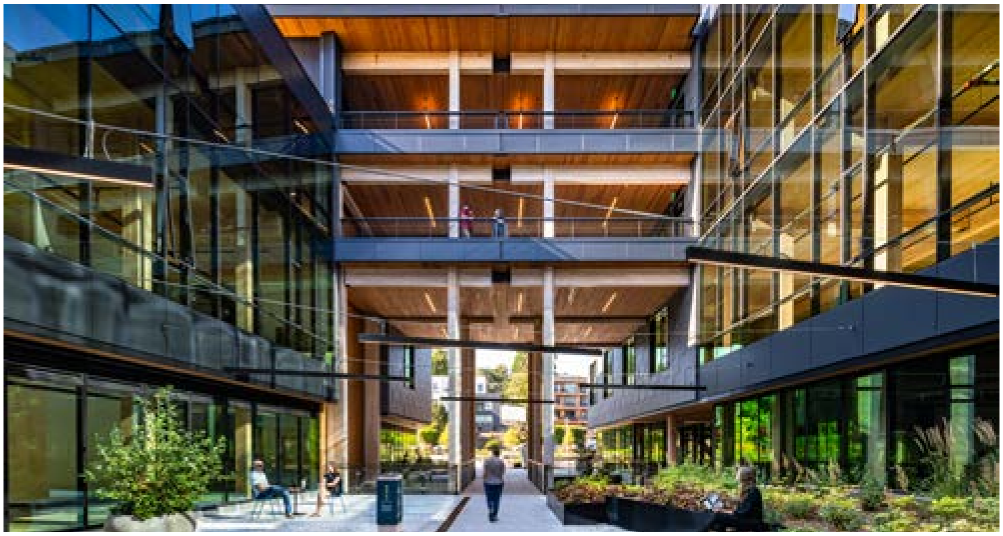
volume lost during the mass timber manufacturing process. In CLT, DLT, and glulam, the lumber is surfaced during the manufacturing process, with about $^1/_{16}$ inch removed from all 4 sides (exact amounts vary by manufacturer). Also, some volume is lost when defects are trimmed from lumber feedstock, 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.



NORTHLAKE COMMONS EXEMPLIFIES THE EVOLUTION OF HEALTHY, RESTORATIVE MIXED-USE OFFICE DESIGN
Source: Weber Thompson; Credit: Built Work Photography

CASE STUDY: NORTHLAKE COMMONS

NORTHLAKE COMMONS IS LAB-READY

PROJECT NAME: NORTHLAKE COMMONS

PROJECT OWNER: HESS CALLAHAN GREY GROUP, SPEAR STREET CAPITAL, THE DUNN LUMBER COMPANY

PROJECT LOCATION: 3800 LATONA AVE. NE, SEATTLE, WA 98105

COMPLETION DATE: JANUARY 29, 2024

ARCHITECT/DESIGNER: WEBER THOMPSON

MASS TIMBER ENGINEER/MANUFACTURER: TIMBERLAB AND KALESNIKOFF

GENERAL CONTRACTOR: SWINERTON BUILDERS, INC.

STRUCTURAL ENGINEER: DCI

MECHANICAL, ELECTRICAL, AND PLUMBING: GLUMAC

OTHER CONTRACTORS: WEBER THOMPSON (LANDSCAPE ARCHITECT)

NORTHLAKE COMMONS EXEMPLIFIES the evolution of healthy, restorative mixed-use office design. At 275,000 gross square feet (GSF), it's one of the largest mass timber lab-ready office buildings in the country with an ambitious program of:

- 163,000 square feet of office/laboratory
- 21,000 square feet of warehouse
- 3,200 square feet of Dunn Lumber retail showroom
- 8,600 square feet of retail and restaurants
- 64,500 square feet of outdoor space
- 165 parking stalls
- 200 bicycle stalls
- A stormwater treatment facility

The project transforms an underused industrial site near Seattle's Lake Union with a design that intersects at 3 core values: health, beauty, and performance, manifested through biophilic design principles.

AS AN AMBITIOUS FULL-BLOCK PROJECT, NORTHLAKE COMMONS ENCOMPASSES PEDESTRIAN AND BIKE TRAIL CONNECTIONS, A STORMWATER TREATMENT FACILITY, AND A PUBLIC PLAZA AS A NEIGHBORHOOD DESTINATION AND GATHERING POINT

Source: Weber Thompson
Credit: Built Work Photography

HEALTH

A post-COVID resurgence of daily commutes downtown weighs heavily on many workers. Addressing the need for healthy work environments and services closer to urban neighborhoods, Northlake Commons stands at the edge of a residential area along Lake Union. Stitching into the urban fabric, a new pathway branches off the 27-mile Burke-Gilman Trail, welcoming building users and the public to the site. A meandering walkway through a public plaza culminates in a lake overlook and a feature staircase, completing a through-block connection. With outdoor spaces on every floor that foster visual or physical connections to nature and community, human well-being is central to the development.

Integrating designs that benefit the health of the urban ecosystem, Northlake Commons includes a regional stormwater biofiltration system that cleans 2.6 million gallons of polluted neighborhood runoff before it reaches Lake Union. Landscaped with native plantings that provide habitat for birds, bees, and pollinators, a swale naturally filters out harmful chemicals that would endanger migrating salmon populations and other marine life.

BEAUTY

Embodying the experience of being deep within a Pacific Northwest forest, the biophilic design concept expresses the distinct layers of a forest's floor, understory, and canopy. Each layer is conceptually represented, from a sunken garden below the public plaza to the towering treelike columns that support a canopy of outdoor workspaces. Every level opens to verdant plantings, wood-grain patterns, or views of Lake Union.

Northlake Commons' materiality honors the 100-year family legacy of the Dunn Lumber Company operating on-site. The building's form takes inspiration from mortise and tenon joinery used in furniture and boat building to create strong connections. With spruce, pine, fir (SPF) Cross-Laminated Timber (CLT) panels, and Douglas-fir glulam beams and columns, the senses can engage with the visual, olfactory, and tactile qualities of wood.

PERFORMANCE

Leadership in Energy and Environmental Design (LEED) Platinum certified, Northlake Commons is a case study in carbon-conscious design, illustrated through its efficient use of mass timber, a slower-cure concrete mix, and a steel Buckling Restrained Braced (BRB) frame lateral system. Together, these strategies reduce embodied carbon by 23 percent compared with a similar concrete-only building. The project also achieved 27 percent energy savings over a LEED baseline.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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. Perhaps their main importance to society is providing a source of fresh water. 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 and then release it into the atmosphere by transpiration. Water ultimately returns to earth in the form of rain. Forests also serve as a major carbon sink. Through photosynthesis, trees remove carbon from the atmosphere as they grow. Forests also allow people to participate in outdoor recreational 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: coniferous (softwood) trees in the coastal and mountainous areas of the West and in the US Southeast; and mixed hardwood and coniferous trees in the US Midwest, Eastern US, and Eastern Canada. 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 trees, 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. For example, yellow poplar (Liriodendron tulipifera) is a hardwood being tested for use in Cross-Laminated Timber (CLT). It is common in the forests of the US east of the Mississippi River and from North Florida northward to the Great Lakes.

As further discussed in chapter 3, the forest products industry commonly categorizes North America into 5 distinct softwood lumber-producing regions: US West, US South, US Other, Eastern Canada, and Western Canada. The categorization is based on a combination of geography and the species of softwood trees most commonly present in each region. For example, 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 most common species. 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. Forests in those regions are typically 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).

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)

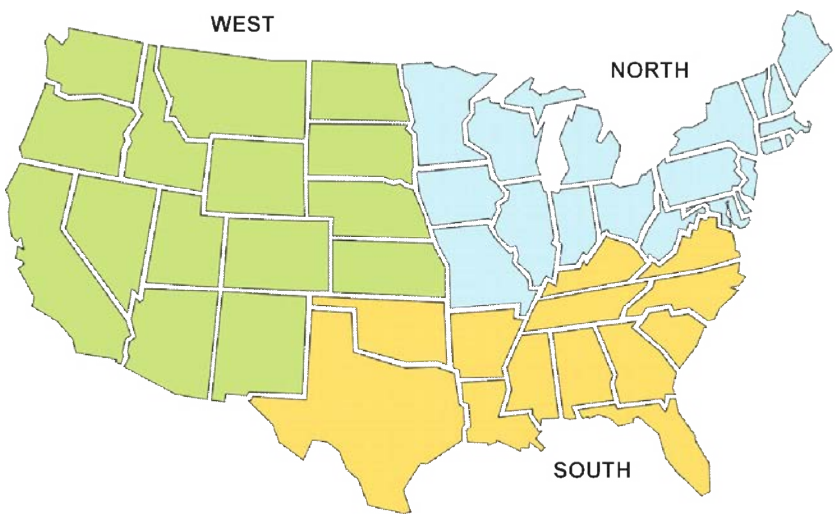


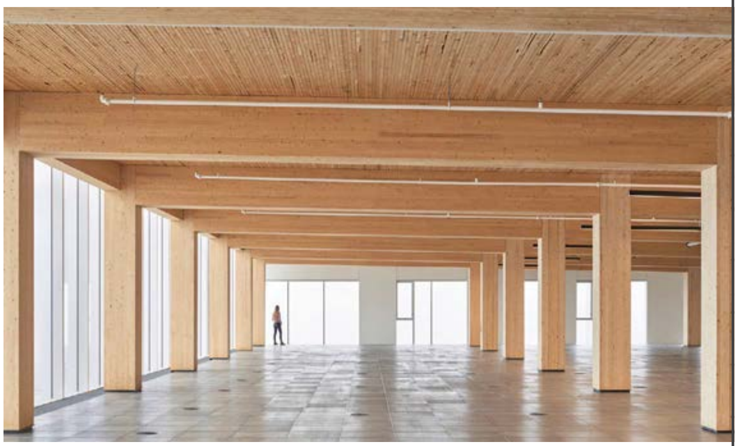
FIGURE 2.2: MAP OF US FOREST REGIONS

US Forests

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 the 822 million acres is composed of 765 million acres defined as forestland and 57 million acres defined as woodland according to the *Forest Atlas of the United States*.[1] While both categories can be described as land containing trees, the distinction is that forestland contains a greater density of trees than woodlands, and forestlands are capable of growing more volume per acre per year. Regardless, the extent of forestland and woodland has been stable in the US since the early 1900s. The extent of forests in the US has been stable even though the US population has more than quadrupled since 1900. Despite the massive growth in the 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.

1 Charles H. Perry, Mark V. Finco, and Barry T. Wilson, *Forest Atlas of the United States*, 2022, https://www.fs.usda.gov/.



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)

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.**

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.

CONSTRUCTION IS UNDERWAY AT JULIA WEST HOUSE IN PORTLAND, OREGON

Source: Walsh Construction Co.

CASE STUDY: JULIA WEST HOUSE

MASS TIMBER DESIGNED FOR PERMANENT SUPPORTIVE HOUSING

PROJECT OWNER: COMMUNITY DEVELOPMENT PARTNERS

PROJECT LOCATION: 580 SW 13TH AVE., PORTLAND, OR 97205

COMPLETION DATE: AUGUST 25, 2025

ARCHITECT/DESIGNER: HOLST ARCHITECTURE

MASS TIMBER ENGINEER/MANUFACTURER: KALESNIKOFF

GENERAL CONTRACTOR: WALSH CONSTRUCTION CO.

STRUCTURAL ENGINEER: KPFF

MECHANICAL, ELECTRICAL, AND PLUMBING: PAE

OTHER CONTRACTORS: CARPENTRY PLUS INC. (MASS TIMBER SUPPLY AND INSTALL), VEGA (CIVIL ENGINEER), UNDERSTORY (LANDSCAPE)

JULIA WEST HOUSE, a permanent supportive housing development designed for aging adults experiencing houselessness, is a compelling example of how mass timber can be a viable option for affordable housing while delivering sustainable and beautiful residences. Located on an eighth of a block in downtown Portland, the 5,000-square-foot site was underutilized as an abandoned low-rise structure with surface parking. Close to health-care services, amenities, and public transportation, the new 12-story, 56,000-square-foot high-rise provides vital connections to the neighborhood as well as in-house services.

A STUDIO UNIT RENDERING HIGHLIGHTS THE EXPOSED CLT CEILINGS

Source: Holst Architecture

Early consideration of mass timber was a key driver of the project's success. Cost comparisons from Walsh Construction Co. during schematic design indicated a 2 percent premium for type IV-B Cross-Laminated Timber (CLT) with glulam post and beam compared to an all-concrete building. The associated 14-week schedule savings, however, made mass timber a compelling option due to lower soft costs. Urban site constraints also influenced the feasibility of mass timber, given the proximity of adjacent streets and other structures. KPFF's Life Cycle Analysis (LCA) of structural system options further supported the use of mass timber, revealing a favorable carbon footprint when compared to conventional building systems. With overall benefits outweighing added cost, Community Development Partners proceeded with CLT, motivating the team to assess code and jurisdictional requirements as one of the first examples of Type IV-B all-wood construction in the US.

Capitalizing on Oregon's early adoption of 2024 International Building Code (IBC) allowances, the design team took advantage of the inherent qualities of mass timber and prioritized the visibility of CLT in key areas that occupants will experience daily. Tall wood ceilings in living and sleeping areas create a sense of openness that belies the modest footprint. Common areas expose as much of the structure as possible while concealing mechanical, electrical, and plumbing (MEP) systems. Designing with mass timber for housing requires careful coordination of building systems to avoid conflicts. The structural team proved the efficacy of 2-way panel spans in corridors based on recent testing, simplifying mechanical routing into units without the complication of beams. Double beams cantilevering the building over the sidewalk also provide convenient locations to drop plumbing between units. Using CLT floors as the diaphragm avoided the need for structural concrete above grade, and sizing wood members to maximize char decreased the overall quantity of gypsum board required for fire resistance.

Designing within the new Type IV-B code required collaboration with building officials early in the project to align interpretation of requirements and ensure a smoother process through permitting. This became especially significant when detailing the 2-hour-rated exposed wood connections and intersections of mass timber with the steel brace frame lateral system. Prescriptive code requirements, paired with existing fire tests and FPE support, helped prove the design's adequate performance to code officials, hopefully easing the way for future high-rise mass timber buildings.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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)

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. 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.

US Standing Timber Inventory

The US Forest Service is a federal agency charged with managing nearly 190 million acres of national forests and grasslands. Its US 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 almost 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

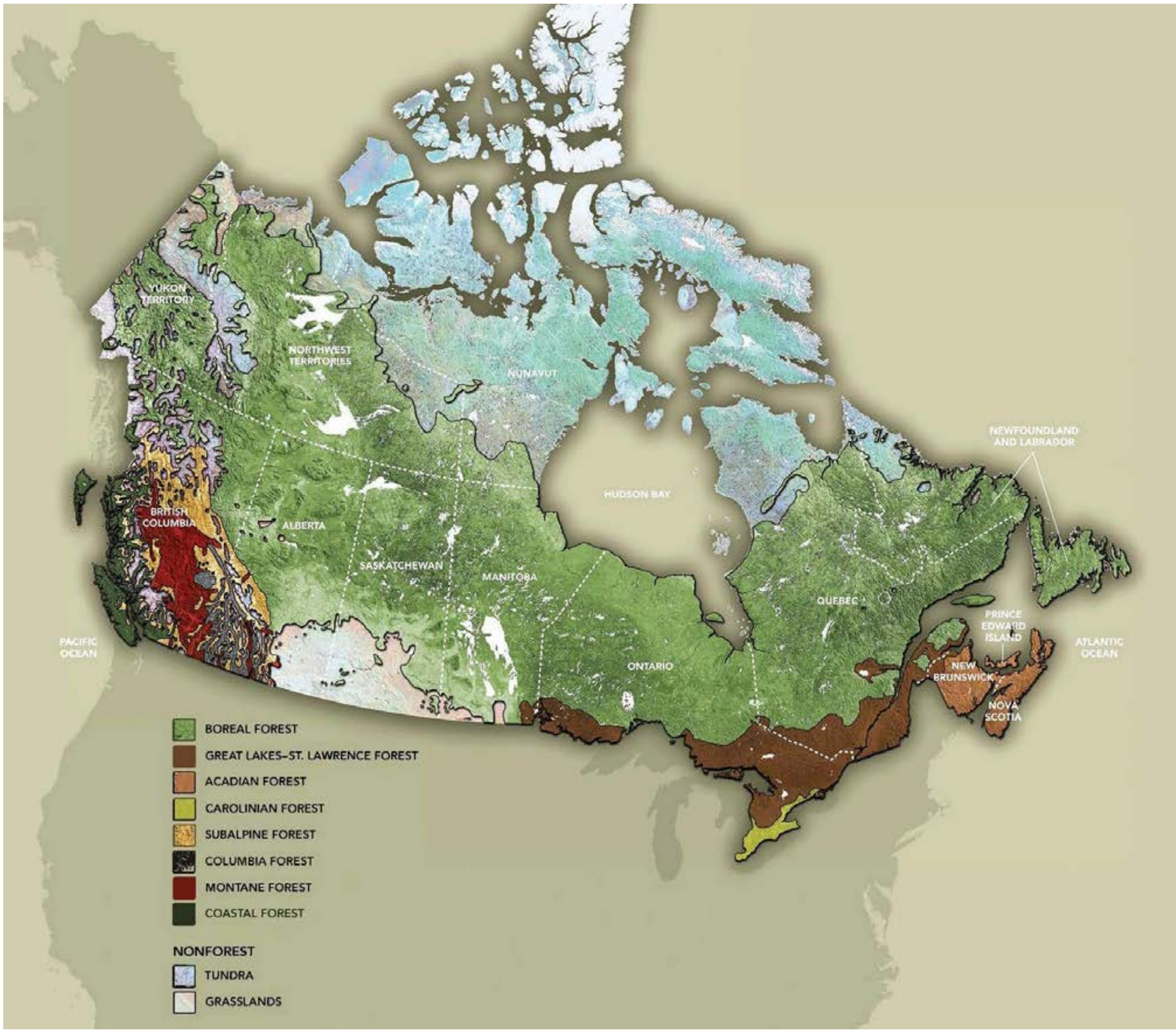


FIGURE 2.3: CANADIAN FOREST REGIONS

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

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.

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

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
2021	1,772,727

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

has been very stable for more than 3 decades. **Figure 2.3** shows several distinct types of forest in Canada. The largest and most commercially important types include a vast boreal forest that stretches the width 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 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: provincial Crown land, territorial Crown land, federal Crown land, private land, and Indigenous land.

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)

Canada's Standing Timber Inventory

The standing timber inventory in Canada as of 2020 was 1.75 trillion cubic feet, nearly 60 percent more standing timber volume than the United States, according to *The State of Canada's Forests: Annual Report 2023*.[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 the decline 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. As previously described, the area of forestland and woodland has been stable for a long time. However, the following sections provide several additional measures of forest sustainability as reported by the US Forest Service's *National Report on Sustainable Forests*.[3]

Another element of sustainability is that forests are growing significantly more wood than is removed by harvests or lost to mortality. Nationwide, net growth is about double annual removals. However, the increasing extent and severity of forest disturbances have had an impact on growing stock. Specifically, the Rocky Mountain Region experienced a decline in growing stock despite a low harvest in the region. Rather, excessive natural mortality from a combination of fire, disease, and insects led to a net loss of growing

2 *The State of Canada's Forests: Annual Report 2023*, https://natural-resources.canada.ca/sites/nrcan/files/forest/sof2023/NRCAN_SofForest_Annual_2023_EN_accessible-vf(1).pdf.

3 Kathleen McGinley, Lara Murray, Guy Roberston, and Eric M. White, *National Report on Sustainable Forests, 2020, 2023*, FS-1217. https://research.fs.usda.gov/treesearch/66829.

stock. In addition to timber harvest, wildfire, insects, and disease, drought is a forest disturbance agent that is affecting forests. This is especially true in the Rocky Mountain Region and the Pacific Coast Region.

Yet another criterion of sustainability is conservation and maintenance of soil and water resources. Assessment of water bodies suggests that they are in poor condition. However, the main cause of this finding does not appear to be due to poor forest management practices. In fact, research shows that silvicultural activities are not a cause of water pollution. Research has also shown that the percentage of forest soils with high levels of acidification continues on a decreasing trend. The condition of water bodies and soils is important to sustainability because both are key to ecosystems providing food, habitat, and resources that all living things need.

Forest carbon is an increasingly important aspect of forest health and sustainability. Forest ecosystems are the largest terrestrial carbon sink on the planet. For example, in 2018, US forests were estimated to take up nearly 550 million metric tons of carbon dioxide equivalent. Since most forests continue on the trend of increasing standing inventory year over year, forests are net carbon sinks. However, as previously described, in some regions, forest disturbances such as fire, drought, insects, and disease have caused forests to be a net emitter of carbon. Chapter 9 provides a more detailed analysis of forest carbon.

Species richness (the number of unique species in an area) is another frequently used 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, projects 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). 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.

Environmental Forest Management Certification

Many forest landowners manage their land with multiple objectives in mind and consider sustainability in their planning and decision-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 sourcing 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 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 of 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:

- <u>American Tree Farm System (ATFS):</u> 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 with about 36 million certified in the US and the balance in 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 (BMPs) 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.

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.

2.3 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 abnormally large quantities of green and dead trees, and thickets of brush. The fuel buildup is particularly acute in western

FIGURE 2.4: EXAMPLE OF A HIGH-INTENSITY FOREST FIRE

North America. High-intensity wildfires are ever more common, with proportionately severe consequences (see **Figure 2.4**).

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 expensive 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 2.5** shows how forest management from the Black Hills Project affected the Bootleg Fire's behavior in Oregon 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.

FIGURE 2.5: 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/

The post-fire aerial photo shows the fire's differing impact on each area. The area that was only thinned was moderately impacted, the untreated area was severely impacted, and the thinning and prescribed fire area suffered 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.

THE V-SHAPED WOODEN COLUMNS ADD TO THE QUIET ELEGANCE OF THE SOUTHWEST LIBRARY

Source: Perkins&Will; Credit: Jim Steinkamp Photography

CASE STUDY: SOUTHWEST LIBRARY DC

MASS TIMBER TRANSFORMS A NEIGHBORHOOD LIBRARY INTO A CITY ICON

PROJECT OWNER: DC PUBLIC LIBRARY

PROJECT LOCATION: 900 WESLEY PLACE, WASHINGTON, DC 20037

COMPLETION DATE: MAY 11, 2022

ARCHITECT/DESIGNER: PERKINS&WILL

MASS TIMBER ENGINEER/MANUFACTURER: STRUCTURECRAFT

GENERAL CONTRACTOR: TURNER CONSTRUCTION

STRUCTURAL ENGINEER: STRUCTURECRAFT

MECHANICAL, ELECTRICAL, AND PLUMBING: INTERFACE ENGINEERING

THE DESIGN CONCEPT for the new Southwest Library is a "pavilion on the park." It offers pathways that encourage the community to explore the library and embrace it as an intuitive part of their neighborhood experience.

The library incorporates biophilic design, promoting the user's connection to nature and creating a calming and restorative feeling that promotes health and well-being. From a distance, the folded plate Dowel Laminated Timber (DLT) roof opens toward the park and invites the public to enter. The

TOP — THE SOUTHWEST LIBRARY'S DESIGN PROMOTES PEOPLE'S CONNECTION TO NATURE

BOTTOM — THE DESIGN MAKES LIGHT A FEATURE OF THE SOUTHWEST LIBRARY'S READING ROOM

Source: Perkins&Will Credit: Jim Steinkamp Photography

roof provides a compelling visual element evoking an open book and creates a sheltering canopy that is an extension of the trees outside of the building.

The V-shaped wooden columns supporting the roof further enhance the warm welcome and the quiet elegance of the building. Inside, expansive windows offer sweeping views of nature and the beauty of the surrounding park while flooding the interior with natural light. More than 90 percent of the interior spaces have access to exterior views.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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. Because kiln-drying is often the bottleneck in a sawmill's annual lumber output capacity, 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.

3.1 RAW MATERIAL SPECIFICATIONS

The following sections summarize the specifications for sawn lumber and Structural Composite Lumber (SCL) used in mass timber products.[1] 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

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. The parallel axis can also be 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, is the portion of *ANSI/APA PRG 320-2019* 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 or species combination (e.g., hem-fir; fir-larch; or spruce, pine, fir [SPF]) recognized by the American Lumber Standards Committee (ALSC) under PS20 or by the Canadian Lumber Standards Accreditation Board (CLSAB) under CSA-0141 with a minimum published specific gravity of 0.35 is permitted.[2] 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 millimeter) across the width of the layer, and plus or minus 0.012 inch (0.3 millimeter) across the length of the layer. Per *PRG 320*, any bow or cup "should be small enough to be flattened out by 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.

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.

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.*

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 be at least 1.75 times the net lamination thickness. For transverse layers, the net width of a board must be at least 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 before 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 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 (e.g., raised grain, torn grain, skips, burns, glazing, or dust). ANSI and 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.

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; 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.

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 a moisture content of 19 percent or less at the time of manufacture. Note that the hardwood dowels used to join 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, so 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.

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).

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.*

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.

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 APA that describe the specifications of lumber to be used in glulam timbers.

ARVOREDO, BRAZIL'S NEW MASS TIMBER RESIDENTIAL CONDOMINIUM, OFFERS A ONE-OF-A-KIND LIVING EXPERIENCE
Source: Noah Tech

CASE STUDY: ARVOREDO

ARVOREDO: THE FIRST MASS TIMBER RESIDENTIAL CONDO IN BRAZIL

PROJECT OWNER: NOAH TECH

PROJECT LOCATION: RUA ARAIOSES, 201, SÃO PAULO, SÃO PAULO, 05442-010

COMPLETION DATE: APRIL 2, 2025

ARCHITECT/DESIGNER: GRUPO SP ARQUITETOS

MASS TIMBER ENGINEER/MANUFACTURER: URBEM

GENERAL CONTRACTOR: NOAH TECH

STRUCTURAL ENGINEER: STAMADE

THE ARVOREDO CONDOMINIUM is an innovative project that represents a significant leap forward in sustainable construction in Brazil, being a pioneer in the use of mass timber for residential developments. Situated in Vila Madalena, one of São Paulo's trendiest neighborhoods, the development comprises 6 units of 4-story townhomes, with areas ranging from 390 square meters to 466 square meters.

The project's standout feature is its hybrid structural design, using concrete in the foundations and leisure areas, while Cross-Laminated Timber (CLT) and glulam form the main structure of

A LIVING ROOM AT ARVOREDO
Source: Noah Tech

the houses, ensuring construction precision and efficiency. This combination was essential for managing the site's challenging topography, and the mass timber method facilitated construction while optimizing space utilization, seamlessly integrating the project with the terrain.

Mass timber, a renewable resource, was selected not only for its environmental benefits but also for its acoustic and thermal insulation properties, ensuring a comfortable and quiet indoor environment for residents. Furthermore, the material contributes to carbon sequestration, storing approximately 600 tons of CO_2 within the structure.

For the Arvoredo townhouses, the choice of fixation system was critical to ensure precision and safety during the assembly of the mass timber structures. All screws for connecting slabs and beams, as well as the fixation plates for the CLT walls, were supplied by Rothoblaas, ensuring high structural performance and ease of assembly. A key innovation was the use of custom-designed 3-in-1 connectors created specifically for the project. These connectors were engineered to lift, lock, and position the columns and beams efficiently, reducing the need for multiple components and streamlining assembly. This efficient construction methodology is driven by the integration of advanced technologies, such as three-dimensional (3D) simulations that optimize assembly schedules and minimize conflicts.

In addition, sunlight and ventilation simulations were conducted to maximize thermal comfort and natural lighting, qualities inherent to mass timber structures. For logistical planning, comprehensive studies were carried out, including route simulations for timber deliveries using Autodesk's Vehicle Tracking, ensuring smooth truck maneuvering despite the site's complex topography.

Developed by Noah Tech, the Arvoredo project was designed to educate and introduce the Brazilian residential market to the benefits of mass timber. Strategic partnerships were essential to the project's success, including collaboration with Urbem, the manufacturer of all its mass timber components; Dexco, responsible for the finishes; and Rothoblaas, provider of the fixation system. Working alongside experts and suppliers ensured that Arvoredo met the highest sustainability standards, offering a one-of-a-kind living experience in Brazil. By blending technological innovation, sophisticated design, and environmental responsibility, Arvoredo illustrates how cutting-edge technology and respect for the environment can reshape urban living in major cities.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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

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 ⅙ 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 ⅓. When wane is limited to one side of a member, the basic shear design value is reduced by ⅙. 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).

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, a 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 timbers have been sawn but not planed; and hewn timbers have been shaped using an axe or other similar tool.

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.

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.[3]

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

3 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.

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 layups of *ANSI/APA PRG 320* that employ product qualification and mathematical models that use principles of engineering mechanics. 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 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.

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.

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 North America from 2020 to 2024. As the data shows, for those 5 years, on average, 39.1 percent of all softwood lumber consumed was for repair and remodeling, followed by nearly 33 percent for residential construction. Thus, historical softwood lumber demand has largely been tied to either new home construction, or the repair and remodeling of existing homes. In the early 2000s, more than 40 percent of all lumber used in North America was for new home construction, and about 26 percent was for repair and remodeling. Since then, the proportion used for new home construction has declined while the proportion used for repair and remodeling has increased.

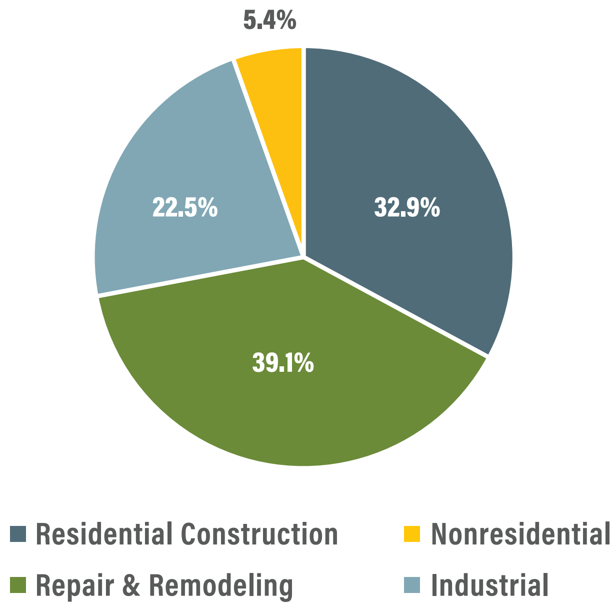


FIGURE 3.2: LUMBER CONSUMPTION BY END-USE MARKET SEGMENT (2020–2024)

Source: Forest Economic Advisors

The industrial end-use segment has averaged about 22.5 percent of all lumber consumed in North America over the last 5 years. It is typically lumber used for applications such as packaging, pallets, and

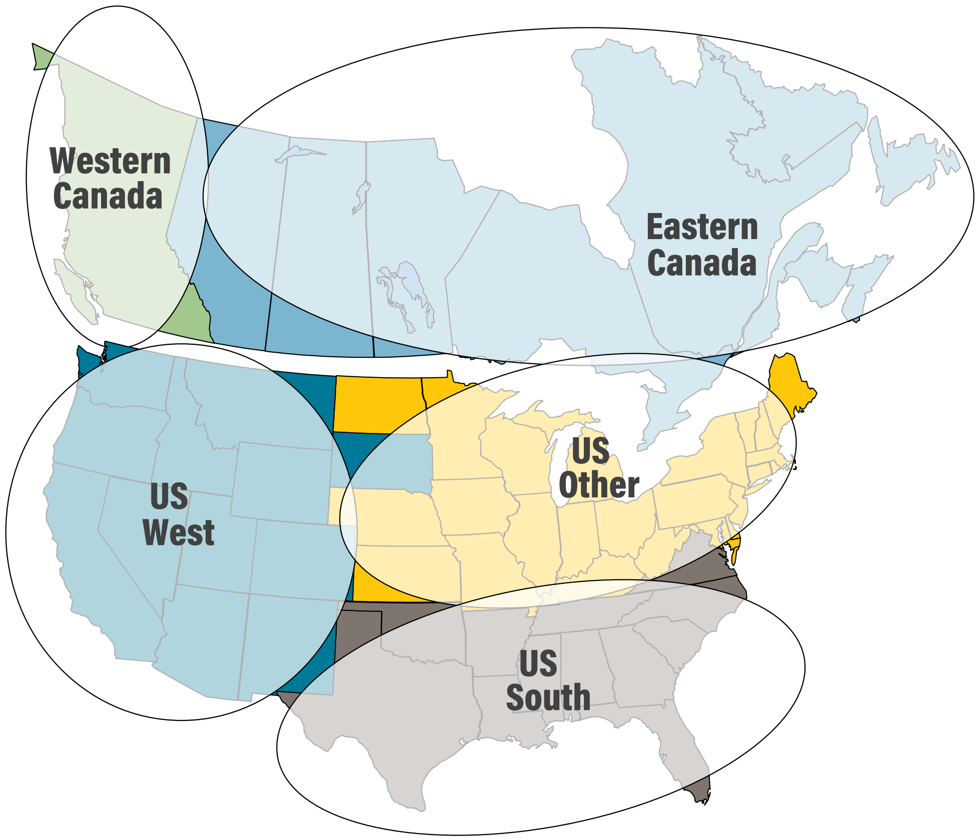


FIGURE 3.3: NORTH AMERICAN SOFTWOOD LUMBER-PRODUCING REGIONS

furniture, which use the lower grades of lumber. Nonresidential construction's share has grown from about 5 percent of all softwood lumber consumed in North America in 2020 to about 6.4 percent in 2024. This trend is driven in large part by the rising demand from mass timber construction. 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.

Where Softwood Lumber Is Produced in North America

Softwood lumber in North America is produced in 5 regions: US West, US South, US Other, Western Canada, and Eastern Canada, as shown in **Figure 3.3**. 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 species in 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 2024 as reported by the WWPA (2024 is a forecast based on the first 8 months of the year) is shown in **Figure**

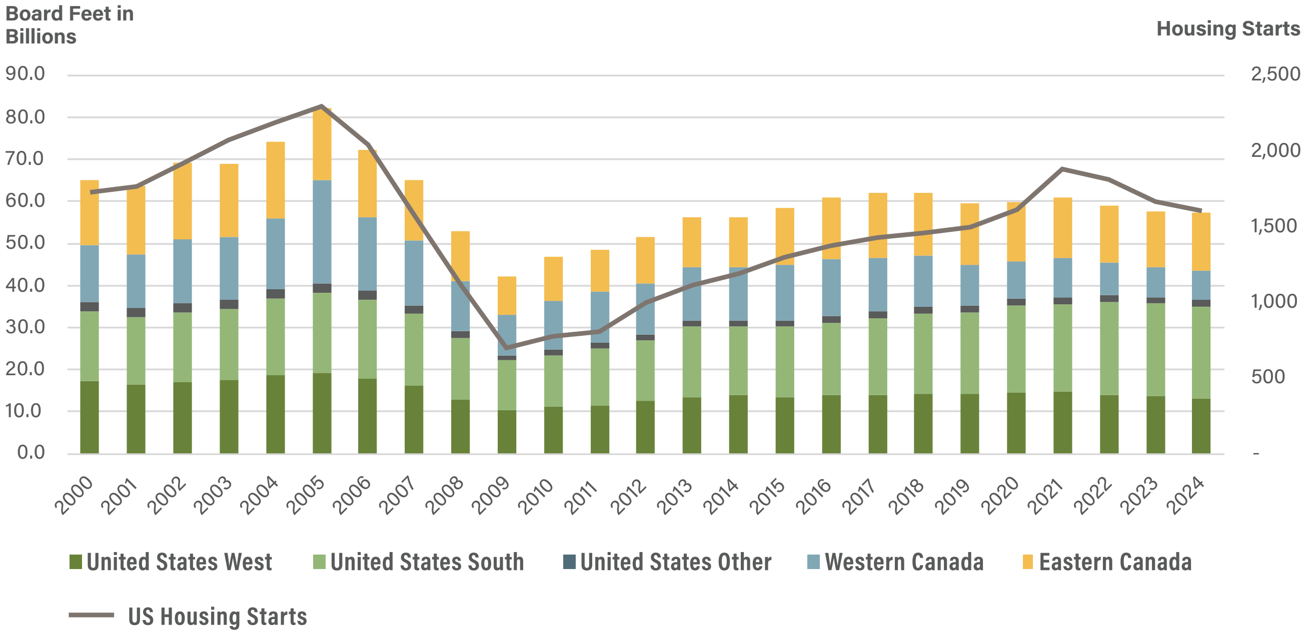


FIGURE 3.4: HISTORICAL UNITED STATES AND CANADIAN SOFTWOOD LUMBER PRODUCTION BY REGION (BOARD FEET IN BILLIONS) & HOUSING STARTS

Source: Western Wood Products Association

3.4. Note that there are some differences in lumber production and consumption (i.e., some lumber produced is in inventory and may not be sold in the same year it is produced). 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 North America. This is shown in the figure by the line. It 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 housing starts. However, in recent years, that relationship appears to be weakening. Housing starts have trended downward since 2021, but at a faster rate than the decline in lumber consumption. Housing starts have dropped by an average of about 5 percent year over year since 2021, while lumber consumption has dropped an average of about 2 percent

year over year since 2021. This discrepancy in long-standing trends is likely largely driven by an increase in softwood lumber consumption in repair and remodeling that occurred during the COVID pandemic. These trends are an important issue in North American lumber supply-and-demand dynamics and are 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 2024. 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; 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 old-growth forests that were not already set aside from logging. Those harvest deferral plans are constraining log supply in the regions and translate into a reduction of about 1.4 billion board feet per year in lumber production compared with 2022 levels. Another issue likely to affect lumber production in both Western Canada and Eastern Canada in 2025 is that the incoming US federal government administration has promised increased tariffs on all goods imported into the US, including softwood lumber. The tariffs are likely to further dampen Canadian lumber production.

US South

There are also major changes still 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 2024 the US South's production tallied 21.8 billion board feet compared to only 13.3 billion board feet in the US West. 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 and improved forest management has reduced timber harvest rotations in the region to about 30 years and 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 standing 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 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 past several years, driven by $2.5 billion of capital investment in new and upgraded sawmilling infrastructure in the region. Despite the increased capacity, some regions still have 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. In other words, the 2024 production level of 21.8 billion board feet is well short of the capacity in place in the region. Lower production levels in 2024 are primarily the result of weaker demand in contrast to the log supply issues affecting the US West and Western Canada.

US West

Lumber production in the US West totaled 13.3 billion board feet in 2024, a decrease of about 300 million board feet from 2023. 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 constraining lumber production in the US West 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; 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.

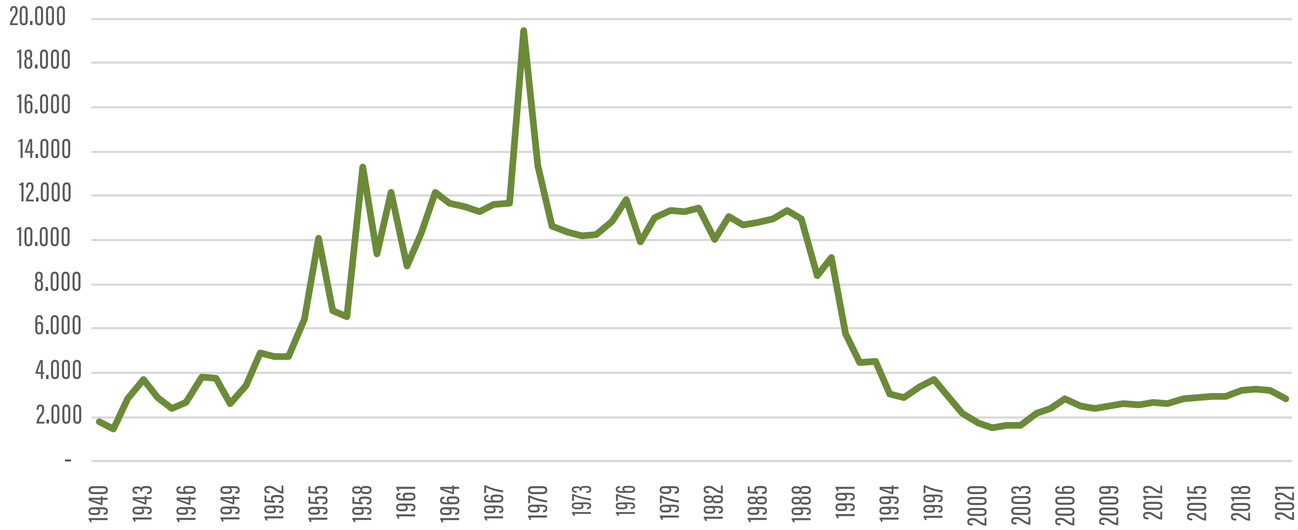


FIGURE 3.5: HISTORY OF US FOREST SERVICE TIMBER SALES IN FISCAL YEAR 1940 TO FISCAL YEAR 2021 (ANNUAL VOLUME BOARD FEET [LOG SCALE] IN BILLIONS)

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

In the meantime, increased lumber production is largely held in check by limited log supply.

The log supply situation is not improving in the US West. In Oregon, the single largest lumber-producing state in the US, 2024 witnessed the full implementation of the Oregon Private Forest Accord, an agreement between timber and conservation groups to change the state's Forest Practices Act. 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 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 accepted a Habitat Conservation Plan (HCP) that reduces timber harvests. Similar issues are affecting Washington, where harvests on state-managed lands are in decline. The net effect of these supply constraints in the Pacific Northwest was that a total of 7 sawmills permanently ceased operation in Oregon and Washington in 2024. Nearly all cited log supply constraints as the key contributing factor.

Eastern Canada

Lumber production in Eastern Canada in 2024 was 14 billion board feet. Over the past 10 years this region has averaged annual production of 14.3 billion board feet. So 2024 was about 2 percent below average, which is consistent with the overall North American drop in lumber production in 2024. Key factors affecting Eastern Canada are that parts of the region are a long distance 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

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 2024 PRODUCTION (BBF)
US West	55%	7.3	5%	0.7	5%	0.7	35%	4.6	13.3
US South	80%	17.5	10%	2.2	5%	1.1	5%	1.1	21.8
US Other	20%	0.3	n/a	n/a	n/a	n/a	80%	1.2	1.5
Western CA	75%	5.1	n/a	n/a	n/a	n/a	25%	1.7	6.8
Eastern CA	50%	7.0	n/a	n/a	n/a	n/a	50%	7.0	14.0
North America Total		**37.2**		**2.8**		**1.8**		**15.7**	**57.4**

TABLE 3.4: ESTIMATED NORTH AMERICAN SOFTWOOD LUMBER THICKNESS MIX IN 2024 (BOARD FEET IN BILLIONS)

supplied with residue from sawmills. As demand for newsprint dwindled, producing lumber 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.

2024 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 WWPA's estimated North American softwood lumber production volumes for 2024. The percentages of production by size values are estimates from sawmill industry benchmarking data collected by the Beck Group. Of the estimated 57.4 billion board feet of lumber produced in North America in 2024, about 37.2 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%	2.6	55%	4.0	5%	0.4	5%	0.4	7.3
US South	40%	7.0	40%	7.0	10%	1.7	10%	1.7	17.5
US Other	10%	0.0	55%	0.2	20%	0.1	15%	0.0	0.3
US Total		**9.6**		**11.2**		**2.2**		**2.2**	**25.1**

TABLE 3.5: ESTIMATED US SOFTWOOD DIMENSION LUMBER GRADE MIX IN 2024 (BOARD FEET IN BILLIONS)

Similarly, it is useful to understand the grade mix, as shown in **Table 3.5**. Using WWPA's 2024 production estimates and the Beck Group's sawmill benchmarking data, the table shows that over 80 percent (20.7 billion board feet out of 25.1 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 7.4 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.

Softwood Lumber Pricing

The purchase of raw material is the single largest cost associated with manufacturing mass timber products, accounting for 50 percent to 75 percent of a plant's total operating cost with the exact point in the range depending mainly on the level of lumber prices. Lumber pricing, therefore, is a key focus 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 35.5 billion board feet per year in 2015 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

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%	2.9	30%	2.2	10%	0.7	10%	0.7	10%	0.7	7.3
US South	25%	4.4	30%	5.2	20%	3.5	15%	2.6	10%	1.7	17.5
US Other	40%	0.1	30%	0.1	10%	0.03	10%	0.03	10%	0.03	0.3
US Total		7.4		7.5		4.3		3.4		2.5	25.1

TABLE 3.6: ESTIMATED US SOFTWOOD DIMENSION WIDTH MIX IN 2024 (BOARD FEET IN BILLIONS)

third-quarter prices just under $500 per 1,000 board feet. 2022 started out much the same, with prices in the first quarter averaging over $1,200 per 1,000 board feet but then trending steadily downward through the remainder of the year to finish around $500 per 1,000 board feet. 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 board feet during the year.

For a longer-term perspective, from 2000 to 2020 the price of dimension lumber in North America averaged roughly $335 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 $225 per 1,000 board feet. The high point was in mid-2018 when prices approached $600 per 1,000 board feet. In 2021 and 2022, 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 approaching and even exceeding $1,000 per thousand board feet in some cases. Reality set in again in 2023 and 2024 when lumber prices returned to levels more in line with long-term trends, hovering just above $400 per thousand board feet in 2023 and just under that level in 2024. Some industry observers, however, believe that the current levels of anemic demand are masking the impact that log supply shortages in western North America will have on lumber prices. In other words, a relatively small spike in demand could bring on disproportionately larger changes in lumber prices because key producing regions in western North America have limited access to logs to increase production to meet demand.

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. Sourcing is especially important for developers seeking to certify a building under Leadership in Energy and Environmental Design (LEED) and similar programs. In addition, large tech companies such as Google and Facebook, which 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 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 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 most consumers consider this attribute 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 expense and the limited market demand, 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 products as possible, regardless of demand from customers.

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 was 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 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.

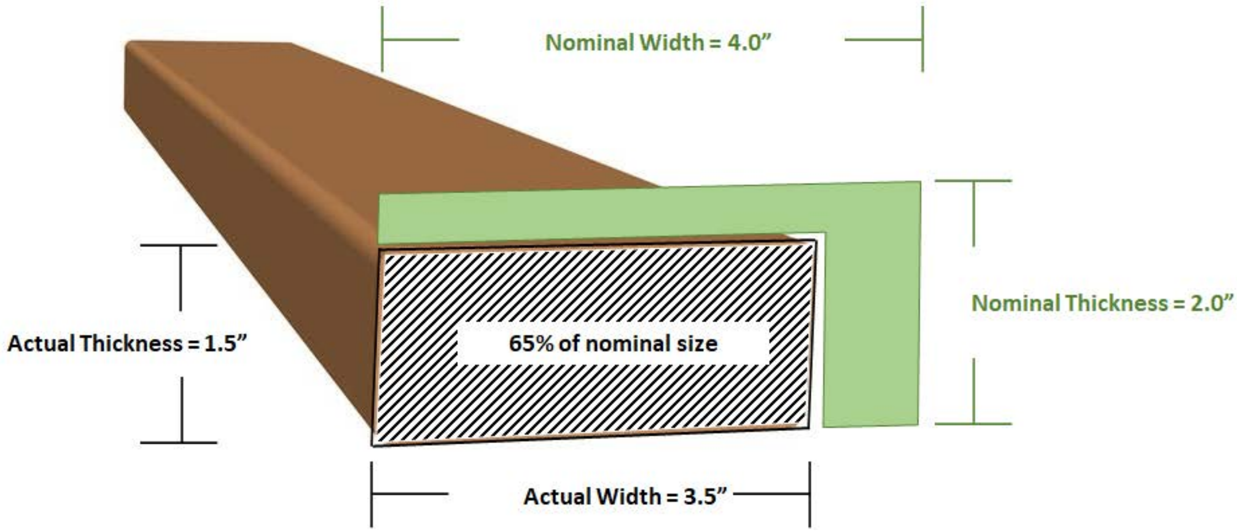


FIGURE 3.6: COMPARISON OF NOMINAL AND ACTUAL DIMENSIONS FOR BOARD FOOT LUMBER TALLY

Source: The Beck Group

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.

3.3 COMMENTARY ABOUT MASS TIMBER AND LAMSTOCK LUMBER SUPPLY

In North America, lumber use in nonresidential construction has risen slowly but steadily from

	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)	Airspace %
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

about 2.0 billion board feet per year in 2011 to about 3.7 billion board feet in 2024. The rise of mass timber building construction is a key contributing factor. However, nonresidential construction is still a small market compared with the amount of lumber consumed in building and remodeling homes and industrial uses. As shown in **Figure 3.2**, nonresidential construction accounts for only about 5 percent of the total North American softwood lumber market. This fact has several important implications on the supply of lumber available to mass timber panel and glulam manufacturers.

First, drying lumber to the lower moisture content needed for mass timber panel and glulam construction translates into higher cost because of the extra drying time and energy expense. Increasing manufacturing costs is anathema to a sawmiller. Also, drying to a lower moisture content lowers grade yield because more grade-reducing defects develop with increased drying. Thus, a smaller proportion of the lumber coming out of each kiln batch can be sold at highest-value grade prices. Finally, to make matters worse, at most sawmills, the dry kiln is the bottleneck in the whole process. Thus, extending kiln residence time for extra drying reduces the mill's annual output. This also has the effect of raising costs because fixed expenses are spread across fewer units of production.

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. That is important because it limits the panel thickness options that CLT manufacturers can cost-effectively produce. For example, 3 is the minimum number of lamellas for making CLT. Since the raw material is 1.5 inches thick, the smallest thickness of CLT panel available from dimension lumber typically finishes at about 4.25 inches thick. In some applications, a 4.25-inch-thick CLT panel is overkill because a thinner panel would meet the required strength properties, reducing project cost because less fiber is used.

An obvious solution is to produce softwood lumber to different thicknesses so that CLT and glulam manufacturers have more options in panel thickness/strength. However, as previously described, softwood 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 it produces thinner boards. Less throughput translates into higher cost. The hit on throughput occurs because, for many processes—such as primary breakdown, planing, edging, and resawing—the processing is linear, along the long axis of each piece. Throughput speed doesn't change appreciably with thinner pieces. Therefore, the result of running thinner material is dramatically less throughput and higher cost.

Additionally, as stated before, 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 the tally advantage that currently arises from the difference between 1.5-inch actual thickness and 2-inch tally thickness. In summary, for a sawmill, the combination of higher costs, lost productivity, and a less favorable tally when producing thinner lumber may be a difficult proposition.

Another issue affecting lumber supply-and-demand dynamics revolves around species preferences. SPF is a type of dimension lumber where different combinations of spruce, pine, and fir species are lumped together and sold as a species group. It is mostly produced in Canada. In many home-building and remodeling applications, SPF is preferred because of its balance of strength; light weight; workability; and small, tight knots. However, in recent years, sawmill closures in Western Canada have limited the availability of SPF, which has caused its price to rise relative to that of lumber made from SYP. Also, at the same time that SPF supplies have dwindled, the supply of SYP lumber has increased with the addition of new sawmilling capacity in the US South. These trends are expected to continue. Thus, there may be opportunity for using more SYP in mass timber panels and glulam, given its expected lower costs.

In response to these issues, many mass timber and glulam manufacturers have sought to develop long-term partnerships with sawmills that are willing to take the time and expense to produce lumber products meeting the needs of mass timber panel and glulam suppliers. Others have added their own drying and planing capacities or are seriously considering doing so.

3.4 CARBON CONSIDERATIONS

The September 2017 issue of *Forest Products Journal* included an article that analyzed the carbon impact associated with the production of softwood dimension lumber in the Pacific Northwest and Southeastern US.[4] Key conclusions of the study were 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. Another 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 require considerable energy and associated carbon emissions to 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 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).

4 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.

T3 ATX EASTSIDE IS A SHORT WALK FROM AUSTIN'S DOWNTOWN CORE

Source: DLR Group; Credit: Connor Steinkamp

CASE STUDY: T3 ATX EASTSIDE

MODERN TIMBER MEETS EAST AUSTIN GRIT

PROJECT OWNER: HINES / KINDER FOUNDATION

PROJECT LOCATION: E 4TH AND WALLER ST, AUSTIN, TX 78702

COMPLETION DATE: NOVEMBER 15, 2023

ARCHITECT/DESIGNER: DLR GROUP

MASS TIMBER ENGINEER/MANUFACTURER: NORDIC

GENERAL CONTRACTOR: HARVEY CLEARY

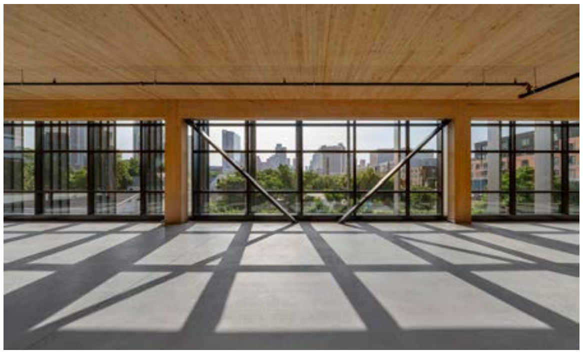
STRUCTURAL ENGINEER: MAGNUSSON KLEMENCIC ASSOCIATES

MECHANICAL, ELECTRICAL, AND PLUMBING: ALVINE

OTHER CONTRACTORS: QUIDDITY (JONES & CARTER) (CIVIL), TBG PARTNERS (LANDSCAPE ARCHITECT)

BUILT WITH A braced mass timber superstructure, T3 ATX Eastside is the first timber office and residential development in the southern part of the United States. This T3—timber, transit, technology—building is on the east side of Austin, Texas, an area that is seeing tremendous redevelopment targeted at a growing younger population, redefining work-life harmony. The development spans 92,000 square feet and features office space across 3 floors, and 15 residential corporate suites. The first floor also includes a flexible amenities program for tenants and residents.

Within a short walk of Austin's downtown core and with a transit stop only a few blocks away, T3 ATX



LEFT — THE MATERIAL PALETTE OF T3 ATX EASTSIDE LAYERS THE EXPOSED TIMBER STRUCTURE AND RICH TERRA-COTTA BRICK WITH COLD-ROLLED STEEL

RIGHT — T3 ATX EASTSIDE IN AUSTIN, TX

Source: DLR Group; Credit: Connor Steinkamp

Eastside celebrates the industrial history of the site, reflecting on the materiality and refinement of metal and wood. Each facade answers the surrounding neighborhood in a unique and tailored fashion, grounding the property at a human scale and washing patrons in the warm richness of wood that few modern live-and-work buildings have. Additionally, the high-performance building facades are optimized for their exposure. As an example, the west facade features perforated metal external sunshades that shave cooling loads and mitigate glare.

The exposed, raw beauty of timber has been linked to enhancing mental and emotional health, in addition to its sustainability benefits. Inside T3 ATX Eastside, the material palette layers the exposed timber structure and rich terra-cotta brick with cold-rolled steel, breaking down the boundaries between inside and outside, providing users with a sense of well-being to perform at their optimal capacity. Bold and colorful art moments by commissioned neighborhood artists further reinforce the building's connection to its place. With the evolution of T3 into the residential space, corporate guests can experience the comforts of home surrounded by the inviting, organic warmth and beauty of the exposed engineered wood.

The building's amenities create an environment akin to an urban loft, while the modern building systems and technological infrastructure support the needs of high-tech tenants and contemporary residents. Due to its small footprint, the design approach required abstract thinking and drew inspiration from the adjacent railways and the connectivity of train cars. Amenity spaces are programmed with moving parts and pieces that create a multiuse, adaptable work-lounge destination with the ability to flex as the users' needs demand.

Anchored by sustainably sourced wood, T3 ATX Eastside offers a lower carbon footprint and embodied carbon advantage than traditional concrete or steel construction, totaling a potential carbon benefit of about 3,200 metric tons of carbon dioxide, equivalent to taking 982 cars off the road for a year or saving the energy to operate 341 homes for a year.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

CHAPTER 4: MASS TIMBER MANUFACTURING

ROY ANDERSON
VICE PRESIDENT, THE BECK GROUP

ERICA SPIRITOS

This chapter focuses on manufacturing mass timber panels and glulam. It includes a review of the manufacturing processes for key mass timber products; a summary of North American manufacturers and their aggregate production capacity, products, and services; and a discussion of strategic and technical mass timber manufacturing issues.

After several turbulent years that included massive lumber price spikes, building project slowdowns, and the transition to new ownership for several mass timber manufacturing facilities, 2024 brought greater stability in mass timber manufacturing capacity. However, changes are looming as new manufacturing facilities have been announced.

As always, mass timber manufacturers continue to refine their services, their supply chains, and the means of bringing products to market. Fabrication (secondary manufacturing) of panels and beams to their final dimensions—including cutouts for doors, windows, plumbing, electrical, and other features—continues to be a valuable service. It also continues to be cited as a bottleneck in the manufacturing process. This year's report, therefore, includes a list of firms that provide those services to complement existing manufacturing capacity. Additionally, mass timber manufacturers continue to add staff with timber engineering expertise, establish partnerships up and down the supply chain, develop design guides, and create supporting businesses that better link the manufacturing and construction sectors.

4.1 MASS TIMBER PANEL TYPES

There are 2 basic types of mass timber panels: structural panels for use in buildings, and nonstructural panels for use as industrial matting (temporary roads). The following sections describe each in more detail.

Structural Panels

Manufacturers that produce mass timber panels typically offer a range of visual grades, strength grades, and species based on the feedstock available in their respective geographic locations. The International Building Code (IBC) requires that all Cross-Laminated Timber (CLT) used in buildings be certified to the PRG 320 standard.

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 view; and industrial grade, for use when a panel surface will be covered up, or in more rustic settings. Each manufacturer offers an array of finishes; in most cases, the finishes can be customized.

Architectural-grade panels utilize a higher visual grade of lumber on the exposed face. The panels may require sanding, stains, or coatings, and the filling of holes, gaps, or knotholes for improved visual quality. 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 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 edges 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.

Matting

Matting panels serve as temporary roading to protect soils and sensitive areas. These mats typically are placed on the ground 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 the past 10 to 15 years, CLT mats have become more common because in many applications they offer superior value. Generally, CLT mats are about half the weight of bolted mats, so they are less costly to transport to the jobsite, and easier and faster to install. Also, bolted mats have gaps between the timbers, which allow dirt, rocks, and debris to build up on the surface of the mat. CLT mats, in contrast, are solid panels that do not have gaps, and are therefore more resistant to dirt and rocks, translating into a longer useful lifespan. CLT mats may be delivered with built-in hardware, making them easier to lift and place using a forklift, excavator, or crane, thereby reducing setup time. When the mats do not have built-in hardware and have reached the end of their useful life, they can be ground into mulch at the jobsite.

4.2 MASS TIMBER PANEL MANUFACTURING PROCESS DESCRIPTIONS

The following subsections describe the basic steps for manufacturing mass timber panels.

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 use well-established technologies borrowed from other segments of the wood products industry—though some of these processes (like lay-up and pressing) are performed on assemblies of unprecedented scale. Although there are variations, 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 designated for CLT manufacturing are removed using a crosscut/chop saw.

Finger Jointing

Once free of impermissible defects, the pieces of lumber (typically 8 to 10 feet in length) are glued together end to end to create boards the length of a panel (20 to 60 feet). Finger-jointing machines cut finger joints into the ends of each board, and apply an adhesive to the joint to securely bond the pieces. The finger joint is designed to be stronger than the wood itself.

In processes that use different grades or thicknesses of materials for alternating layers, the material flow for the longitudinal and transverse layers must 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 required for 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 each board 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 inadequate pressure and poor bond integrity in that location.

Panel Lay-Up

The finger-jointed, surfaced, and cut-to-length boards are assembled into a panel 1 layer at a time. In a 3-layer (3-ply) panel, for example, all the long pieces that make up the longitudinal axis are laid onto the press bed. Next, a glue spreader travels over them, applying a layer of glue to the wide surfaces. Then the short pieces are loaded into the press bed, making up the panel’s transverse axis. Another layer of glue is applied. And finally, the long pieces making up the second longitudinal layer (major strength axis) are loaded onto the press bed.

Note that, for some panels, glue is applied to the narrow surfaces (edges) of lumber as well, in a process known as edge-gluing. Many manufacturers in Europe begin the process with edge-bonding each layer to expedite the production process.

Pressing

After all panel laminations have been loaded onto the press, the panel is pressed to allow the adhesive to cure.

Variations in the adhesive and pressing technology affect the press time and the amount of energy consumed in this process. Pressurized air and hydraulics are 2 approaches to pressing panels that do not require heat. Radio frequency curing is another method for producing CLT that reduces press times and ensures uniform glue curing across all layers of the CLT panel. Since adding radio-wave energy complicates the process, these types of presses typically cure the lay-up piecewise, a segment at a time.

CNC Fabrication

Mass timber panels are now ready for final fabrication, which involves cleaning up and squaring panel edges, and cutting them to their final dimensions. Typically, the final manufacturing is accomplished with robotic Computer Numerical Control (CNC) machine centers. CNC machines will cut each panel to its precise geometry, route any recesses for spline connections, and cut openings for windows and doors, as well as heating, ventilation, and air conditioning (HVAC), plumbing, and electric networks. Many CLT plants use an in-line sanding machine to surface the visible face of the panel if an architectural finish is required.

Packaging and Shipment

The final step involves marking pick points for lifting hardware, which will allow a crane at the construction site to safely and efficiently pick and place each panel. For shipping, panels are typically sequenced for installation so they can be moved directly into place from the truck bed. That entails precise management and timing of the production and transportation sequences and requires close coordination between manufacturers and contractors.

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 1 of the 2 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

REGENERATING THE MARINE AREA, KATAJANOKAN LAITURI PROVIDES FINLAND'S CAPITAL WITH NEW BIOPHILIC AMENITIES, INCLUDING OPEN-PLAN OFFICES, A HOTEL, EVENT SPACE, RESTAURANTS, CAFÉS, AND A ROOFTOP TERRACE THAT GENERATIONS TO COME CAN ENJOY

Source: Stora Enso; Credit: Kalle Kouhia

CASE STUDY: KATAJANOKAN LAITURI

STORA ENSO'S HEAD OFFICE: LANDMARK, LOW-CARBON LANDSCRAPER

ARCHITECT/DESIGNER: ANTTINEN OIVA ARKKITEHDIT OY

MASS TIMBER ENGINEER/MANUFACTURER: STORA ENSO

GENERAL CONTRACTOR: PUURAKENTAJAT RAKENNUS OY

STRUCTURAL ENGINEER: SWECO RAKENNETEKNIIKKA OY

MECHANICAL, ELECTRICAL, AND PLUMBING: GRANLUND OY

OTHER CONTRACTORS: HAKA PKS OY, RAISION PUUSEPÄT OY, PUNKAHARJUN PUUTAITO OY, TIMBERPOINT OY

WELCOME TO KATAJANOKAN LAITURI, the 247,600-square-foot (23,000-square-meter) low-carbon landscraper, home to the world's leading renewable materials company, Stora Enso.

The internationally acclaimed urban redevelopment sets a new benchmark in Life Cycle Analysis (LCA)-led design and provides outstanding biophilic amenities to Helsinki with waterfront hotel rooms, event space, open-plan offices, restaurants, cafés, and rooftop terraces.

RJC ENGINEERS
WEYERHAEUSER
MINDA
NISUS CORPORATION
USNR

THE STRUCTURAL FRAME CONSISTS OF OVER 2,000 BESPOKE LOAD-BEARING MASS TIMBER ELEMENTS PREFABRICATED AND DELIVERED AS A KIT-OF-PARTS
Source: Stora Enso; Credit: Kalle Kouhia

As one of the largest and most established wood suppliers and forest owners, Stora Enso holds the top market position for Cross-Laminated Timber (CLT), (sawing capacity 191 million cubic feet/5.4 million cubic meters) and operates the largest fully automated coating line, with a capacity of 5.4 million square feet (500,000 square meters). So it's perfectly fitting that Stora Enso has used the most resource-efficient methods and materials available today to create its new head office.

The structural frame comprises over 317,000 cubic feet (8,980 cubic meters) of CLT and Laminated Veneer Lumber (LVL) with preinstalled steel parts.

All structural LVL beams and columns are LVL G LX. They were further processed by a specialist subcontractor, who cut them to shape and block-glued them to their final dimensions before sanding and coating them with ultraviolet and moisture protection to specification. The ground-floor columns (diamond-shaped multipanel columns) were preinstalled with glued-in rods to create the interface with the concrete basement and foundations.

Each individual piece was manufactured with tight tolerances with a combination of visual and nonvisual surfaces. Stora Enso has a reputation for some of the best CLT surface qualities, enabling much of the load-bearing CLT walls to be left exposed.

As Europe's leading industrial component manufacturer, Stora Enso provided the extremely strong, load-bearing window components (Effex® Dura) to support the 700 panoramic windows.

Katajanokan Laituri was built to last at least 100 years. The mixed-use flexible design allows the building to be adapted for different commercial uses over time, reducing the need for demolition. At the end of the building's service life, the elements can be dismantled and reused in other buildings and long-life products.

From the ground to the finish, including the facade, everything was completed in just 7 months and perfectly on schedule. The framing schedule was accurate within 2 days, thanks to the use of Stora Enso's digital tool, CLT360, which increased on-site efficiency, helped reduce the overall build time, and enabled optimized logistics and delivery planning.

MATERIALS BY STORA ENSO (APPROXIMATE NET VOLUME)

- CLT walls, floors, roofs, and stairs: 211,889 cubic feet (6,000 cubic meters)
- combination of visual quality, nonvisual quality, and industrial visual quality
- LVL beams and columns: 56,504 cubic feet (1,600 cubic meters)
- Effex® Dura window components: 3,531 cubic feet (100 cubic meters)

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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.

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 stacked on their short dimension and assembled into a panel. Holes are drilled along the edges, and hardwood dowels are pressed into the holes to create a tight fit. As DLT does not have diaphragm capacity, producers will often install plywood sheathing on the top face, to give the panel in-plane shear capacity. 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.

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 that of 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.

Veneer-Laminated Timber Panels Manufacturing

Veneer-laminated timber panels (such as Mass Plywood Panels, or MPPs) are a veneer-based Engineered Wood Product (EWP). The first step in manufacturing Veneer-laminated timber is to produce appropriately sized and graded veneer of an acceptable (typically softwood) species. Veneer-Laminated Timber 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 panels, 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 panel. These joints are staggered throughout the panel, so they do not create weak points. A 6-inch-thick panel, for example, is made up of 6 1-inch billets, each made of 9 plies of veneer, for a total of 54 veneer plies. Throughout the manufacturing process, the entire panel 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 1 panel.

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 is manufactured in Europe and 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 1 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 thin bitumen paper layer would be integrated in the lay-up to provide airtightness.

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, as lumber is layered in alternating orientation to create strength in 2 directions. 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 AG 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 layer of bitumen paper integrated between the wood layers to provide airtightness.

4.3 NORTH AMERICAN MASS TIMBER PRODUCTION CAPACITY

This section provides an assessment of mass timber manufacturing capacity. Manufacturer information was collected from personal communication with manufacturers, publicly available

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	St. Thomas, ON, CA	Operating		
Freres	Lyons, OR, US	Operating		
Kalesnikoff	South Slocan, BC, CA	Operating		
Mercer International	Spokane, WA, US	Operating		
Mercer International	Okanagan Falls, BC, CA	Operating		
Mercer International	Conway, AR, US	Operating		
Nordic Structures	Chibougamau, QC, CA	Operating		
SilvaSpan	New Lowell, ON, 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		
Vaagen Timbers	Colville, WA, US	Operating		
Composite Recycling Technology Center	Port Angeles, WA	Operating - Small Scale		
Euclid Timber Frames	Heber City, UT	Operating - Small Scale		
International Timber Frames	Donald, BC	Operating - Small Scale		
Timber Age Systems	Durango, CO	Operating - Small Scale		
Total			**1,557,000**	**1,022,000**
Element5	St. Thomas, ON, CA	Expansion	n/a	n/a
Fabric Workshop	Redding, CA, US	Planned	n/a	n/a
Mosaic Timber (Sierra Institute)	Taylorsville, CA	Planned	n/a	n/a
Stoltze Mass Timber	Columbia Falls, MT, US	Planned	n/a	n/a
Timberlab	Millersburg, OR, US	In construction	n/a	n/a

TABLE 4.1: CURRENTLY OPERATING NORTH AMERICAN MASS TIMBER PRODUCTION PLANTS

information from manufacturers' websites, and information compiled by industry experts. Please note that the status of manufacturing operations is constantly changing; the information that follows was current as of December 2024.

North American Mass Timber Panel Capacities

Table 4.1 shows the estimated **theoretical maximum production capacity** of the North American mass timber manufacturing facilities to be 1.557 million cubic meters per year (55 million cubic feet per year) as of late 2024. Importantly, theoretical capacity is a calculation of a plant's capacity, assuming that the available space in each press is fully utilized 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 (which has the effect of lowering capacity), the estimated **effective production capacity** is 1.022 million cubic meters per year (36.1 million cubic feet per year).

As an example of the capacity reduction that occurs because of the differences in press size and actual panel 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 15 feet long (produced in billets that are 45 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 15 feet of the press is not filled. The same is true for panel width. In this scenario, only 8 feet of the 10-foot

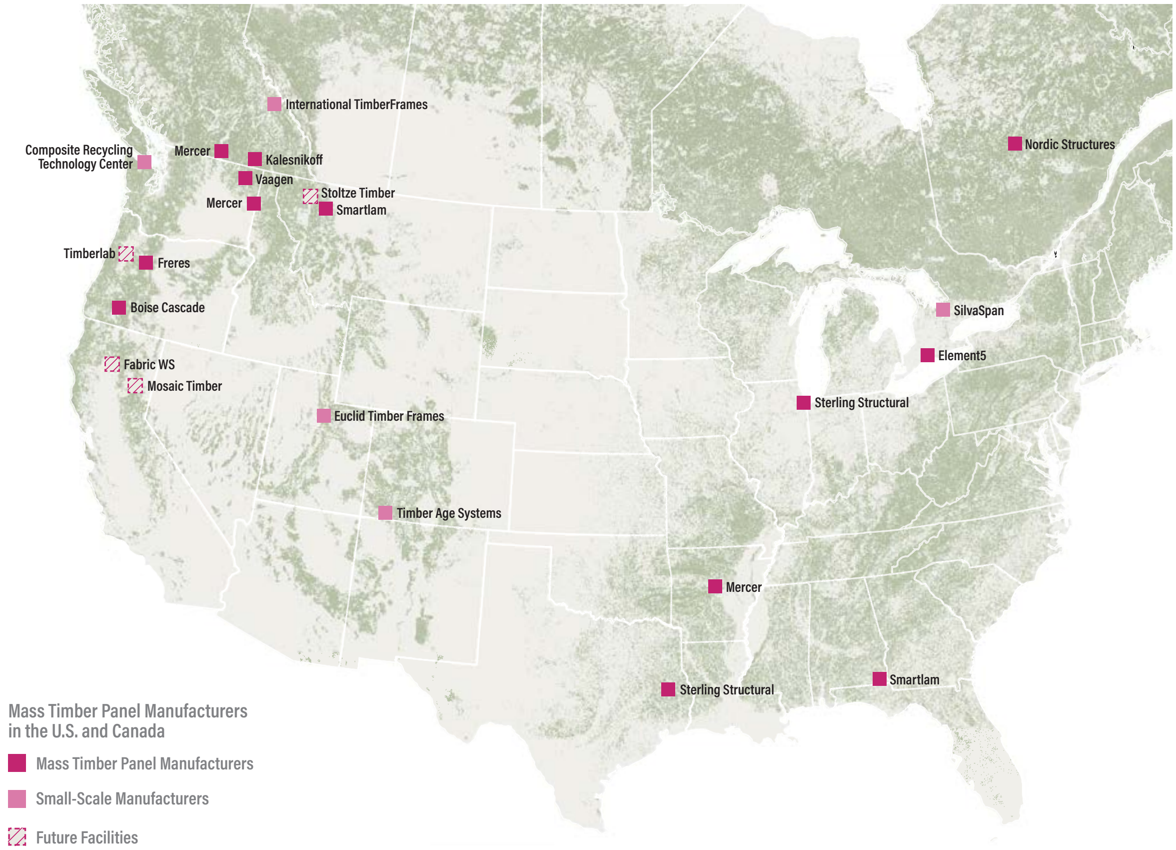


FIGURE 4.1: LOCATION OF NORTH AMERICAN MASS TIMBER MANUFACTURING FACILITIES

Source: The Beck Group

press width is used. And finally, if the press has a total depth of 1 foot and the panels are 5.5 inches thick, then 2 layers of panels fit in the press, which means that only $^{11}/_{12}$ of the press's depth is used. Based on the experiences 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.[1] At the time of this writing (early 2025), there are 15 larger-scale operating facilities in North America. And, as shown at the bottom of the table, 11 additional manufacturing facilities are operating at a small scale, or are expected to commence operation in the next few years.

Figure 4.1 shows the locations of North American mass timber panel manufacturing. 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 due to the abundance and diversity of available species, including Douglas-fir, Western larch, hemlock, spruce, pine, 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

1 The estimated effective production capacity may differ slightly from 65 percent because of rounding the capacities for the individual plants.

COMPANY	PRODUCT/SERVICE	CITY/STATE/COUNTRY
Cascadia Structural Solutions	Fabrication	Portland, OR, US
Cut-My-Timber Inc.	Fabrication	Portland, OR, US
Sauter Timber	Fabrication	Rockwood, TN, US
Spearhead	Fabrication	Nelson, BC, CA
StructureCraft	Fabrication	Abbotsford, BC, CA
Timber Systems	Fabrication	Lapeer, MI, US
Timberlab	Fabrication	Portland, OR, US
Timberlab	Fabrication	Greenville, SC, US
Timberlyne	Fabrication	Boerne, TX, US
Western Wood Structures	Fabrication	Tualatin, OR, US

TABLE 4.2: NUMBER OF OPERATING FACILITIES IN NORTH AMERICA

South, where the available species is Southern Yellow Pine (SYP), which is a mix of longleaf, loblolly, slash, and shortleaf pines. While there is still no mass timber manufacturing facility in California despite its large timber resource and its significant sawmilling industry, 2 new facilities are in development. Fabric Workshop is planning to develop a CLT and glulam manufacturing facility in Redding, California, and the nonprofit Sierra Institute is launching a company called Mosaic to produce CLT in Taylorsville, California. Finally, note that 4 small-scale mass timber manufacturers are included on the map, but since their production volumes are very small, they are not included in the capacity estimate. Texas CLT in Magnolia, Arkansas, had been included in prior years, but that plant has permanently closed. Among the CLT manufacturers, Mercer, Vaagen, Kalesnikoff, SmartLam, Element5, and Nordic Structures all also produce glulam beams.

North American Glulam Capacity

While many CLT manufacturers 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**. Also shown in the figure are 9 CNC fabrication facilities, which are stand-alone facilities that provide fabrication services to glulam and CLT manufacturers, to transform industry products into custom building components before they are shipped to the construction site. The fabrication facilities are listed in **Table 4.2.**

The glulam companies and their estimated production capacity is shown in **Table 4.3**. Note that, like mass timber panel manufacturing, a capacity factor has been applied to the glulam capacity estimate to show both the theoretical maximum production capacity and the effective production capacity.

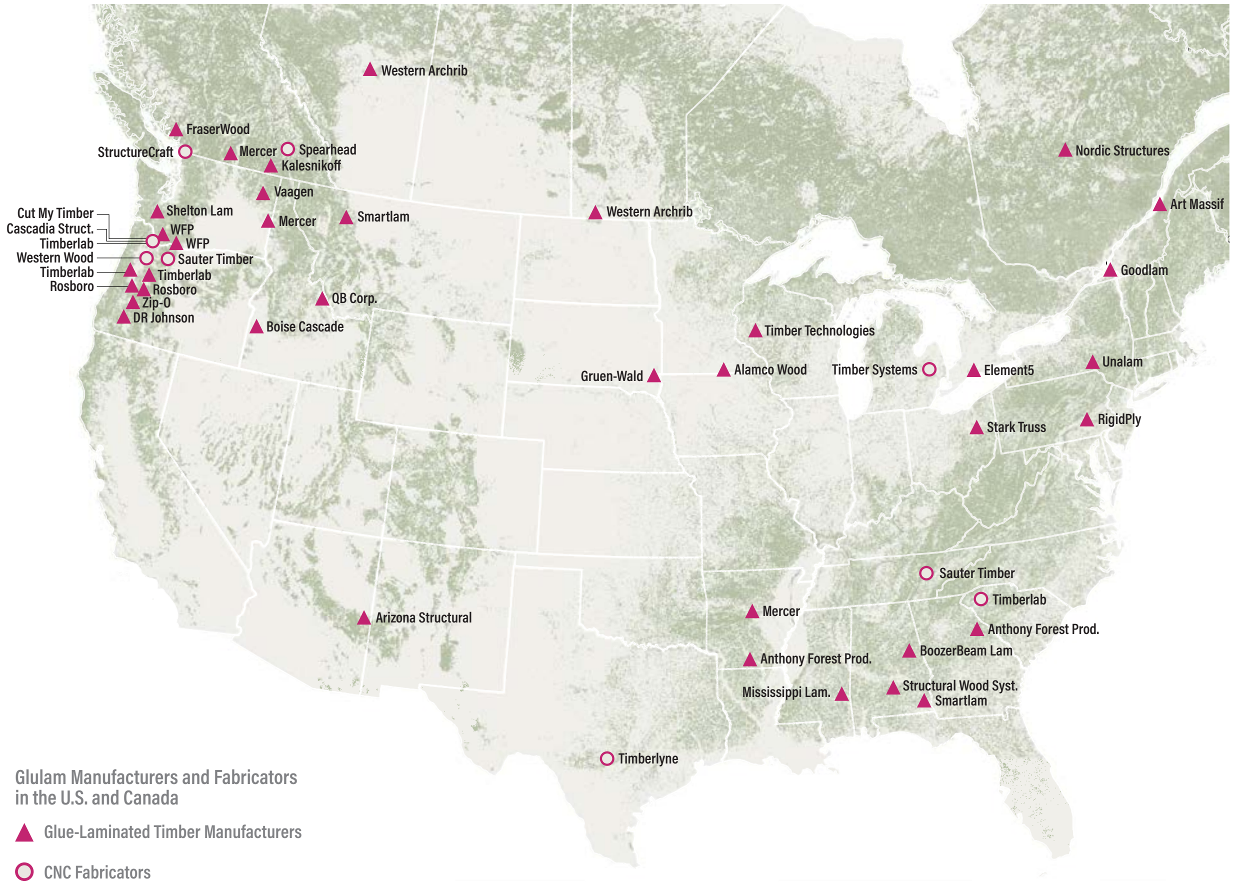


FIGURE 4.2: LOCATION OF NORTH AMERICAN GLULAM MANUFACTURING PLANTS

Source: The Beck Group

There are several things to note about the North American glulam manufacturers. First, glulam manufacturers commonly refer to production and capacity in board feet, which differs from the units of measurement shown in **Table 4.3**. The assumed conversion factors are: (1) 18.5 nominal board feet per finished cubic foot of glulam, and (2) 35.314 cubic feet per cubic meter. Second, over the past 10 years, their aggregated annual output has averaged about 300 million board feet (MMBF) per year. The estimated aggregated theoretical maximum capacity of all the existing glulam-only plants in North America is 650 MMBF per year. Note, however, that many plants are relatively small operations that specialize in producing small volumes of high-value custom beams. These plants typically do not publish their annual capacity. Additionally, capacity is a difficult thing to measure for glulam facilities since many can produce beams well over 100 feet long. Technically, the press space for those longer beams is part of their capacity. However, the market for such long beams is very small, so the press space for longer beams is not used consistently. This situation illustrates why developing a consistent methodology for estimating North American glulam production capacity is difficult.

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

COMPANY	LOCATION	STATUS	ESTIMATED THEORETICAL MAXIMUM PRODUCTION CAPACITY OF OPERATING PLANTS (M_3/YEAR)	ESTIMATED EFFECTIVE PRODUCTION CAPACITY OF OPERATING PLANTS (M_3/YEAR)
Alamco Wood Products LLC	Albert Lea, MN, US	Operating		
Anthony Forest Products Company - Eldorado Laminating	El Dorado, AR, US	Operating		
Anthony Forest Products Company - Washington Laminating	Washington, GA, US	Operating		
Arizona Structural Laminators	Eagar, AZ, US	Operating		
Art Massif Structure De Bois Inc.	Saint Jean Port Joli, QC, CA	Operating		
Boise Cascade	Homedale, ID, US	Operating		
Boozer Laminated Beam Co. Inc.	Anniston, AL, US	Operating		
DR Johnson Wood Innovations	Riddle, OR, US	Operating		
Fraser Wood Industries, Ltd.	Squamish, BC, CA	Operating		
Goodlam, Division of Goodfellow Inc.	Delson, QC, CA	Operating		
Gruen-Wald Engineered Laminates, Inc.	Tea, SD, US	Operating		
Harrison Industries (Structural Wood Systems)	Greenville, AL, US	Operating		
Mississippi Laminators	Shubata, MS, US	Operating		
QB Corporation	Salmon, ID, US	Operating		
Rigidply Rafters	Richland, PA, US	Operating		
Rigidply Rafters	Oakland, MD, US	Operating		
Rosboro	Springfield, OR, US	Operating		
Rosboro	Veneta, OR, US	Operating		
Shelton Lam and Deck	Chehalis, WA, US	Operating		
Stark Truss Company, Inc.	Canton, OH, US	Operating		
Starwood Rafters	Independence, WI, US	Operating		
Timber Technologies Inc.	Colfax, WI, US	Operating		
Timberlab Laminators	Drain, OR, US	Operating		
Timberlab Laminators	Swiss Home, OR, US	Operating		
Unadilla Laminated Products (Unalam)	Unadilla, NY, US	Operating		
Western Archrib	Edmonton, AB, CA	Operating		
Western Archrib	Bossevain, MB, CA	Operating		
WFP Engineered Products	Vancouver, WA, US	Operating		
WFP Engineered Products	Washougal, WA, US	Operating		
Zip-O-Laminators	Eugene, OR, US	Operating		
Total			**1,000,000**	**650,000**

TABLE 4.3: ESTIMATED PRODUCTION CAPACITY OF NORTH AMERICAN GLULAM COMPANIES

THE EXPOSED GLULAM STRUCTURE AND ARTWORK BRING VIBRANCY TO THE COMMUNITY GATHERING SPACES

Source: Opsis Architecture; Credit: Lara Swimmer/Esto

CASE STUDY: REDMOND SENIOR AND COMMUNITY CENTER

ADVANCING SOURCING TRANSPARENCY WITH CLIMATE-RESILIENT WOOD

PROJECT OWNER: CITY OF REDMOND

PROJECT LOCATION: 8703 160TH AVE. NE, REDMOND, WA 98052

COMPLETION DATE: MAY 1, 2024

ARCHITECT/DESIGNER: OPSIS ARCHITECTURE (ARCHITECT OF RECORD), JOHNSTON ARCHITECTS (ASSOCIATE ARCHITECT)

MASS TIMBER ENGINEER/MANUFACTURER: CARPENTRY PLUS (MASS TIMBER CONTRACTOR), FRERES LUMBER (MPP PROVIDER)

GENERAL CONTRACTOR: ABSHER CONSTRUCTION

STRUCTURAL ENGINEER: LUND OPSAHL LLC

MECHANICAL, ELECTRICAL, AND PLUMBING: PAE CONSULTING ENGINEERS

THE REDMOND SENIOR and Community Center is a 52,000-square-foot civic landmark designed to enhance the well-being of Redmond's diverse population, particularly seniors. Situated on the Redmond Municipal Campus, the center weaves together urban and natural environments, extending the Civic Commons and connecting to the Sammamish River Trail. Shaped by extensive public input, the project exemplifies sustainability and inclusivity, focusing on accessibility, environmental responsibility, and occupant well-being. Exposed glulam framing and Mass Plywood Panels (MPP) serve as both structural and aesthetic ele-

THE DINING AND EVENTS TERRACE IS AMONG THE SPACES DESIGNED TO PROMOTE HEALTH AND WELLNESS
Source: Opsis Architecture; Credit: Lara Swimmer/Esto

ments, embodying biophilic design principles to create a warm, inviting environment. The center aims to bring residents together, fostering cross-generational interaction and promoting health and wellness.

A PATH TOWARD A CARBON-NEUTRAL FUTURE

The mass timber structure establishes a precedent for future sustainable development while demonstrating the city's commitment to achieving carbon neutrality by 2030. The use of climate-resilient wood led to a 24 percent reduction in embodied carbon and the storage of 977 metric tons of carbon dioxide. This is equivalent to taking 286 cars off the road annually or powering 143 homes for a year.

In addition, the all-electric center is designed to achieve a projected 56.2 percent energy-cost savings. The expansive rooftop photovoltaic array generates renewable energy, significantly reducing the building's carbon footprint. Designed for grid optimization and long-term energy efficiency, the building serves as a model for sustainable design while prioritizing the health and well-being of the community.

WOOD SOURCING TRANSPARENCY

The center earned the first-ever US Green Building Council Leadership in Energy and Environmental Design (LEED) Innovation Credit for climate-resilient wood. In collaboration with the construction team and wood adviser Sustainable Northwest, the project team fully disclosed the forests where the MPP was sourced, demonstrating that these forests are managed to enhance climate resilience. Climate-resilient wood is traceable back to its landowners and focuses on intentional forest stewardship to achieve ecological outcomes, such as enhancing biodiversity, reducing wildfire risks, storing more carbon, and promoting mixed-age stands.

For the community center, 26,250 cubic feet of MPP were traced back to sustainably managed Bureau of Land Management forests near Carlton, Oregon, in the Willamette Valley. Wood traceability at this level is often unknown or difficult to confirm. The project recognized ecological forest stewardship beyond existing wood certifications and brought forward a pathway for climate-resilient wood tracking that had not been incorporated into any green building certification system.

HYBRID STRUCTURE

Although the building is predominantly mass timber, the cantilevered walk/jog track required a hybrid solution. The project team optimized long-span mass timber elements, integrating them harmoniously with steel framing and concrete shear walls. The exposed structure creates a warm, expressive framework that seamlessly blends social, recreational, and cultural spaces into a light-filled design, uplifting Redmond's community and its vision for a carbon-neutral future.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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, 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 the Western US (in Oregon); and Anthony Forest Products (owned by Canfor), which operates 2 plants in the US South (1 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 glulam plants. In contrast, the rest 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 4.4** 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 ends of the supply chain. Still others are stand-alone businesses. **Table 4.5** 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-based 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, element of the mass timber supply chain is the additional support services that mass timber manufacturers often 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.

Architectural Design and Project Support

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

Structural engineering services: Many manufacturers can provide stamped engineering documents for the mass timber structure, through a delegated design process.

Building Information Modeling (BIM): As a precursor to the manufacturing process, virtual construction or BIM teams will work to translate the design intent of a set of construction documents into fabrication-level information. The modeling process includes the entire timber structure and all connection hardware. There is also the potential for coordination with other trades to plan for

COMPANY	CITY	STATE/ PROVIDENCE	SPECIES	STATUS	LENGTH (FEET)	THICKNESS AND WIDTH (INCHES)
Alamco Wood Products LLC	Albert Lea	MN	SYP, DF, AC, POC	Certified	Up to 110'	
Anthony Forest Products Company - Eldorado Laminating	El Dorado	AR	SYP	Certified	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	Certified	8' to 60'	3.125" to 5.5" wide and 7.25" to 28.875" deep
Arizona Structural Laminators	Eagar	AZ	DF, SYP	Certified		
Art Massif Structure De Bois Inc.	Saint Jean Port Joli	QC	SPF	Certified (CSA)		
Boise Cascade	Homedale	ID	DF/L, AC,	Certified	Up to 60'	3.125" to 14.25" wide and 6" to 48" deep
Boozer Laminated Beam Co. Inc.	Anniston	AL	SYP	Certified	6' to 54'	3.125" to 28.875" wide and 8.75" to 28.875" deep
DR Johnson Wood Innovations	Riddle	OR	DF, AC, POC, SYP	Certified	Up to 135'	up to 24" wide and 60" deep
Element5	St. Thomas	ON	SPF	Certified	Up to 52.5'	3.15" to 6.89" wide and 4.13" to 39.37" deep
Fraser Wood Industries, Ltd.	Squamish	BC	DF, AYC, POC, SPF	Cerftified	Up to 60'	up to 10.75" wide and 73.5" deep
Goodlam, Division of Goodfellow Inc.	Delson	QC	DF, SYP, SPF	Cerftified		
Gruen-Wald Engineered Laminates, Inc.	Tea	SD	SYP, SPF	Cerftified		
Harrison Industries (Structural Wood Systems)	Greenville	AL	SYP	Non-certified	8' to 20'	
Mississippi Laminators	Shubata	MS	SYP	Certified	Up to 52'	4.0" to 8.0" wide and up to 39" deep
QB Corporation	Salmon	ID	DF, SYP, WRC, AC	Certified	Up to 130'	up to 20" wide and 108" deep
Rigidply Rafters	Richland	PA	SYP, DF, AC, POC	Certified		
Rosboro	Springfield	OR	DF	Certified	Up to 72'	3.25" wide by 4" deep to 8.75" wide by 40" deep
Rosboro	Veneta	OR	DF	Certified	Up to 100'	3.125" to 6" wide and 8" to 18" deep
Shelton Lam and Deck	Chehalis	WA	DF	Certified		
Stark Truss Company, Inc.	Canton	OH	SYP, SPF	Certified		
Starwood Rafters	Independence	WI	DF	Certified	6' to 56'	
Timber Technologies Inc.	Colfax	WI	DF, SPF, SYP	Non-certified	8' to 62'	
Timberlab Laminators LLC	Drain	OR	DF, SYP, AC, POC	Certified	Up to 130'	up to 16.25" wide and 72" deep
Timberlab Laminators LLC	Swiss Home	OR	AC, WRC, DF, HF, POC	Certified	Up to 130'	up to 18.25" wide and up to 72" deep
Unadilla Laminated Products (Unalam)	Unadilla	NY		Certified		
Western Archrib	Edmonton	AB	DF, SPF, AC	Certified	Up to 150'	3.125" to 25.25" wide and 4.5" to 84" deep
Western Archrib	Bossevain	MB		Certified		
WFP Engineered Products	Vancouver	WA	DF, SYP, AC, POC	Certified	Up to 90'	up to 16" wide and 72" deep
WFP Engineered Products	Washougal	WA	DF, SYP	Certified	Up to 95'	Up to 16" wide and 48" deep
Zip-O-Laminators	Eugene	OR	DF, AC	Certified	8' to 115'	up to 16" wide and 60" deep
Zip-O-Laminators	Eugene	OR	DF, AC	Certified	8' to 115'	Up to 16" wide and 60" deep

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

TABLE 4.4: CURRENTLY OPERATING NORTH AMERICAN GLULAM MANUFACTURERS

COMPANY	WEBSITE	PANEL BRAND NAME	DESIGN GUIDE	CERTIFIED	PRODUCTS	SPECIES	PANEL TYPES	STRESS GRADE	PANEL THICKNESS	MAX WIDTH	MAX LENGTH	ENVIRONMENTAL CERTIFICATION
Element5	https://elementfive.co/	E5 CLT & E5 Nano CLT	Yes	Yes	CLT, GLT, BOXX Panels	SPF	A, I	V2, E1	up to 15"	11.15	52.5'	FSC
Freres	https://frereslumber.com/	MPP	Yes	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	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	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	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")	**9.8', 11.25'	**52', 51.75'	FSC, SFI
Sterling Solutions	https://www.sterlingsolutions.com/	Sterling Structural & Terralam	Yes	Yes	CLT	SYP, SPF-S, EH-T	A, I, 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	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	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
SilvaSpan	http://www.silvaspan.com/	SilvaSpan NLT	No	Yes	NLT	SPF, but can do others	A, I	Unknown	3.5" to 11.25"	12'	60'	Unknown
Vaagen Timbers	https://vaagentimbers.com/	Vaagen CLT	Yes	Yes	CLT, Glulam	SPF, DF-L	A, I	V1M3, V2M8, V3M8, V5M3(N), E2M5	4.13" to 9.63"	4'	60'	FSC

TABLE 4.5: 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 panels with max dimensions 11.5' wide and 51.4' long.*

factory-made penetrations into panels and beams to accommodate everything from electrical conduits to sprinkler pipes and plumbing.

Connection hardware: Manufacturers will source connection hardware required to assemble a mass timber structure and deliver a complete kit-of-parts.

On-site installation: 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 offer installation 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.

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.

There is no one-size-fits-all solution for procuring mass timber. Some project teams prefer to buy all products and services from a single entity, while others are willing to piece together a comprehensive package on their own. The complexity of a project and the offerings of suppliers near the site may inform the strategy.

OFFICE INTERIOR WITH PERMANENT CLT FORMWORK FOR FLOOR PLATES AND COLUMNS

Source: Hiroyuki Hirai

CASE STUDY: TAMADIC NAGOYAH

BIOPHILIC CODE INNOVATION: CLT AS PERMANENT FORMWORK

PROJECT OWNER: TAMADIC HOLDINGS

PROJECT LOCATION: 2-15-25 MARUNOUCHI, NAKA-KU, NAGOYA, AICHI, JAPAN, 460-0005

COMPLETION DATE: NOVEMBER 1, 2021

ARCHITECT/DESIGNER: SHIGERU BAN ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: SUIHOO FABRICATING COMPANY

GENERAL CONTRACTOR: OBAYASHI CORPORATION

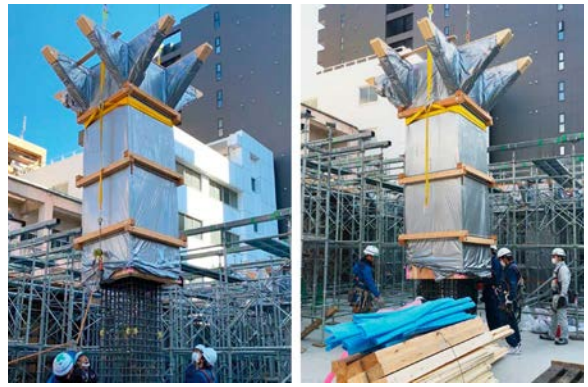
STRUCTURAL ENGINEER: HIROKAZU TOKI, SHUNYA TAKAHASHI, KEIICHI KANEKO

MECHANICAL, ELECTRICAL, AND PLUMBING: TETENS OFFICE

THE JAPANESE BUILDING code is prohibitively strict with regard to timber construction. It is not possible to build a multistory, unencapsulated timber structure in most urban contexts. Tamadic, an aerospace and automotive engineering company, commissioned a building that could innovate within these constraints to craft a warm wooden interior as the embodiment of an inspiring and healthy workplace.

Tamadic Nagoya is an 8-story office building with a simple square plan. The 12.8-foot-tall (3.9 meters) ground floor consists of the lobby, showroom, and manufacturing lab; the second through seventh floors are offices; and the top-floor pent-

THE EXTERIOR OF THE OFFICE BUILDING
Source: Hiroyuki Hirai



LOWERING PERMANENT CLT FORMWORK OVER STEEL REBAR BY CRANE
Source: Hiroyuki Hirai

house hosts a multipurpose hall, roof terrace, and sauna. Parking is accommodated in the basement.

Given the strict code parameters, a glulam structure could not be built in Nagoya, Japan. Instead, a unique hybrid approach was devised: Tamadic Nagoya employed Cross-Laminated Timber (CLT) as permanent formwork for the concrete floor slab and column structure. The timber provides supplemental structural support and acts as a finish material. This approach defies the restrictions placed on buildings for which timber acts as primary structure.

The use of permanent formwork has many benefits, most notably the warm and welcoming environment cultivated by the abundant use of wood. Additionally, this technique shortened the overall construction schedule. Multiple site activities took place concurrently because the formwork did not need to be removed after the concrete cured. However, perhaps the greatest benefit is the sustainability of the approach: the construction process did not create sacrificial formwork, which would typically be discarded, and no additional materials were needed as a finish layer.

The assembly has high strength and rigidity, minimizing vibration and deflection. Additionally, the composite structure is noted for its fire resistance and sound insulation.

The columns were constructed in a similar manner. The first step was to configure the rebar; next, an open box composed of 4 CLT boards was lowered over the rebar by a crane, then cast with concrete. Like the floor assembly, the composite columns rely on the concrete's structural integrity, but they benefit from the addition of timber. In full-scale mock-up tests, the columns had 1.3 to 1.6 times the rigidity of a concrete column alone. The CLT, therefore, contributes significantly to the control of deflections under lateral loads due to wind and earthquakes, making the building more resilient. The concept of resilience is now recognized as an important component of sustainability, keeping buildings useful for longer lifespans and ultimately requiring less material because there is no need to repair or replace them as often.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

CHAPTER 5: DESIGNERS AND SPECIFIERS

EMILY DAWSON, AIA
OWNER, SINGLE WIDGET | FIELD EDGE

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 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 oversize 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**).

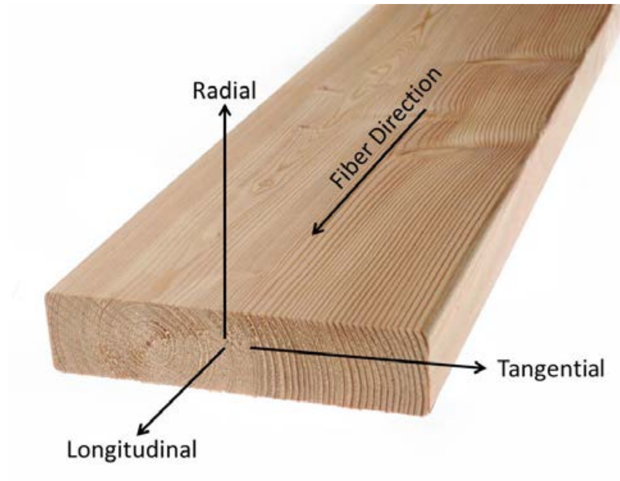


FIGURE 5.1: LUMBER STRENGTH ILLUSTRATION

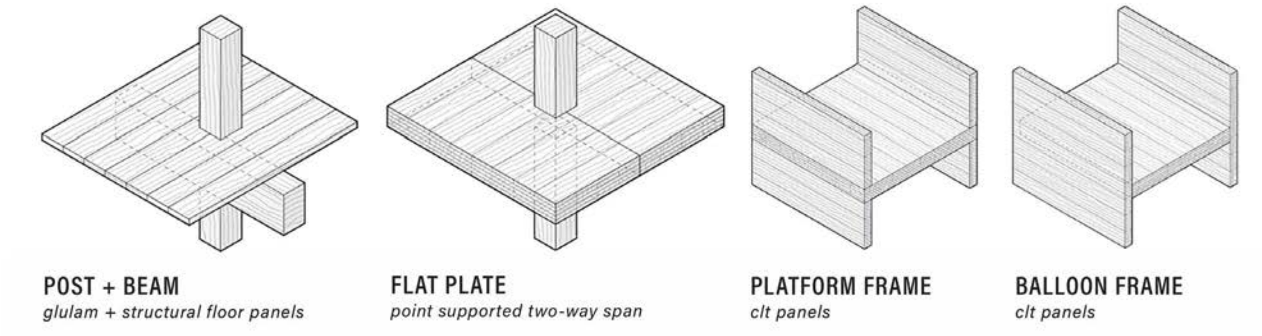


FIGURE 5.2: STRUCTURAL MORPHOLOGIES FOR MASS TIMBER HOUSING
Source: Gray Organschi Architecture

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 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, ANSI's *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 Canadian Standards Association *CSA O177*, the sample must be CLT rather than glulam.

Internationally, polyurethanes (PURs) 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, mostly in Japan. By combined output volume of panels, the use of PUR is 82 percent globally, followed by melamine formaldehyde (MF)/MUF at 15 percent, then EPI and PRF at 1 percent and 2 percent, respectively. MPP uses a phenol formaldehyde 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.

FIGURE 5.3: SELF-TAPPING TIMBER SCREWS

Source: MTC Solutions

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.

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).

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/

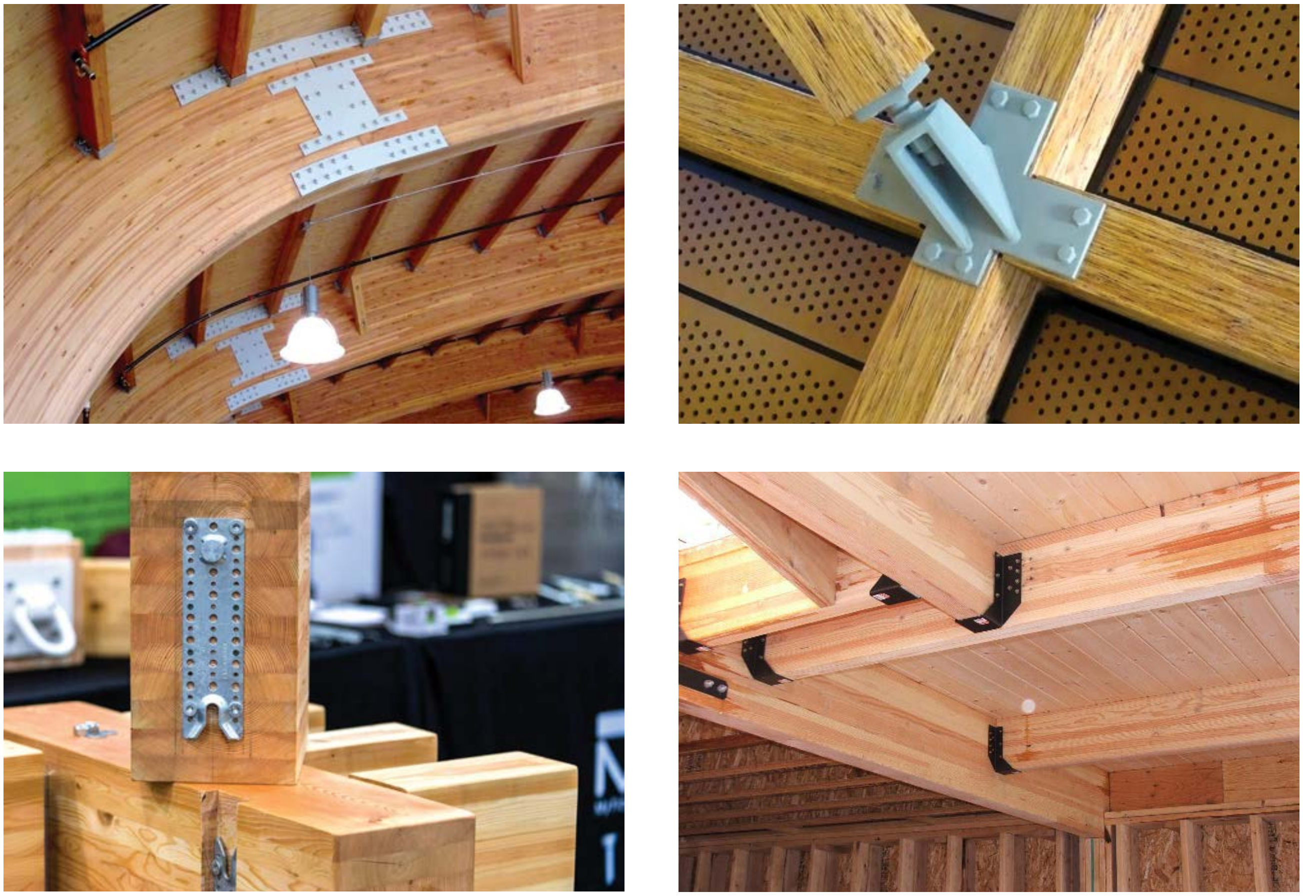


FIGURE 5.4: MASS TIMBER CONNECTOR EXAMPLES

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

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

Traditional joinery entails cutting and joining wood together to create structural connections without adding other materials. Mechanical connectors are commonly metal; they 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 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 to 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.

FIGURE 5.5: CNC COLUMN AND BEAM JOINERY

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

The National Design Specification (NDS) for Wood Construction 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 required 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 design process can increase the cost-effectiveness of a joinery-based design approach.

CONSTRUCTION IS UNDERWAY AT THE UBC GATEWAY BUILDING ON JUNE 19, 2024

Source: RJC Engineers; Credit: Justin Eckersall

CASE STUDY: UBC GATEWAY

UBC GATEWAY: INTRODUCING A HYBRID SYSTEM TO NORTH AMERICA

PROJECT OWNER: UNIVERSITY OF BRITISH COLUMBIA, UBC PROPERTIES TRUST

PROJECT LOCATION: 5955 UNIVERSITY BOULEVARD, VANCOUVER, BC, CANADA

COMPLETION DATE: SEPTEMBER 1, 2025

ARCHITECT/DESIGNER: PERKINS&WILL, SCHMIDT HAMMER LASSEN ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: ENGINEER: RJC ENGINEERS WITH SUPPORT FROM CREE BUILDINGS

MANUFACTURER/SUPPLIER: CON-FORCE STRUCTURES, VAAGEN TIMBERS

GENERAL CONTRACTOR: HEATHERBRAE BUILDERS, URBAN ONE BUILDERS

STRUCTURAL ENGINEER: RJC ENGINEERS

MECHANICAL, ELECTRICAL, AND PLUMBING: STANTEC (MECHANICAL AND PLUMBING), SMITH + ANDERSON (ELECTRICAL)

UNIVERSITY OF BRITISH Columbia's (UBC) $180 million Gateway building is the first landmark to welcome students on campus—a gateway to the school. Now under construction, this 6-story, mass timber space champions UBC's commitments to relations with Indigenous peoples, low-carbon resilience, and community health.

The 270,000-square-foot facility will house an array of features, including lecture theaters, classrooms, wet and dry labs, gyms, and offices. To promote interaction, UBC Gateway will co-locate the schools of nursing and kinesiology, integrated student health services, and UBC Health.

Inspired by traditional Musqueam building materials, UBC Gateway's architecture is a creative collaboration between Perkins&Will and Schmidt Hammer Lassen. The design considers natural light, warm aesthetics, and the way people will move through space.

Aligning with these architectural priorities, RJC Engineers offered the CREE Buildings system as 1 of 4 options, and the team ultimately chose it as the best option. This proprietary system revolutionizes how structures are constructed with hybrid panels made of precast concrete and glulam beams. Using hybrid timber as a major component enables the structure to resist heavy loading from large labs and amenities. It also makes long-span structural designs and high ceilings possible. The resulting warmth of elegantly exposed timber columns reinforces the idea of wellness.

UBC Gateway is North America's first-ever building to leverage CREE solutions. Spearheading the structural engineering, RJC sets a new standard for sustainable construction. Although CREE Buildings provided engineering and design support, their designs and tree species were based on European standards. Bridging the gaps between national codes was crucial for design decisions. RJC developed new design considerations to solve vibrations, as well as seismic considerations that are specific to British Columbia.

UBC Gateway called for 3-meter by 10.5-meter panels, the longest span with which CREE Buildings has ever worked. RJC designed all components, working with the contractor and subtrades to revise original system details with a focus on expediting construction.

To learn from active projects in Germany, RJC traveled to Brussels, Belgium, and Heiden, Germany, with the contractor and erector. Employing techniques from overseas in conjunction with other innovations, RJC Engineers designed a new system tailored to Gateway. The new design incorporated suggestions from both the contractor and trades to make erection smoother. This included the panel-to-panel connection, end connections, and grouting sequences to get to the next level quickly.

When fabrication kicked off, RJC visited the fabricator to review the complete system, fabrication ideas, and expected quality control. The visit was a chance to share the wood system along with necessary design considerations for this concrete-only precast plant. A subsequent trip entailed working hands-on with the trades—rebuilding the ends of a panel to show how the system could come together more easily. Direct collaboration on the plant floor paved the way for an efficiently fabricated and erected system with a short turnaround time.

Using Wood First principles, the project targets Leadership in Energy and Environmental Design (LEED) Gold for energy performance. Additionally, UBC Gateway is on track to become the university's first building to meet the Canada Green Building Council's Zero Carbon Building Design Standard.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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

Source: Timberlab Inc.

In some cases, removing steel from a joint can increase the fire resistance of an assembly. For example, Heartwood, the first Type IV-C building in Seattle, used joinery to create a 2-hour fire-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 fuse 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.

Splines

Spline connections combine joinery concepts and dowel connectors to structurally join large mass timber panels with smaller EWPs or steel compo-

FIGURE 5.7: WOOD NAIL COIL AND LIGNIN WELDING

Source: LIGNOLOC®

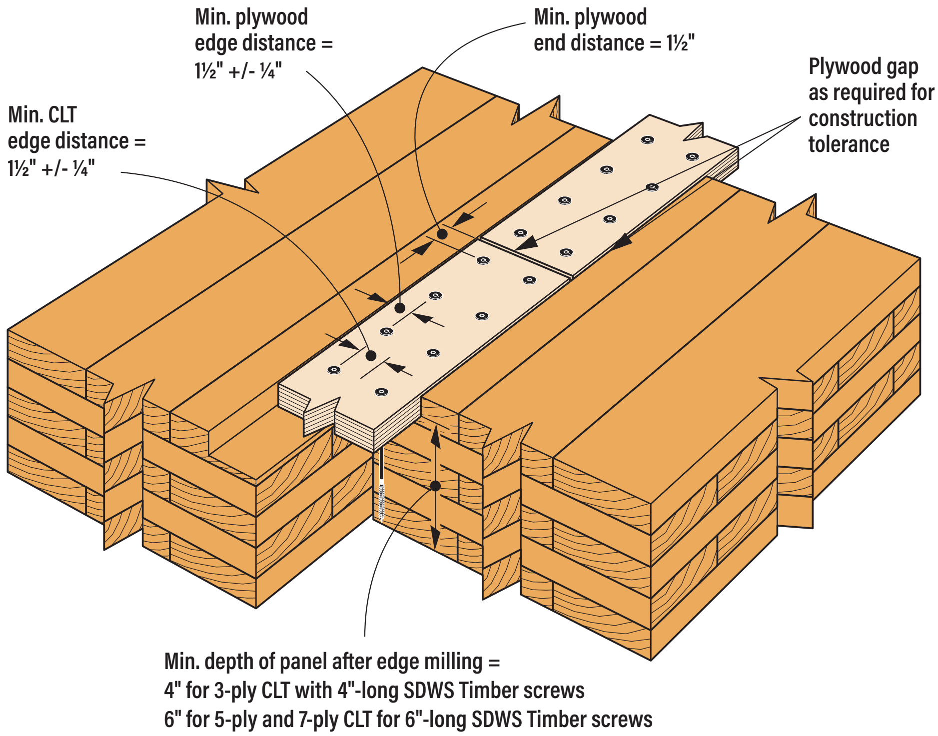


FIGURE 5.8: CLT SPLINE CONNECTION DIAGRAM WITH GAP AND FASTENER RECOMMENDATIONS

Source: Simpson Strong-Tie

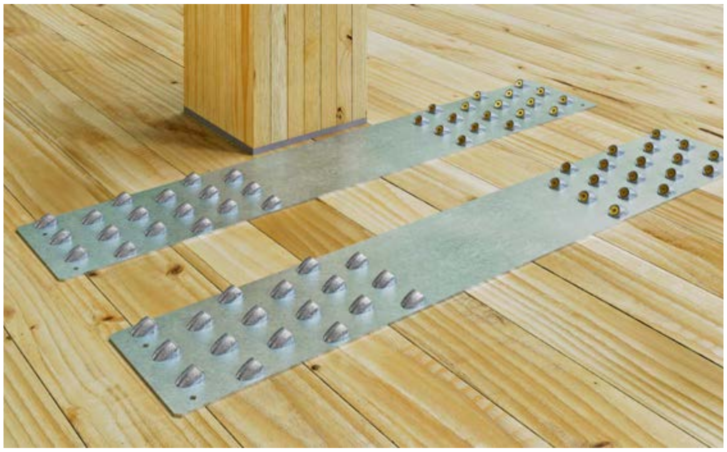
nents. A typical spline connection involves routing the connecting edges of 2 mass timber panels with a shallow groove, laying joinery boards in the groove, and fixing them in place with nails or screws (see **Figure 5.8**). This type of connection can also be achieved with plates connected on the panel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




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.*

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	CAD/Revit Library
	Mass Timber Connections Index
	A Look into Wood-to-Wood Connections (video)

TABLE 5.1: MASS TIMBER RESOURCES FOR DESIGNERS

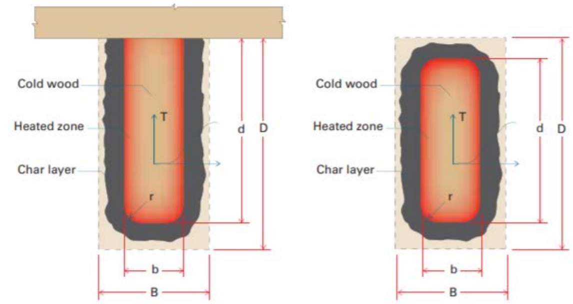
Source: WoodWorks.org/resources/

5.3 FIRE RESISTANCE

Many mass timber products are large, thick, airtight masses of wood. These properties are inherently fire-resistant. This might 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

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

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, 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. As a result, the calculated effective char depth will be 20 percent greater than the nominal char rate to account for reductions of strength and stiffness of wood directly adjacent to the char layer.[3] The effective char rate per hour gets slower the longer the wood burns because 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.

3 American Wood Council, Technical Report 10, *Calculating the Fire Resistance of Wood Members and Assemblies.*

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,[4] 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.[5] 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.

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

5 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).[6] 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 materials 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 improves the ability to build over contaminated soils with minimal 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.[7]

Using less concrete also 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.

Seismic Performance

Some of the oldest wooden buildings in the world are in Japan, the most seismically active country

6 https://techxplore.com/news/2022-08-invisible-coating-wood-fireproof.html

7 1 De Haro, San Francisco, Dean Lewis, DCI Engineers.

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,[8] enabling the buildings to dissipate significant seismic energy without damage.

Building codes are the main tool for addressing seismic risks. They establish 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, even 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 *2021 Special Design Provisions for Wind and Seismic (SDPWS).*[9] 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. They include a low-seismic CLT shear wall option with a structural R-value of 1.5, as 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*

8 https://web-japan.org/nipponia/nipponia33/en/topic/

9 https://awc.org/codes-standards/publications/sdpws-2021

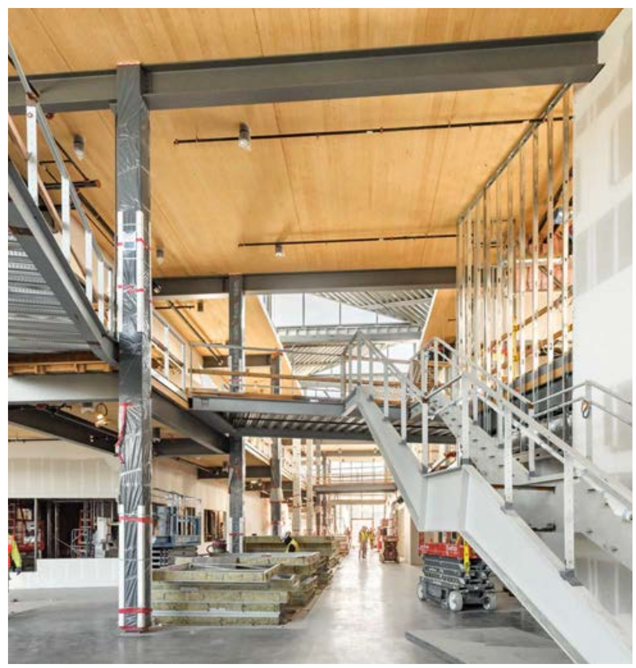
Design Guide that includes working examples using the new CLT diaphragm requirements.

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 7-22* (2022 edition). Research is ongoing on higher R-value, lower design force shear wall systems, including mass timber rocking wall testing.[10]

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

10 Led by Shiling Pei of Colorado School of Mines.



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

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

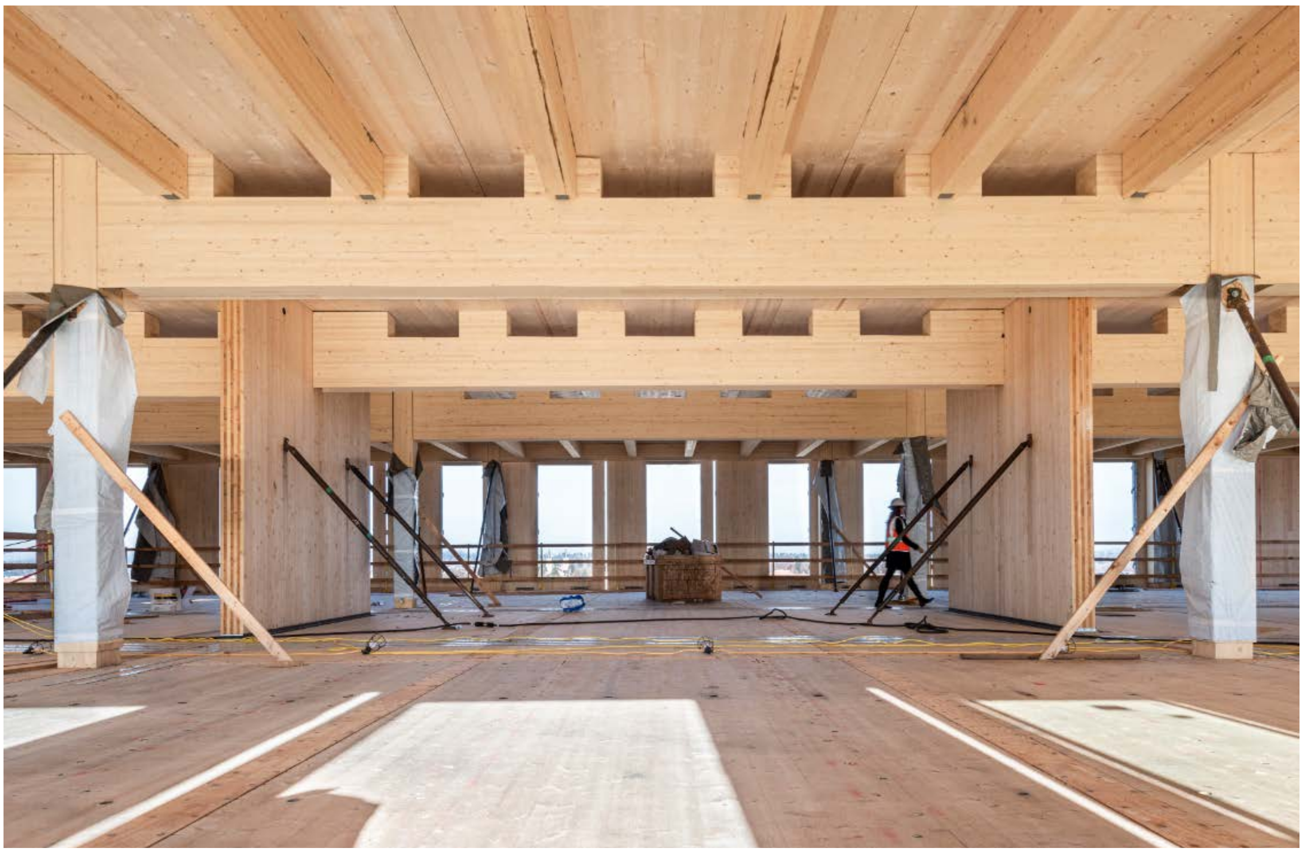
Peavy Hall, Oregon State University
Source: Evan Schmidt

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

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

Hybrid Slabs

Some building programs require spans that are difficult to accomplish with mass timber panels alone. An efficient classroom building on a 30-



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

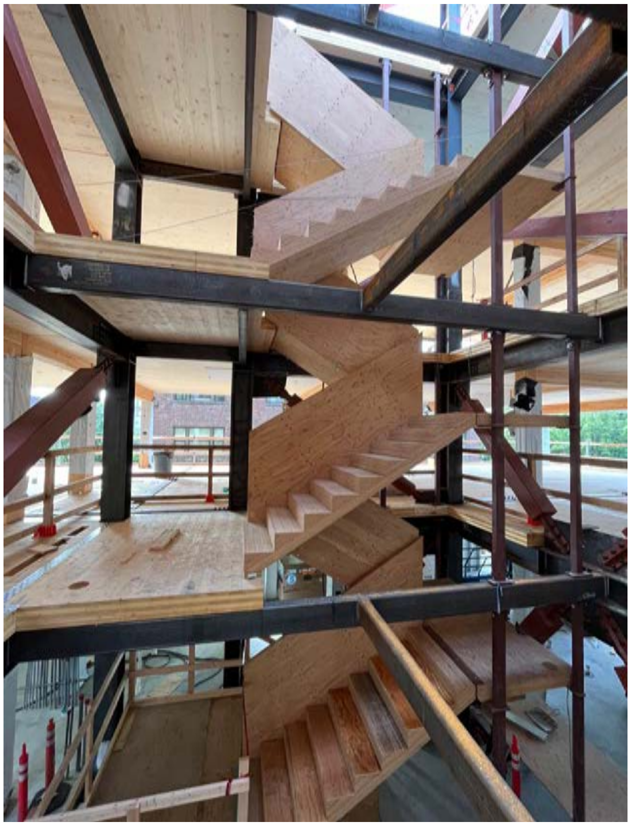
foot grid, for example, might at first seem to call for solid timber floors with a thick section that would be cost-prohibitive. For such projects, designers may instead consider adding beams, tension cords, or composite slabs, or they could rethink standard grid approaches developed with other construction 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: 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 might be difficult and expensive to handle during deconstruction, weighing on the cradle-to-grave carbon balance of buildings that use them. Concrete cure times should be considered and construction sequencing optimized, so using composite decks does not offset the time-saving advantages of timber framing.

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**).

Timber-timber composite floor panels are timber slabs with thickened timber sections that increase



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 Inc.

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. As with composite concrete-timber slabs, another hybrid lateral strategy, 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 that 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 designed with

FIGURE 5.25: POST-TENSIONED CLT 'ROCKING' SHEAR WALL INSTALLATION

Peavy Hall, Oregon State University; Credit: Hannah O'Leary

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.[11]

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.[12] When designing military buildings, architects

11 University of Utah et al., Wood Innovations Grant, "BRB Braced Frames for Seismically Resilient Mass Timber Buildings," USDA Forest Service, 2021.

12 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
	US 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 US 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.

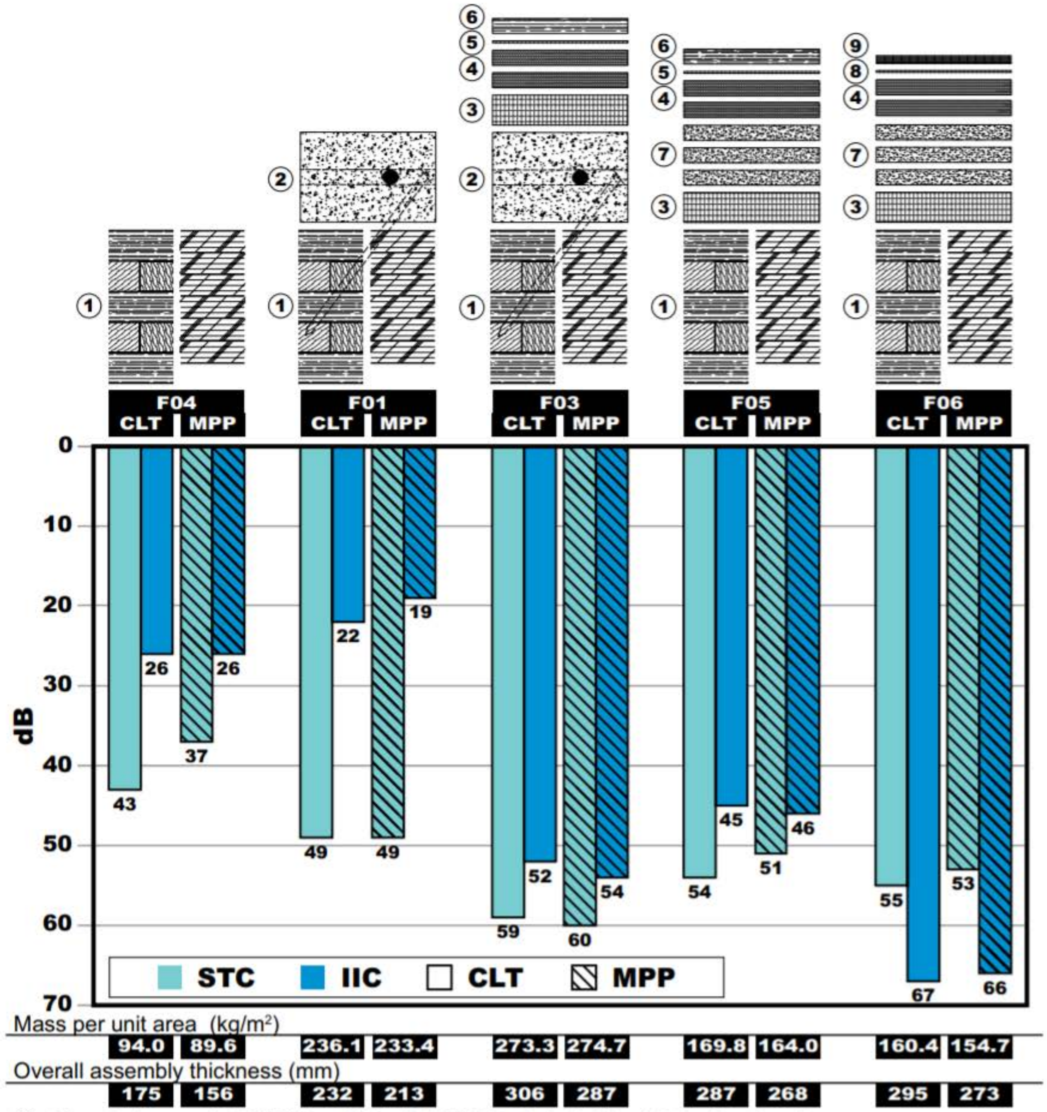
Initial blast-resistance tests conducted at Tyndall Air Force Base in Florida validated acceptable levels of blast resistance for structures built with NLT and CLT. All structures remained intact and matched modeling predictions for acceptable levels of damage.

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.[13]

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.

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



1. Mass timber panel, 6-7/8" 5-lam CLT or 6-1/8" MPP, single half-lap joint in direction of span
2. 2-1/4" concrete slab @ 145 pcf density, #3 rebar, 6" o.c. in span direction, 12" o.c. perpendicular to span, 8mm x 220mm shear fastener, 12" o.c. field spacing @ 45º
3. 1" acoustic underlayment, install in opposing direction to flooring
4. 5/8" OSB, 2 layers, glued in direction of span, stagger seams, adhere with construction adhesive
5. 1/8" acoustic underlayment
6. 6-1/2" x 1/2" random length engineered pine floating floor, T&G, sanded, oiled
7. 1/2" cement board, 3 layers, stagger seams, adhere with construction adhesive
8. 3/8" 8lb carpet pad
9. 1/2" pile nylon carpet, 97.5 oz/sq.yd face weight

FIGURE 5.26: CLT AND 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

THE GARDEN VIEW OF THE CLT HOUSE IN SAN NICOLAS
Source: Dovat Arquitectos; Credit: Carly Angenscheidt

CASE STUDY: CLT HOUSE, SAN NICOLAS

CLT HOUSE RECEIVES NATIONAL ENERGY EFFICIENCY AWARD

PROJECT OWNER: CAROLINA DOVAT

PROJECT LOCATION: LA HORQUETA 3270, MONTEVIDEO, URUGUAY, 13000

COMPLETION DATE: JULY 1, 2022

ARCHITECT/DESIGNER: DOVAT ARQUITECTOS

MASS TIMBER ENGINEER/MANUFACTURER: X LAM DOLOMITI

GENERAL CONTRACTOR: ENKEL, COXAR

STRUCTURAL ENGINEER: X LAM DOLOMITI

MECHANICAL, ELECTRICAL, AND PLUMBING: ESTUDIO HOFSTADTER, ESTUDIO PITTAMIGLIO

DURING THE COVID-19 pandemic, Carolina Dovat faced the stark reality that, as human activity slowed, nature responded dramatically. In this context, she questioned the role of architecture and construction in a world where buildings are major contributors to carbon emissions. This reflection sparked her drive to begin working with mass timber, leading Dovat Arquitectos to embrace the challenge of becoming agents of change in their country: Uruguay.

She and her team embarked on designing their own mass timber house, the first in the nation. Dovat Arquitectos conceived of this single-fam-

CLT HOUSE SAN NICOLAS UNDER CONSTRUCTION, WITH THE MASS TIMBER STRUCTURE EXPOSED

Source: Dovat Arquitectos
Credit: Carly Angenscheidt

CLT HOUSE SAN NICOLAS INCORPORATES A WILDLIFE-FRIENDLY GARDEN

Source: Dovat Arquitectos
Credit: Carly Angenscheidt

ily mass timber house as nestled in a coniferous forest. Aligned with the studio's philosophy emphasizing low environmental impact and people-centered design, they harnessed the benefits of biophilic design to create spaces that promote both physical and psychological well-being.

This residential project presented an opportunity to showcase a design where wood, in its various forms, becomes the central element, guiding the viewer on a visual journey from the living pine trees planted in the earth to the CLT walls and slabs, all crafted with fine architectural finishes.

The 500-square-meter house is developed over 2 floors, with reception areas and family spaces seamlessly connected and opening to the garden on the ground floor. Upstairs, the bedrooms offer an immersive experience with nature through large windows that connect to green rooftops and the lush canopies of the surrounding trees.

The entire structure was built using mass timber, in a conscious effort to avoid concrete, though some of the pillars and slabs were deliberately left exposed as a design feature. For the exterior finishes, materials were selected to require minimal maintenance, and a photovoltaic roof was incorporated to allow for the generation of a significant portion of the electricity needed for year-round use.

The design was completed with a wildlife-friendly garden aimed at enhancing the natural biodiversity of the area, where native species take center stage both on the ground and across the 2 green terraces on the upper floor.

In 2023, this project received the National Energy Efficiency Prize in the residential category by the Ministry of Industry and Energy of Uruguay.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

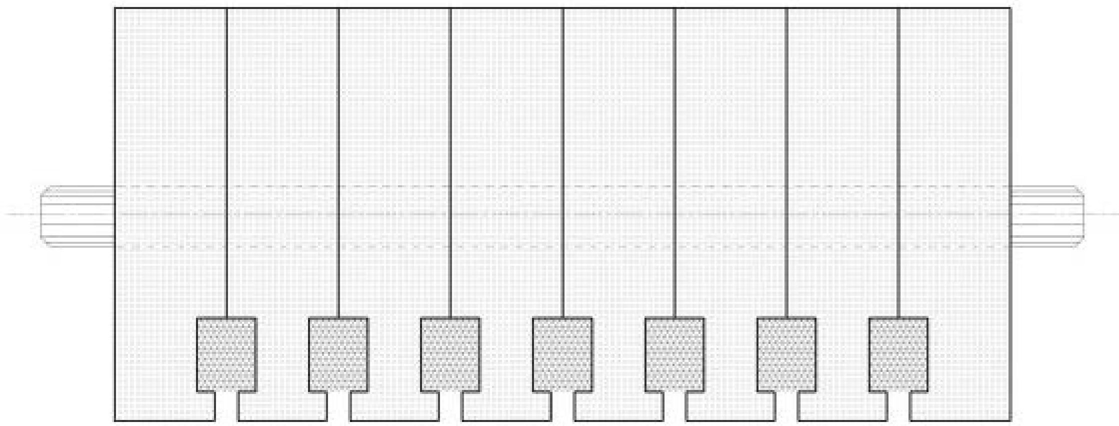


FIGURE 5.27: SIDE VIEW OF ACOUSTICALLY DESIGNED DLT PANEL

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.[14] Additionally, some guidelines have been developed for floor assemblies, including raised access floors, "dry" buildups that 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[15] 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 well 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.

14 https://www.woodworks.org/wp-content/uploads/Acoustically-Tested-Mass-Timber-Assemblies-WoodWorks.pdf

15 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/.

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 engineered to improve the Noise Reduction Coefficient (NRC) rating of the exposed structural surface and provide additional sound absorption (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 lifespan 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

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

other materials for comparison) and their thermal conductivity values.

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 lifespan, 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 improves the building envelope's R-value from R-16 to R-22.[16]

Air infiltration rates of exterior envelopes contribute significantly to the energy performance of a building. CLT and MPP have exceptionally low air infiltration rates, making them good choices for the high-performing exterior walls required for very low-energy building design. A recent blower door test for the aforementioned higher- education project, which used an MPP wall assembly coupled with limited glazing area and

16 Washington State University-Vancouver Life Sciences Building, 2024; Architect: SRG + CannonDesign, Contractor: Andersen Construction.

punched window openings, resulted in an airtightness rating of .06 cubic feet per minute per square foot (cfm/ft^2)—more than 4 times better than the Washington State Energy Code baseline of .25 cfm/ft^2.[17]

5.7 MOISTURE

Mass timber designers 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 practices. Designers will find additional relevant information on weather protection and moisture management during construction in section 6.

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 percent 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

17 Washington State University-Vancouver Life Sciences Building, 2024; Architect: SRG + CannonDesign, Contractor: Andersen Construction.

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

Source: Kaiser+Path; Credit: Kevin Lee

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.[18]

A project studying water in mass timber[19] 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 is providing benchmark data for engineering models. In early 2020, 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, and 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. Although there are no published requirements and recommendations

18 RDH Building Science, *Mass Timber Building Enclosure Best Practice Design Guide, V2, 2021.*

19 Arijit Sinha, *Water and Mass Timber*, Oregon State University (OSU), https://tallwoodinstitute.org/water-and-mass-timber/.

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/

may vary, project teams are finding that a MC below 15 percent is appropriate for a floor slab before it is encapsulated with topping 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-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. These cracks, or checks, pose no structural performance concerns but can be aesthetically undesirable to some building owners. Often, the best approach is to set expectations early in design that when using a natural structural material, surface quality can change with time. Avoiding large fluxes in MC and slowing the drying time of wet panels can minimize checking, but some checking is normal and natural.

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 might 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 a common preservation technique for exterior wood structures such as bridges, decks, railroad ties, and telephone poles. Not all treatments are appropriate for occupied structures because many formulas come with human health risks. Treatments come at a higher cost than coatings, but they are highly effective at reducing susceptibility to decay. 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 with adhesives. Treated mass timber panels could also have insect-repellent capabilities, expanding geographic acceptance into regions with termites. But the large sizes of the panels make postfabrication treatment impractical with the available processes.

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, it can be largely avoided with details that useend-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.

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

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

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 be more efficient and successful. Well-coordinated and accessible or exposed services also make maintenance easier over the life of the building.

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 pre-bid 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 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 those 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 might also offer assistance in all these functions to clients selecting external designers and/or contractors.

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)
9. Institute for Health in the Built Environment, University of Oregon (Eugene, Oregon)

Southwest

10. Natural Hazards Engineering Research Infrastructure (NHERI) Shake Table (San Diego, California)
11. Colorado School of Mines (Golden, Colorado)

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

12. Colorado State University (Fort Collins, Colorado)

Northeast

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

Southeast

19. Clemson Wood Utilization and Design Institute (Clemson, South Carolina)
20. Virginia Tech Sustainable Biomaterials Lab (Blacksburg, Virginia)
21. 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,

FIGURE 5.32: PRECISE PREFABRICATED MATERIAL INTERSECTIONS
IZM Building, CREE and Hermann Kaufmann
Source: Emily Dawson

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 the component 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

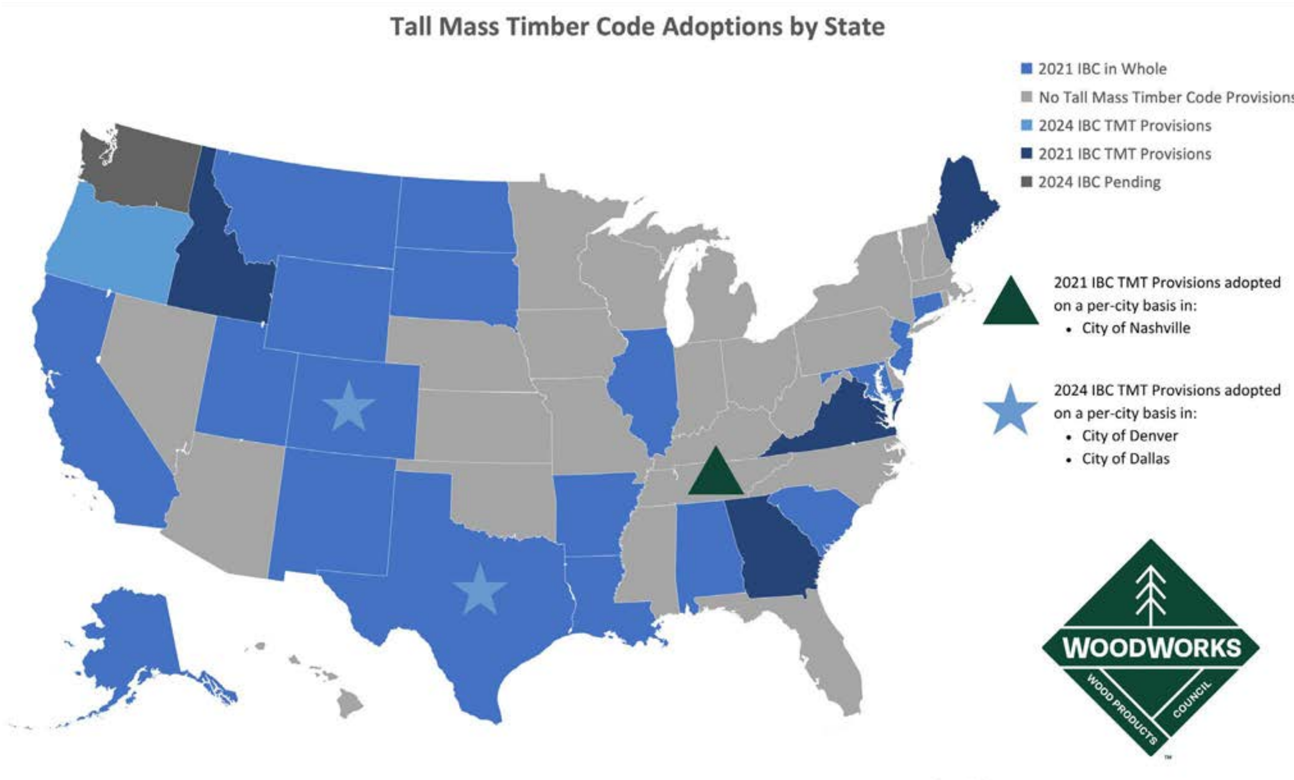


FIGURE 5.33: TALL MASS TIMBER CODE ADOPTIONS BY STATE

Source: WoodWorks

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 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, the team 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. That 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,

FIGURE 5.34: NATIONAL BUILDING CODE OF CANADA ADOPTION BY PROVINCE

II, III, and V) allow for the use of wood elements, though some will require additional protections to increase fire resistance. Many education, office, and multifamily housing project 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 residen-

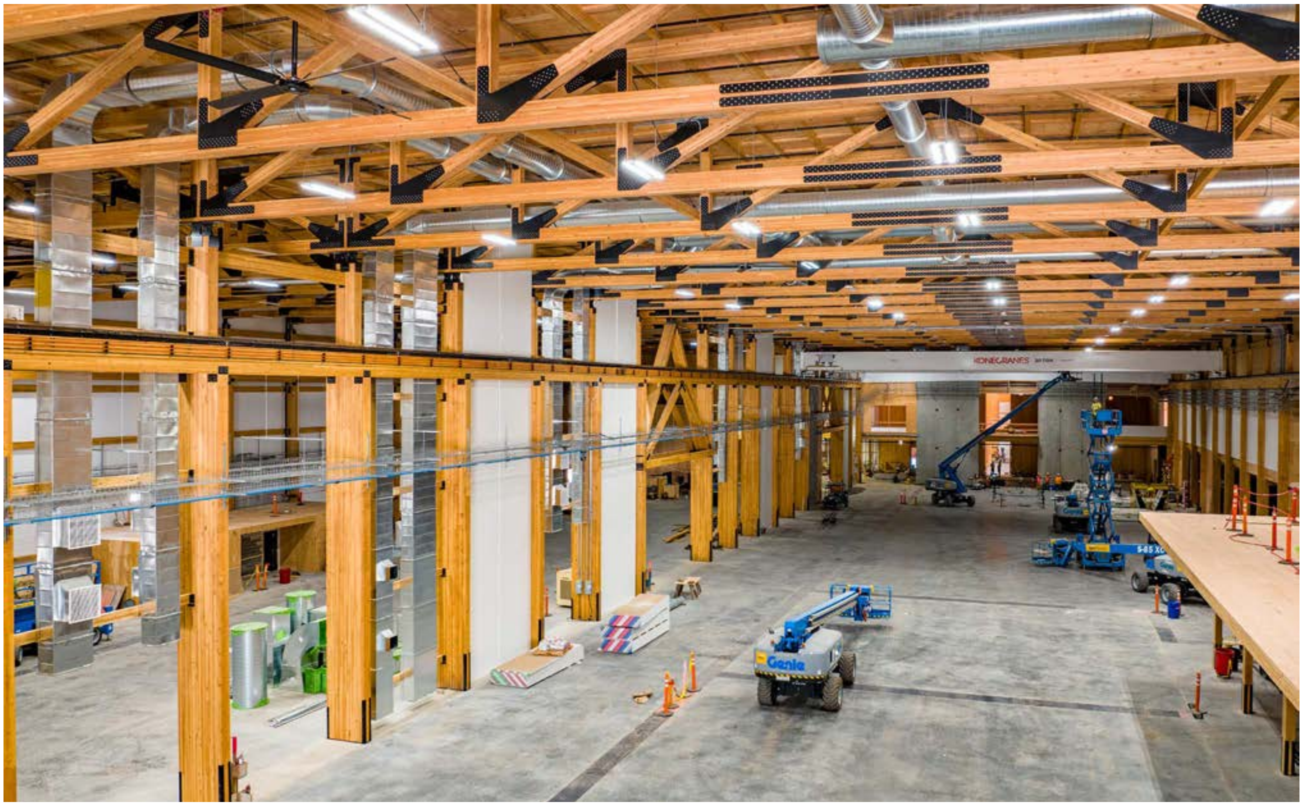


FIGURE 5.35: TYPE VB CONSTRUCTION

Janicki Industries Building 10, Hamilton, WA
Source: Vaagen Media, Credit: Structural design by DCG Watershed

tial, 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 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 Provisions 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.

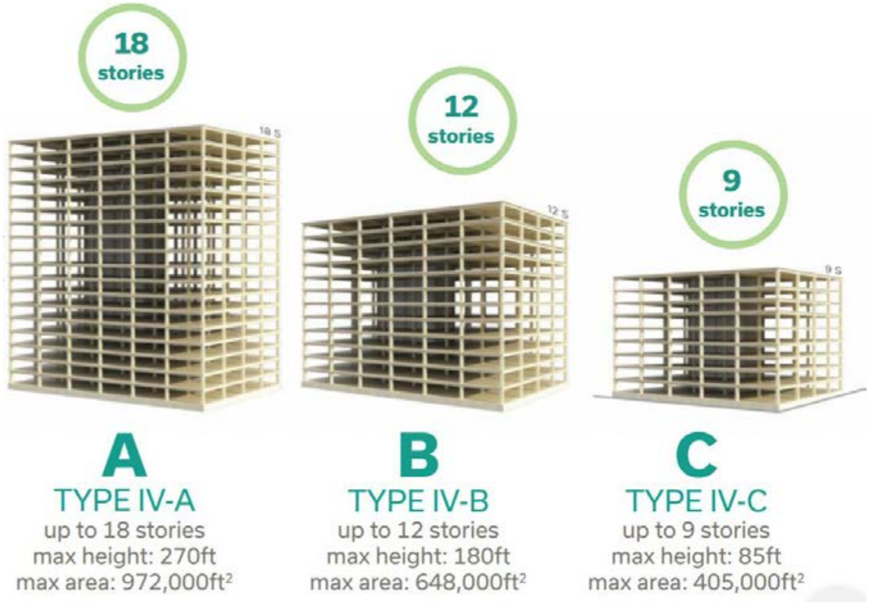


FIGURE 5.36: TALL WOOD CONSTRUCTION TYPES ADDED TO THE 2021 IBC

Source: Think Wood Research Brief Mass Timber 2021 Code

United States

Keeping in mind that timber can be used structurally in any construction type that allows it (see **Figure 5.35**), progressive improvements to building codes that address the use of timber as a fire-resistant material have been crucial 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.

Type IV-C: Maximum 9 stories, 85 feet in height, and 405,000 square feet in area. 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

FIGURE 5.37: TYPE IV-C CONSTRUCTION
Heartwood, Seattle, WA
Source: atelierjones; Credit: Lara Swimmer

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[20] 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 2024, 11 projects have been reported under the IV-C designation (see **Figure 5.37**), and 68 projects have used IV-HT (see **Figure 5.38**). Projects using construction Types IV-A (see **Figure 5.39**) and IV-B are fewer but growing in number.

20 https://www.ri.se/en/what-we-do/projects/fire-safe-implementation-of-mass-timber-in-tall-buildings

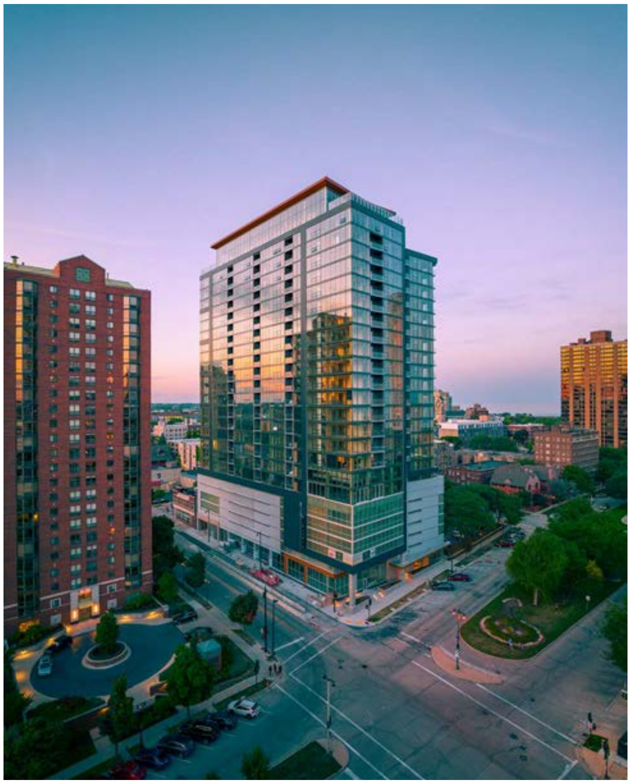


FIGURE 5.38: 19 STORIES TYPE IV-HT OVER A 6-STORY CONCRETE PODIUM

Ascent, Milwaukee, WI
Source: New Land Enterprises; Credit: Nate Vomhof

FIGURE 5.39: 1 STORY OF STEEL OVER 16 STORIES OF TYPE IV-A

1510 Webster, Oakland, CA
Source: oWow; Credit: Andrew Nelson

Oregon and Washington have been leaders in the adoption of mass timber construction, proactively adopting the Tall Wood Provisions in 2018, and doing the same with the 2024 provisions, this time joined by the cities of Denver and Dallas. Nineteen states have fully adopted the 2021 code, and four 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 AWC Wood Design Standards Committee has recently completed over 5 years of design standards development for the 2024 editions of the NDS for wood construction (ANSI/AWC NDS-2024) and the Fire Design Specification (FDS) of wood construction (ANSI/AWC NDS-2024)[21] (see **Figure 5.40**). Engineers and architects

21 https://awc.org/resource-hub/?gcat=codes-and-standards

FIGURE 5.40: 2024 NDS AND 2024 FDS

American Wood Council Design Standard
Source: American Wood Council

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's chapter 16 were made to bring its provisions into alignment with provisions in 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 NDS chapter 16:

- NDS 16.2.2.4 has been added to permit the use of an approved char model for CLT that uses FDS provisions that address 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 gives 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.

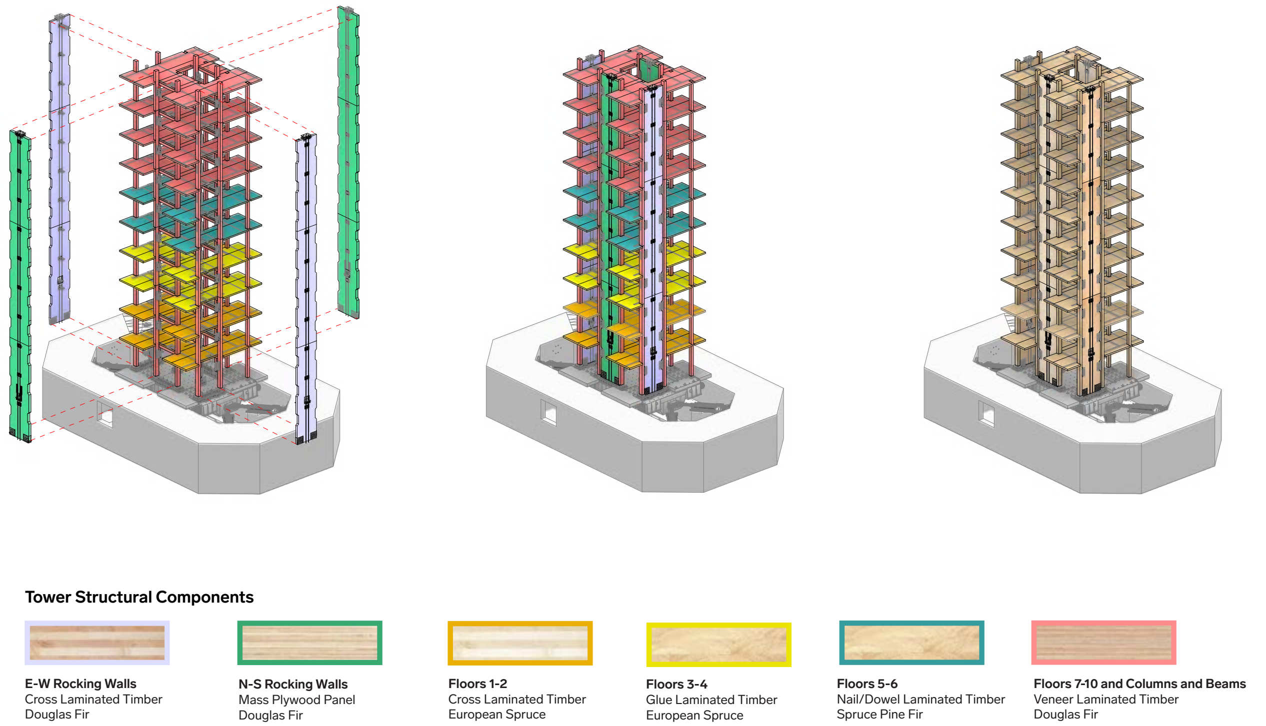


FIGURE 5.41: NHERI TEST CONSTRUCTION DIAGRAM

Source: LEVER

- 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, the University of California San Diego's NHERI[22] 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, Glue-Laminated Timber [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 damage from the simulated earth-

22 The Shake Table is at the Englekirk Structural Engineering Center, and part of the National Science Foundation's NHERI network, https://nheri.ucsd.edu/.

quakes. 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[23] demonstrated that "it is safe to utilize CLT in an exterior wall application above 40 feet in

23 Timberlab Inc. et al., Wood Innovations Grant, "Cross Laminated Timber Exterior Wall Testing to NFPA 285 Test Standard" (USDA Forest Service, 2021), https://www.fs.usda.gov/sites/default/files/TimberLab-FireSafe.pdf.

FIGURE 5.42: 10-STORY TIMBER TOWER EARTHQUAKE TEST
NHERI Shake Table, 2023
Source: Timberlab Inc./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/

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

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 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 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 incorporated new requirements into the state building code to limit embodied carbon emissions in commercial projects over 100,000 square feet and school projects over 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.

Scott Mooney contributed to chapter 5, 2025 edition.

THE LOBBY HAS A HEAVY TIMBER ROOF STRUCTURE AND A SKYLIGHT
Source: hcma architecture + design; Credit: Nic Lehoux

CASE STUDY: TƏMƏSEW' TXʷ AQUATIC AND COMMUNITY CENTRE

AQUATIC CENTER IS CANADA'S FIRST COMPLETED ZERO CARBON BUILDING

PROJECT OWNER: CITY OF NEW WESTMINSTER

PROJECT LOCATION: 65 E SIXTH AVE., NEW WESTMINSTER, BC, CANADA V3L 4G6

COMPLETION DATE: MARCH 31, 2024

ARCHITECT/DESIGNER: HCMA ARCHITECTURE + DESIGN

MASS TIMBER ENGINEER/MANUFACTURER: KALESNIKOFF

GENERAL CONTRACTOR: HEATHERBRAE BUILDERS

STRUCTURAL ENGINEER: FAST + EPP

MECHANICAL, ELECTRICAL, AND PLUMBING: AME CONSULTING GROUP (MECHANICAL ENGINEER); AES ENGINEERING (ELECTRICAL ENGINEER)

THE TƏMƏSEW' TXʷ Aquatic and Community Centre in New Westminster, British Columbia, aims to be the heart and soul of the community and a place for all to connect. Woven into the landscape with a dramatic unifying roof, the building makes a strong civic statement while being sensitive to the natural environment and human-scale experience.

Designed by hcma architecture + design, the center is intended for people of all ages and abilities; it's shaped by how communities engage in recreation today and into the future. It includes a 4-pool aquatic center with sauna and steam rooms, universal washrooms and change rooms,

THE 50-METER LAP POOL HAS A MASS TIMBER ROOF IN A SAWTOOTH DESIGN

Source: hcma architecture + designCredit: Nic Lehoux

a fitness center, gymnasium, community rooms, licensed childcare, administrative offices, as well as significant new plazas and green spaces.

təməsew' txʷ is Canada's first aquatic center certified as Zero Carbon Building–Design, eliminating building fossil fuel combustion and aiming for a 92 percent reduction in greenhouse gas (GHG) emissions compared with the existing facility.

Wood has a declarative prominence throughout the facility, chosen for its technical proficiency, striking character, and emanation of warmth. Its use reflects the architect's innovative and evolving embrace of wood in aquatic design that spans over 2 decades. Sharp planes of Cross-Laminated Timber (CLT) hang from long-span steel trusses high above the lap pool, forming a distinctive, dynamic sawtooth structure. Cranked panels of CLT animate the busy leisure pool, and an array of glulam beams airs a confident, welcoming, and friendly presence atop the bustling lobby space.

Standing out in the design is the abundance of indirect light that pours into the lap pool from the north through clerestories embedded in the sawtooth trusses. A mass timber solution made this possible despite poor soil conditions on-site. Much lighter than a conventional steel or concrete structure, mass timber allowed for a more lightweight, economical structure that also supports the daylight aspirations for the lap pool.

Mechanical and electrical systems and a concealed walkway for maintenance are nested within the hybrid steel-mass timber trusses. The integration of these systems is a union of form and function, where the CLT doubles as a structural member and an architectural element. The sawtooth roof structure allows natural light to flood the natatorium—and can also be uplit when needed—to create a beautiful quality of light for swimmers.

The warmth of wood, in terms of its tone and tactile nature, provides a biophilic quality not often found in aquatic environments, which need to be impervious and sterile. Through wood, a warm, natural depth that's rare in other robust materials like glass, tile, stainless steel, and concrete can be achieved.

Beyond the natatorium, the use of wood carried through in places like the guardrail, elevator wraps, and stair picket brings an organic, hearty, and durable texture directly to the hands of visitors.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

CHAPTER 6: BUILDERS

EMILY DAWSON, AIA
OWNER, SINGLE WIDGET | FIELD EDGE

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.

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.

FIGURE 6.1: TALL TIMBER RISING

Ascent
Source: Thornton Tomasetti

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.

1 Construction Materials Market Research, 2023, https://www.alliedmarketresearch.com/construction-materials-market-A68813.

FIGURE 6.2: LIGHT WOOD-FRAMING

Canyons
Source: K+P; Credit: Scott Noble

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 that must resist swaying in the wind. These properties make wood highly effective for dynamic loading and fatigue resistance. 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 can be combined with mass timber in a hybrid structural system. It is widely used in low- and mid-rise multifamily and 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 its low cost and the availability of materials. The smaller format of the buildings means workers can move the materials around a jobsite more easily than they

FIGURE 6.3: POST AND BEAM BUILDING

UMass Amherst
Source: Architect Magazine

can larger and bulkier ones, such as steel beams. They can also use relatively common, inexpensive, and 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 might 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, increasing the cost of in-place materials. Some projects are now utilizing wall panels prefabricated off-site or precut lumber packages that greatly reduce on-site waste. However, of all the building styles discussed here, light wood-frame carries the lowest resistance to fire damage. Although this system is in common use among building trades, it is labor-intensive, and schedules can be impacted by a lack of labor availability.

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 provide fire resistance. Heavy timber includes laminated beams and columns and composite beams and columns with minimum code-defined dimensions, but not laminated panels.[2] In this construction style, large timbers form vertical columns and horizontal beams which are connected either with wooden joinery or metal connectors (see **Figure 6.3**). A key implication of this design

2 2021 International Building Code, Table 2304.11.

FIGURE 6.4: A CROSS-LAMINATED TIMBER (CLT) AND GLULAM RESIDENTIAL BUILDING

C12
Source: K+P; Credit: Andrew Pogue

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. 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 were low- to mid-rise. However, the 2021 US building code allows timber buildings up to 18 stories (270 feet), with reduced encapsulation requirements established in the 2024 version of the code. Canada has also developed the Tall Wood Provisions. 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.

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/

Mass timber introduced 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 that offer solutions akin to a turnkey package from design through construction also might create conflicts with parties bidding for individual parts of a project and design-bid-build contract models.

Recognizing the urgent need to train construction teams and trades in the US in mass timber, WoodWorks published resources (see **Table 6.1**) to help guide contractors on the particularities of bidding, planning, and constructing with mass timber.[3] With partners nationwide, WoodWorks also offers workshops on mass timber project management and training in installation. In addition, many unions and local colleges and trade schools offer training specifically geared to mass timber construction.

To bid and plan mass timber projects successfully, build team members should familiarize themselves with project optimization during design 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 developer 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 processes balances the premium costs of early planning with increased use

3 WoodWorks, Mass Timber Construction Manual (October 2021).

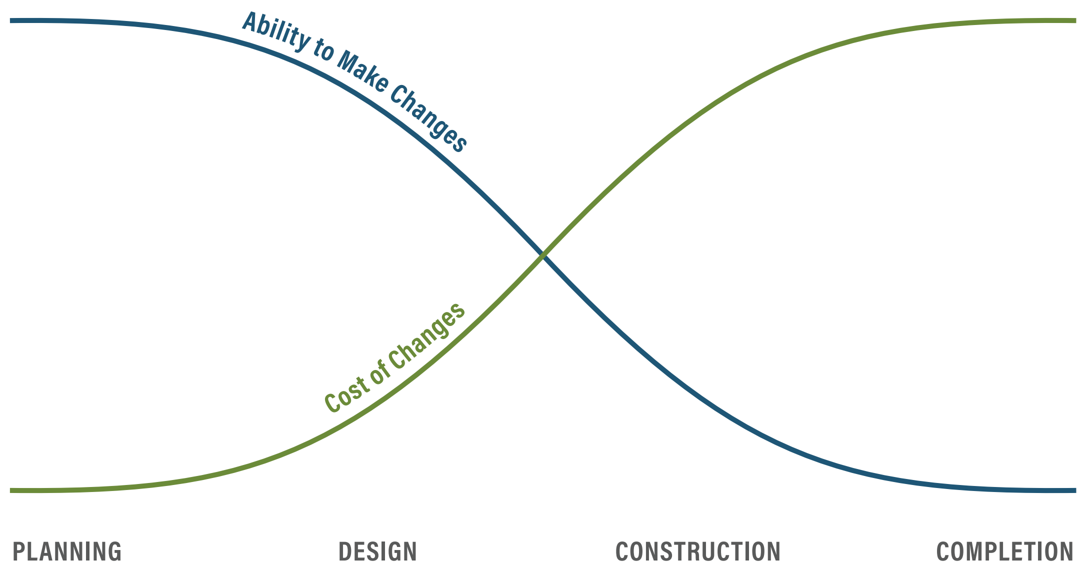


FIGURE 6.5: COST OF CHANGES

of high-value materials and prefabrication. Early communication among the design, manufacturing, and construction teams can also lead to efficiencies generated by using available component sizes, prefabrication, and high-precision CNC finishing. Beginning layout and detail optimization later in the process, such as during bidding, 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 (see **Figure 6.5**); one cost advantage 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 protection (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, leading to the subcontractors “working together like a well-oiled machine.”[4]

This high level of coordination and the early involvement of integrated design, fabrication, and construction teams are often offered as part of a package by seasoned mass timber companies or by contracting companies specializing in mass timber construction.

For best practices concerning coordination, WoodWorks has created mass timber cost and

4 www.buildingCarbon12.com

FIGURE 6.6: MASS TIMBER STRUCTURE AND PREFABRICATED FACADE PANELS

1510 Webster, Oakland, CA

Source: The Engineered Wood Association (APA)

design optimization checklists to assist project teams (see **Table 5.3**).[5]

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, such as insurance, interest, and general conditions.

Identical buildings are not typically constructed using different structural materials, 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 material reductions throughout the building, such as reduced foundation and excavation costs, and the elimination of framing, drywall, and finish painting or wall coverings.

Oakland-based developer oWOW produced a full-building cost comparison between the final design of their residential tower 1510 Webster 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 6.6**) that allowed the in-house construction crews to raise each floor in 3 to 4 days with enclosure following closely. Compared with the concrete alternative, the mass timber building saved over 25 percent on costs and 6 months of construction time.

5 https://www.woodworks.org/wp-content/uploads/wood_solution_paper-Mass-Timber-Design-Cost-Optimization-Checklists.pdf

1265 BORREGAS, SUNNYVALE, CALIFORNIA, LENDS TO GOOGLE'S GOAL TO ACHIEVE NET-ZERO EMISSIONS BY 2030

Source: Michael Green Architecture; Credit: Ema Peter

CASE STUDY: 1265 BORREGAS

OFFICE BUILDING PRIORITIZES HEALTH OF PEOPLE, PLANET

PROJECT OWNER: GOOGLE

PROJECT LOCATION: 1265 BORREGAS AVENUE, SUNNYVALE, CA 94089

COMPLETION DATE: SEPTEMBER 3, 2024

ARCHITECT/DESIGNER: MICHAEL GREEN ARCHITECTURE, SERA ARCHITECTS

MASS TIMBER ENGINEER/MANUFACTURER: STRUCTURLAM MASS TIMBER CORPORATION

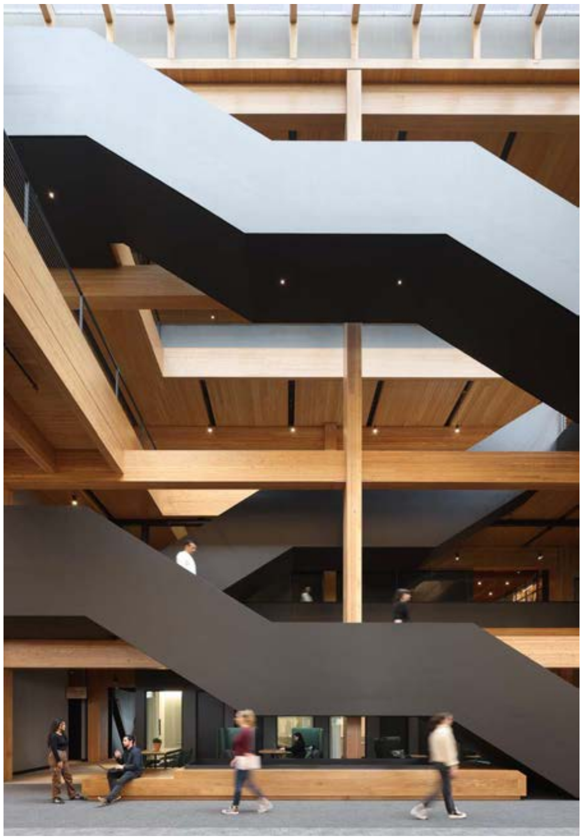
GENERAL CONTRACTOR: XL CONSTRUCTION

STRUCTURAL ENGINEER: EQUILIBRIUM CONSULTING INC.

OTHER CONTRACTORS: HOLMES FIRE, ELEVATED CONSTRUCTION SERVICES, KINSOL

THE IMPRESSIVE 5-STORY office building in Sunnyvale, California—Google's first ground-up mass timber development—sets new standards for sustainable and biophilic design, construction techniques, material sourcing, and carbon reduction.

The goal for 1265 Borregas was to create a scalable building solution that puts health and sustainability first and lends to Google's goal of achieving net-zero emissions by 2030. Elegant in its simplicity, the Leadership in Energy and Environmental Design (LEED) Platinum building leverages mass timber to dramatically reduce carbon emissions and create a warm, welcoming, and healthy workspace. Importantly, 1265 Borregas is projected to have 96 percent fewer



ABOVE — LIGHT IS A KEY FEATURE OF THE BUILDING'S INTERIOR COMMUNITY SPACE

Source: Google; Credit: Mark Wickens

LEFT — THE INTERIOR STAIR AND SKYLIGHTS AT GOOGLE'S FIRST GROUND-UP MASS TIMBER DEVELOPMENT IN SUNNYVALE, CALIFORNIA

Source: Michael Green Architecture; Credit: Ema Peter

embodied carbon emissions than an equivalent steel and concrete structure, factoring in sequestration.

The beauty and simplicity of the design and engineering is celebrated by keeping the structure authentic and exposed. For example, the glulam beams and columns and Cross-Laminated Timber (CLT) panels are left exposed throughout the interior; the biophilic design strategies distinguish 1265 Borregas from other offices. The design team used mass timber to emphasize occupant health and well-being, blending natural materials with daylit interiors, views, and organic textures to create a workplace that aligns naturally with the company's commitment to sustainability.

Unusual design elements add to the building's comfort and energy efficiency. Not only is the building all-electric with photovoltaic solar panels on the roof, but Accoya wood blinds were integrated into the closed-cavity facade for increased building performance and comfort. The blinds automatically track the sun and respond to levels of light, limiting glare while allowing views of the landscape. Architects mixed single- and double-height spaces and connected them with an atrium illuminated by a timber-and-glass skylight, bringing natural sunlight into the workspace and creating visual and physical connections between teams and individuals within the building.

This project prioritizes the health of people and the environment, meeting ambitious biophilic and sustainability goals by using mass timber to build a high-performance building.

"This project promotes health, connects to nature, and addresses the global need for repeatable, affordable, and sustainable new buildings," said Natalie Telewiak, principal, Michael Green Architecture.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

Insurance

Insurance for mass timber buildings is a fast-changing landscape, and elevated premiums for builders' risk insurance continue to be a challenge. Although insurers' perceptions of combustibility are shifting away from comparisons with light framing, no alternative between this paradigm and "noncombustible" exists yet as a standard in the industry. The new International Building Code (IBC) construction types do not translate directly into a new Insurance Services Office classification,[6] which is how insurers classify risk categories. Some insurers are creating their own risk classification, but there is no standard, making the creation of pools of actuarial data challenging. Without actuarial data, insurers will add premiums to account for unknowns or decline coverage altogether.

Some insurers are starting to see the future market in decarbonized construction and find assurance in successful projects with trusted builders.[7] It is imperative that builders have as part of their project management team an insurance broker well versed in mass timber construction to navigate the insurance labyrinth and ensure adequate coverage and potentially more affordable premiums. Several valuable resources help project teams make the best case for partnership with insurers. The UK[8] and US *Mass Timber Insurance Playbook*[9] editions are an excellent starting point, as well as a project team questionnaire[10] and other resources[11] on the WoodWorks website.

Procurement

Mass timber components are custom products made 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.

The advantages of contractor involvement in early project planning include valuable insight into materials 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 help ensure that the planning team has plenty of time to coordinate and approve shop drawings.

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

6 https://www.irmi.com/term/insurance-definitions/building-construction-categories-(iso)

7 https://axaxl.com/press-releases/axa-xl-announces-tailored-insurance-to-help-clients-address-mass-timber-construction-risks-in-north-america

8 https://builtbn.org/knowledge/mass-timber-insurance-playbook/41

9 https://www.woodworks.org/resources/mass-timber-insurance-playbook/

10 https://www.woodworks.org/resources/mass-timber-project-questionnaire-for-builders-risk-insurance/

11 https://www.woodworks.org/resources/insurance-for-mass-timber-construction-assessing-risk-and-providing-answers/

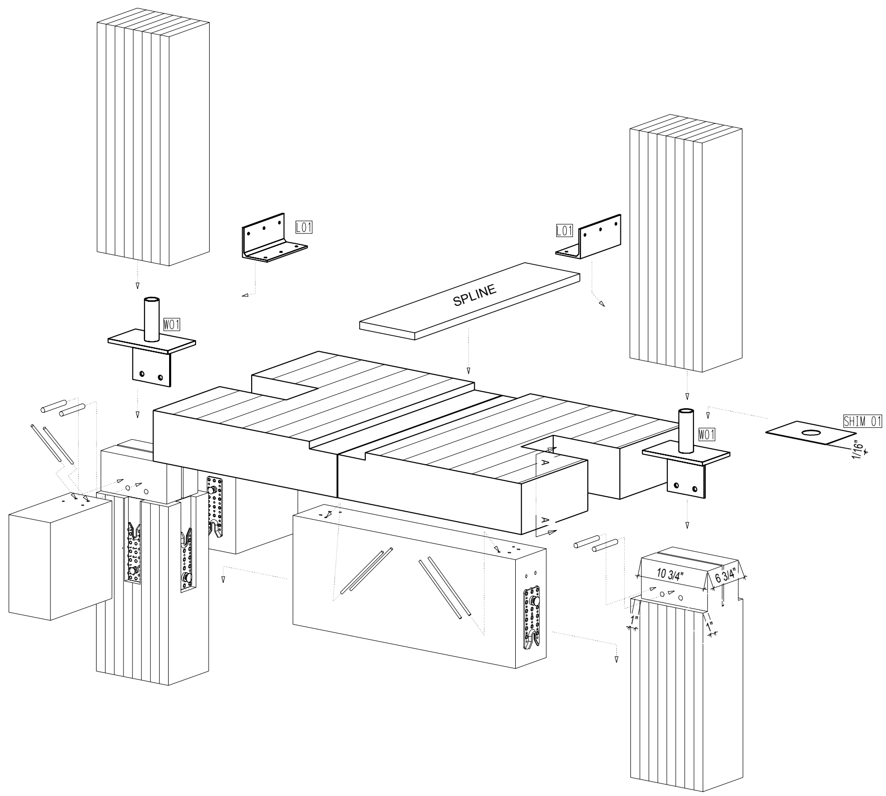


FIGURE 6.7: KIT-OF-PARTS ASSEMBLY DIAGRAM FOR TIMBER COLUMN, BEAM, AND CLT FLOOR ATTACHMENTS

Carbon12, Portland, Oregon
Source: Kaiser+Path

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 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 6.7**), using the model for materials takeoffs and ordering, clash detection (a digital analysis of potential field conflicts) for all building

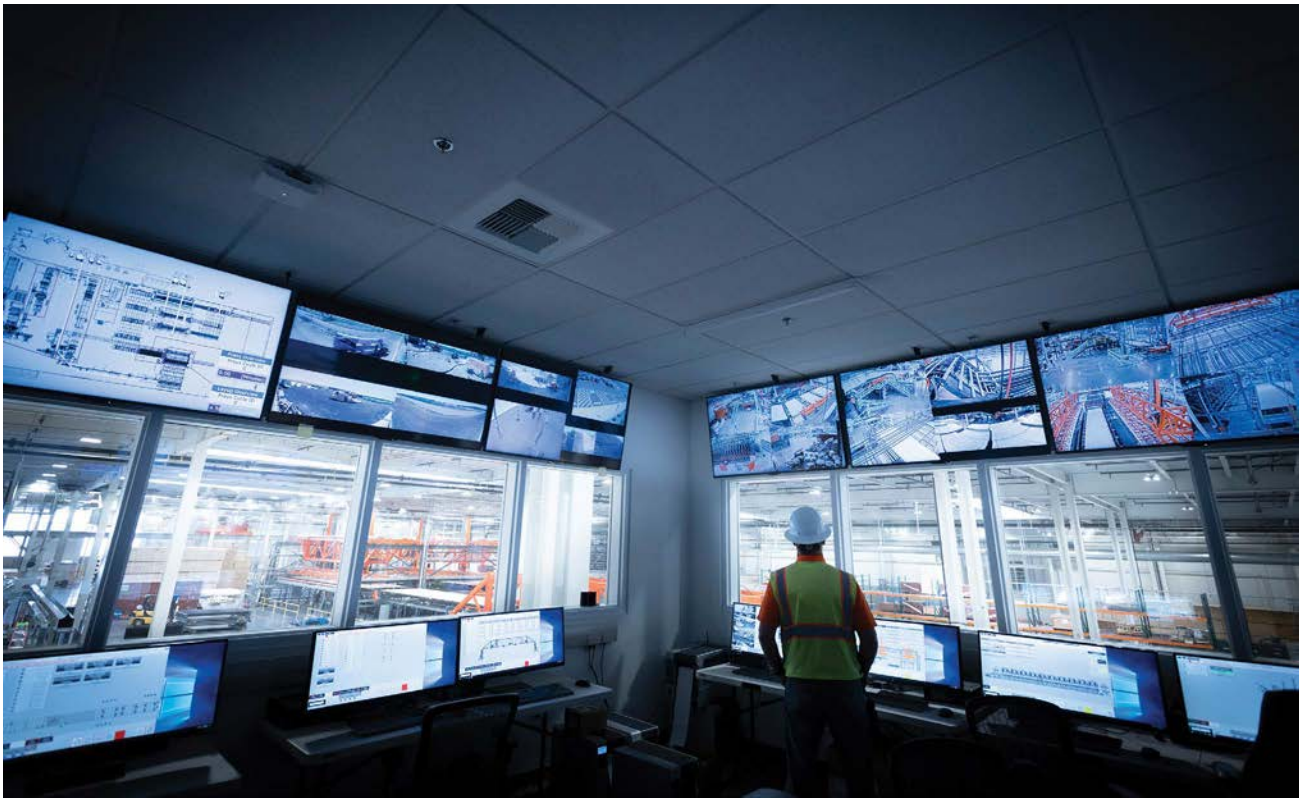


FIGURE 6.8: FACTORY CONTROL TOWER
Source: Mercer Mass Timber

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.[12] 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

12 https://www.modular.org/what-is-modular-construction/

FIGURE 6.9: PRECISION COMPONENTS QUICKLY ASSEMBLED ON A CONSTRAINED SITE

Project One, San Francisco, California, Gurnet Point Construction, DCI Engineers, Freres Lumber Co.

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, such as facades or mechanical systems, into larger components. This is especially beneficial 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 6.9**). Located on a site in San Francisco with no lay-down area, the building's original structural framing schedule was estimated at 3 months. Us-

THE OLYMPIC AQUATICS CENTRE IN PARIS HOUSED THE 2024 GAMES
Source: © Jad Sylla, for schlaich bergermann partner

CASE STUDY: OLYMPIC AQUATICS CENTRE

HANGING BY A FIBER: PARIS 2024 OLYMPIC AQUATICS CENTER

PROJECT OWNER: ÉTROPOLE DU GRAND PARIS

PROJECT LOCATION: 345 AV. DU PRÉSIDENT WILSON, SAINT-DENIS, FRANCE 93200

COMPLETION DATE: APRIL 4, 2024

ARCHITECT/DESIGNER: VENHOEVEN CS & ATELIERS 2/3/4

MASS TIMBER ENGINEER/MANUFACTURER: MATHIS SAS

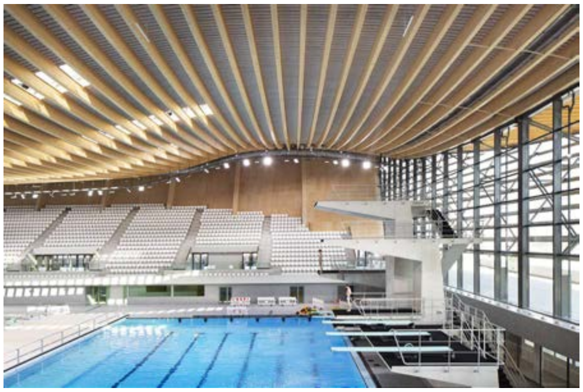
GENERAL CONTRACTOR: BOUYGUES BÂTIMENT ILE-DE-FRANCE

STRUCTURAL ENGINEER: SCHLAICH BERGERMANN PARTNER

MECHANICAL, ELECTRICAL, AND PLUMBING: INEX

THE OLYMPIC AQUATICS Center (OAC) housed the indoor diving and synchronized swimming events at the Paris 2024 Olympics. Its main structural feature is a catenary roof formed of 8-inch by 20-inch cross-section hanging wooden tension elements spaced at 3 feet to 6 feet and reaching a maximum span of approximately 295 feet across the pool.

A key design consideration was the project's sustainability goals. An efficient, lightweight timber tensile form was chosen to minimize the structural material in the roof. The customized concave ge-



THE CLEARANCE HEIGHT ABOVE THE DIVING PLATFORM IS REFLECTED IN THE UNDULATING GEOMETRY OF THE OLYMPIC AQUATICS CENTRE ROOF
Source: © Jad Sylla, for schlaich bergermann partner

ometry of the roof closely matches the required usable area of the indoor swimming pool to reduce the volume of the hall by approximately 30 percent compared to a flat roof, leading to corresponding energy savings for heating a smaller space. The roof structure is fitted with photovoltaic panels that generate 25 percent of the sports facility's total electricity requirements.

Spruce glulam was specified for all primary structural elements in the interior, including columns, truss girders, and catenary elements; Douglas-fir glulam was used for the exterior exposed elements. Fabricated steel plate was used only for the connections between timber elements and the external vertical tension tie-down bars that are exposed to the elements. The completed roof buildup above the timber catenary elements—wooden purlins, felt, metal corrugated deck, and foam glass integrated with a synthetic waterproof covering—creates a stiff panel system.

Suspended roofs are efficient structures under uniformly distributed loading; however, they are sensitive to asymmetric loads and wind suction. With a classic suspended roof made of lightweight steel ribbons, the roof would have required additional stabilizing bracing or ballast to resist these load cases. In the OAC, the deeper timber catenary elements provide additional stiffness, enabling the roof to resist any compression and bending stresses from these asymmetric or inverted loads.

Tensile forces at the ends of the hanging timber roof elements are resolved through stiff horizontal truss girders that sit on each side of the roof edge. These girders—varying in depth from 9 feet to 29 feet and with chords exceeding 15 inches by 59 inches in cross-section—act as the load-collecting backbone for the structure and feature extremely low deformations. The roof support points, each consisting of an inclined column (23 inches by 59 inches) and tension anchor, transfer the forces to the foundations. Two centrally arranged steel-braced bays provide lateral stability perpendicular to the catenary axis. Lateral stiffness parallel to the catenary axis is provided through the force triangle of inclined columns in compression and vertical tie-rods in tension, arranged at a 34-foot grid spacing.

The heights of the inclined columns vary along the longitudinal axis of the building to adapt to the clearance profile of the swimming pool hall. As a result, all 91 roof catenary tension elements have different shapes. Consequently, the timber elements and connection plates were fabricated using 5-axis Computer Numerical Control (CNC) technology, with all custom steel knife plates and large welded connection details installed in the shop before delivery to site.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

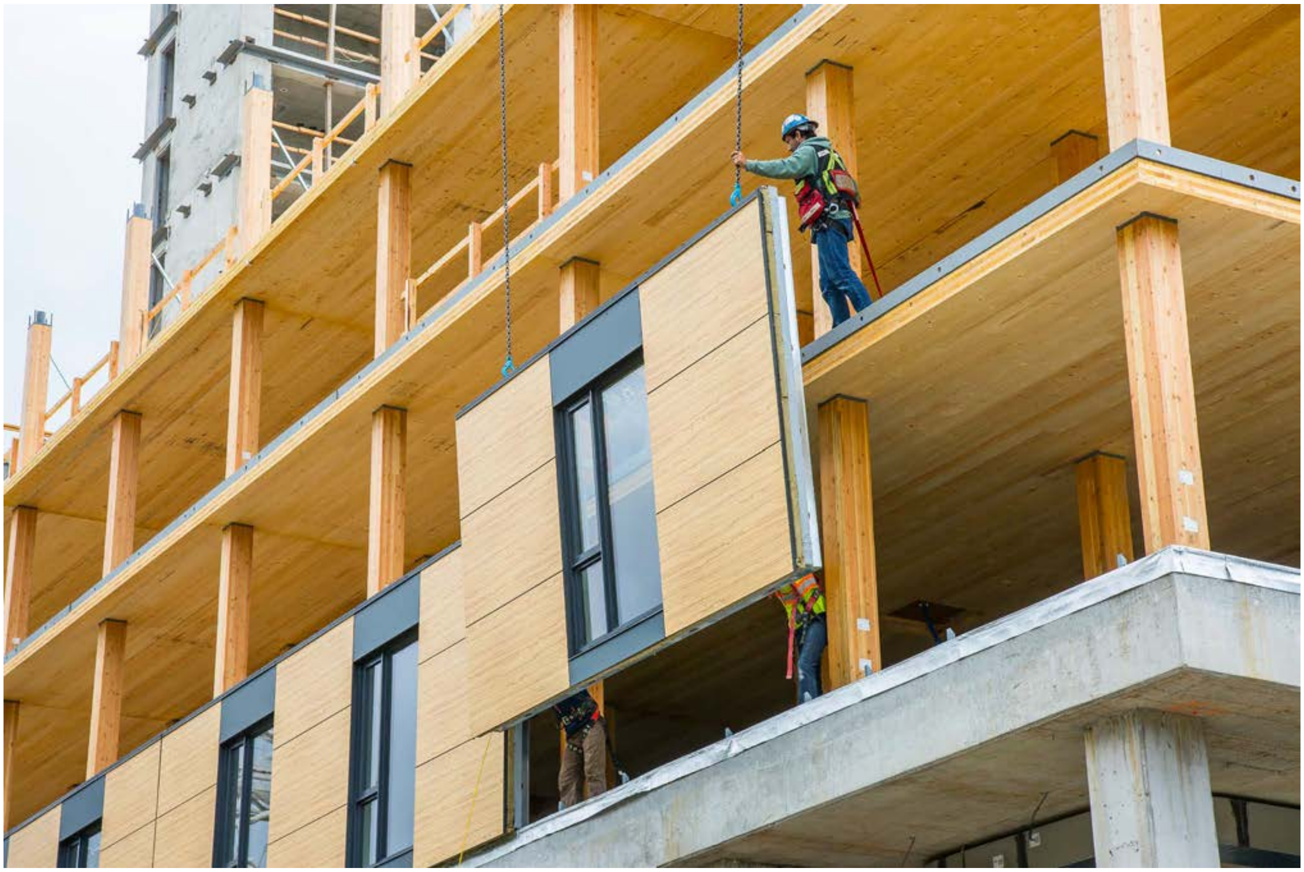


FIGURE 6.10: PREFABRICATED FACADE PANELS FOLLOW CLOSELY BEHIND STRUCTURAL FRAMING

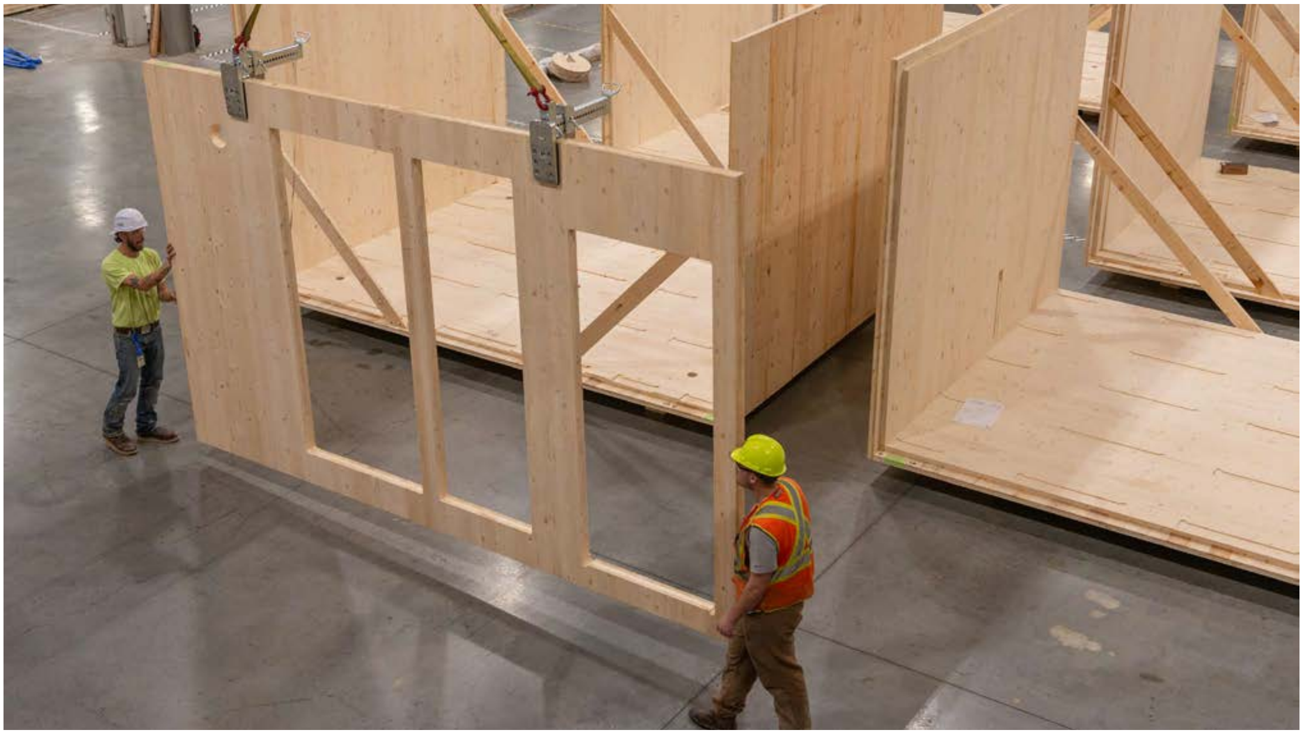
Brock Commons
Source: Naturally:wood; Credit: KK Law

ing precision-fabricated MPP components for the floors and roof, and panelized light-frame walls and moment frames, the structure was completed in just 24 working days.[13] 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 6.10**), providing immediate weather protection and savings in on-site scaffolding, time, labor, and risk. In fall 2017, only

13 Information from Freres Lumber Co. Inc.



66 days after 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.

TOP — FIGURE 6.11: ASSEMBLING PREFABRICATED COMPONENTS IN A FACTORY SETTING

BOTTOM — FIGURE 6.12: A SMALL FRAMING CREW GUIDES PANEL PLACEMENT

Canyons
Source: K+P

Relocation of Labor

When more labor takes place at a manufacturing facility (see **Figure 6.11**), on-site construction crews become smaller (see **Figure 6.12**). 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 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.

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 the University of Utah, "By moving to prefabrication, the construction industry and its workers can experience a much safer environment by a factor of 2."[14]

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, increases safety risks, and compromises quality. Controlled temperatures, air quality, noise, and 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 homes and communities. Some remote jobsites require temporary accommodations, and crews travel home only on weekends. Long and always-changing commutes are challenging for workers and their families, and they must sacrifice family time, sleep, and/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 previously, factory environments make jobs accessible to workers with a wider range of physical strength, 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 of greater job accessibility ripple beyond projects and companies into healthier, more sustainable communities.

14 Ryan E. Smith, *Prefab Architecture*, 2010, 86.

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 laborer is much more skilled than any mass-production laborer in previous generations, moving to more intellectual, computer, or even management tasks."[15] Such a range of job opportunities supports diverse communities—especially beneficial in rural areas 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 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.

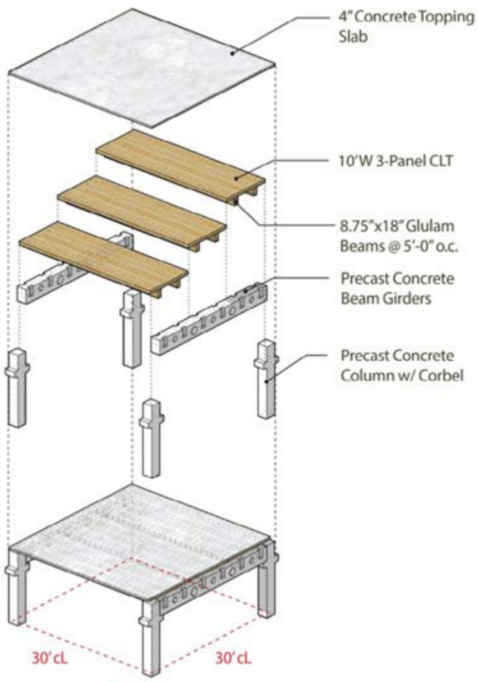
Concrete

Accepted tolerances for cast-in-place concrete can be around ½ inch to 1 inch in multiple planes.[16] 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 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

15 Ryan E. Smith, *Prefab Architecture*, 2010, 87.

16 American Concrete Institute ACI 117-10 outlines accepted tolerances, typically between ½ inch and 1 inch for walls, columns, openings, etc.



ABOVE AND RIGHT — FIGURE 6.13: COMPOSITE TIMBER AND PRECAST CONCRETE STRUCTURE

Adidas North American Headquarters, Portland, Oregon
Source: Lever Architecture and Turner Construction

considering for exposed components with a high level of finish quality (see **Figure 6.13**).

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[17] (see **Figures 6.14** and **6.15**).

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 might have a higher up-front cost, but they might contribute

17 American Institute of Steel Construction.

to schedule savings by reducing field conflicts and retrofits (see **Figure 6.16**).

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.

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 isn't unique 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 might take more time than conventional trucking companies are willing to tolerate without extra charges. An-

TOP — FIGURE 6.14: MASS TIMBER AND STEEL HYBRID BUILDING

Karuna – One North
Source: K+P; Credit: Josh Partee

BOTTOM — FIGURE 6.15: CLT FLOOR DECKS WITH STEEL FRAMING

Brentwood Public Library, Brentwood, California
Source: Holmes Structures
Credit: Blake Marvin Photography

FIGURE 6.16: OFF-THE-SHELF BEAM CONNECTIONS AND CUSTOM COLUMN CONNECTIONS

Carbon12, Portland, Oregon
Source: Kaiser+Path

other one is the ability to care for the integrity of weatherproof packing that might need 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, routes with clearance constraints or challenging terrain, or constrained urban sites (see **Figure 6.17**). The transport team can advise on route strategies and restrictions, and any added costs associated with oversize loads. Shipping loads are also informed by weight distribution, as well as by panel size and shape. Unusually shaped panels are more challenging to balance for transport, potentially increasing the number of trucks required or complicating sequencing. Efficient and safe loading of the materials on the trucks often takes precedence over the installation sequence. 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 6.18**).

Understanding the loading and shipping approach before the materials arrive on-site reduces delivery conflicts. Coordinating a huge volume of mass timber materials has storage, schedule, and liability implications at both the manufacturing facility and the construction site. A 2018 case

FIGURE 6.17: 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 6.18: STAGING AND HANDLING

Source: Nordic Structures

study published by the DLR Group[18] recommends that the construction team dedicate an engineer to manage a project's mass timber fabrication and delivery schedule.

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 us-

18 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 6.19: CRANE LIFTING WITH SLINGS

District Office, Portland, Oregon
Source: Andersen Construction; Credit: Pete Eckert

ing 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.

FIGURE 6.20: PICK POINT LIFTING DEVICE OPTIONS

MTC
Source: MTC Solutions

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 6.19**. Key aspects of this process are the placement, number, and strength of the “pick points,” or lifting devices.

Figure 6.20 illustrates several types of lifting devices, all of which are attached to mass timber elements using screws. The type and number of screws depends on, among other factors, the weight of the panels and method of rigging. The devices pictured are designed for loads from a few hundred pounds up to nearly 5 tons. 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. Some pick points also enhance 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


FIGURE 6.21: TIMBER FRAME AND STEEL CORE PROGRESSING IN COLD, SNOWY WEATHER

Carbon12, Portland, Oregon
Source: Kaiser+Path

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.

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 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

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

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 humidity. Steel, while more forgiving than concrete, has certain temperature requirements for proper welding. Mass timber components, on the other hand, can be installed regardless of weather conditions. This has excellent implications for reducing weather delay contingencies when timelines overlap the 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 6.21**). 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 is imperative; it 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 timber builders.[19] Experienced builders, meanwhile,

19 Graham Finch, RDH Building Science Inc., "Moisture Management for Mass Timber Buildings," 2020.

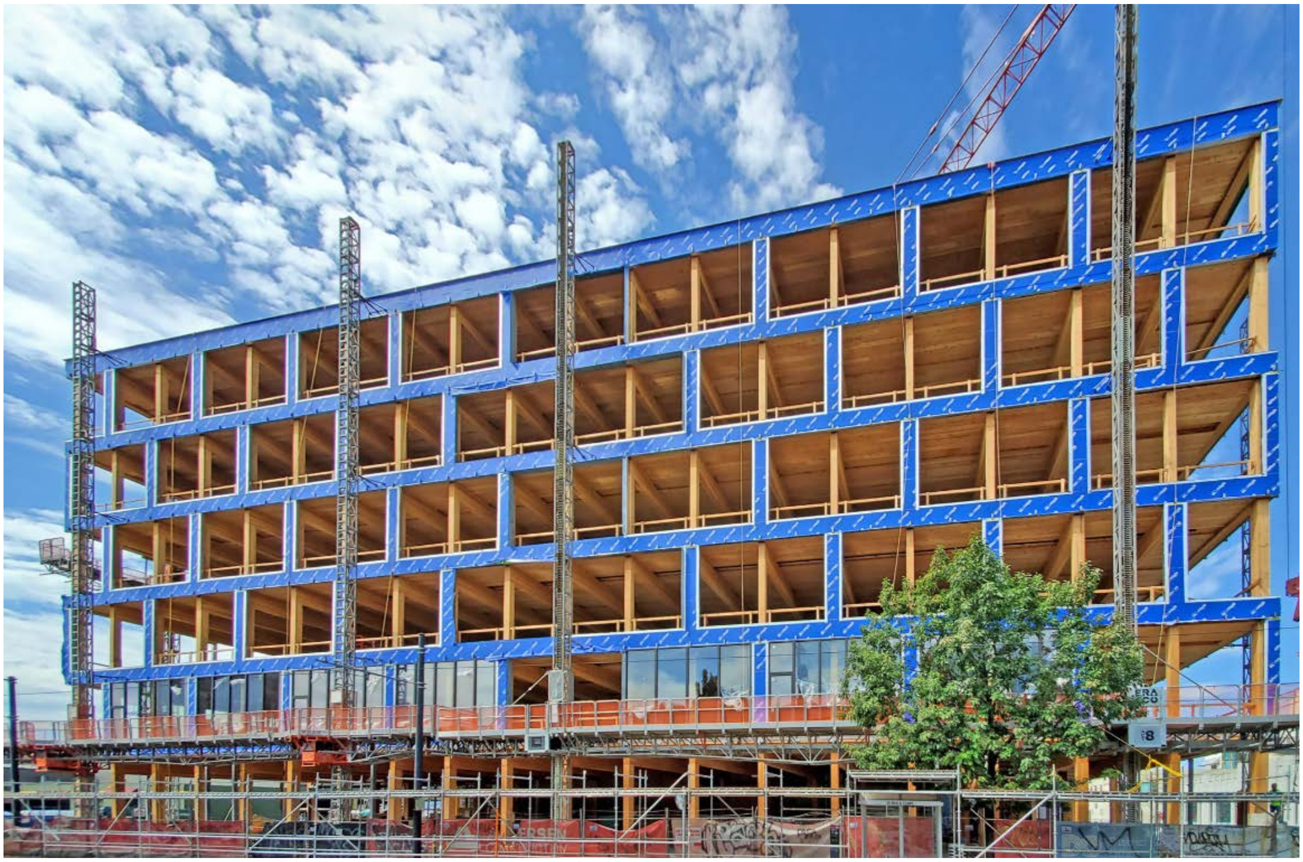


FIGURE 6.22: DISTRICT OFFICE IMPLEMENTED A MOISTURE MANAGEMENT PLAN
District Office, Portland, Oregon
Source: Andersen Construction

are developing best practices. While constructing both the George W. Peavy Forest Science Center and the District Office (see **Figure 6.22**) during Oregon's wet months, Andersen Construction created a 4-part moisture management plan (see **Figure 6.23**) 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 more likely to be left exposed as a finished surface and to need protection from staining from water-borne contaminants. Moisture uptake is quickest where timber components are most vulnerable, at the end-grain. That is also where

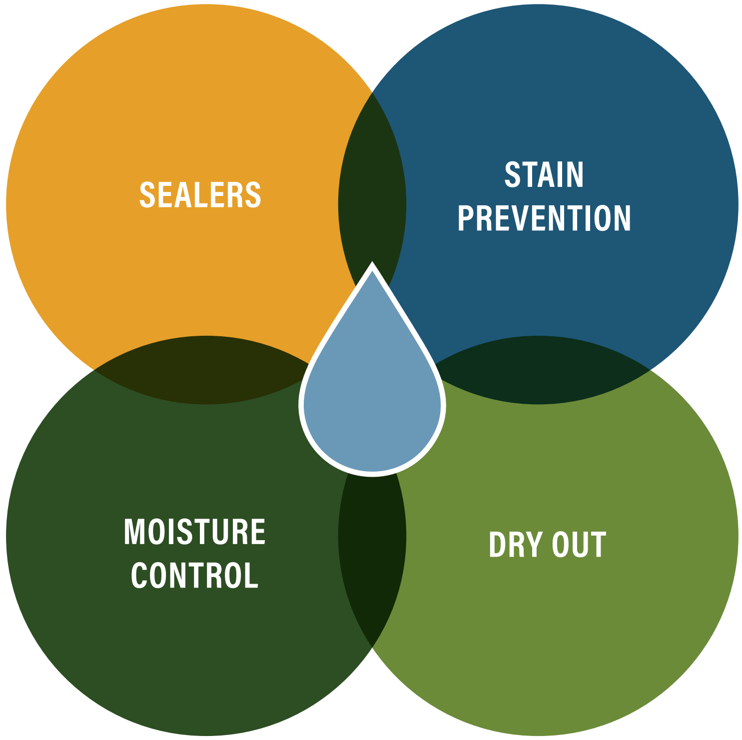


FIGURE 6.23: MOISTURE MANAGEMENT PLAN OUTLINE
Multiple sources

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 an exposed finish 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 environment to which they are exposed. Mass timber manufacturers are responsible for protection during trans-

FIGURE 6.24: CLT PANELS PROTECTED WITH WRAP FOR TRANSPORT AND ON-SITE STORAGE

C12
Source: K+P; Credit: K+P

port, commonly accomplished by durable plastic wrap, as shown in **Figure 6.24**. 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[20] 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 have predicted. The measured MC over time at the 2-inch depth was more responsive to weather

20 Brad Carmichael, Emily Dawson, and Jeff Speert, "Mass Timber Moisture Monitoring and Simulation: A Marine Climate Case Study," 2022, ASHRAE and https://www.youtube.com/watch?v=JtYk6MBzHLs.

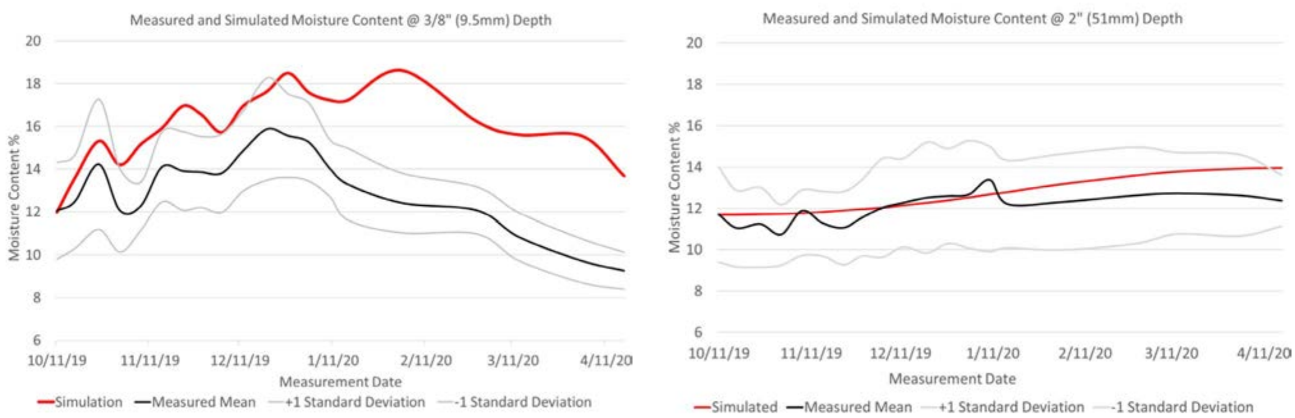


FIGURE 6.25: SURFACE AND INTERNAL CLT PANEL MOISTURE CONTENT DURING CONSTRUCTION

The Canyons, Portland, Oregon

Source: 4EA Building Science; Credit: Brad Carmichael, Emily Dawson, Jeff Speert

changes than the simulation, and it tracked the corresponding peaks and valleys of the ⅜-inch depth more closely (see **Figure 6.25**). The measured results show a time lag of about 2 to 3 weeks for moisture to fluctuate at the 2-inch depth, but it also showed that the highest MCs were at lower overall percentages at that depth. MC readings were consistently lower than 16 percent at the 2-inch depth, 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 for several weeks to months, even during winter in the Pacific Northwest.

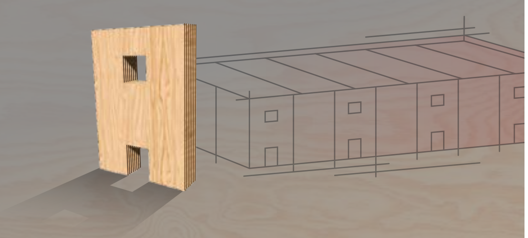
Dry Out

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 with less heat 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. Low heat and adequate air circulation are key to a proper dry out.

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.

Scott Noble contributed to chapter 6, 2025 edition.



POLYGON SENSORS MONITOR WOOD MOISTURE CONTENT ON TRUEBECK'S MASS TIMBER PROJECT

Source: Polygon US Corporation; Credit: Kevin Lockard

CASE STUDY: TIMBERVIEW VIII

MOISTURE MITIGATION FOR MASS TIMBER IN AFFORDABLE HOUSING PROJECT

PROJECT OWNER: C & J PROPERTY DEVELOPMENT LLC

PROJECT LOCATION: 540 NE 99TH AVE., PORTLAND, OR 97220

COMPLETION DATE: OCTOBER 5, 2024

ARCHITECT/DESIGNER: ACCESS ARCHITECTURE

MASS TIMBER ENGINEER/MANUFACTURER: KALESNIKOFF (MASS TIMBER MANUFACTURER), CARPENTRY PLUS (INSTALLER)

GENERAL CONTRACTOR: TRUEBECK CONSTRUCTION

STRUCTURAL ENGINEER: DCI ENGINEERS

MECHANICAL, ELECTRICAL, AND PLUMBING: CALIBER PLUMBING/MECHANICAL (DESIGN-BUILD), SDC (SYSTEMS DESIGN CONSULTANTS)

OTHER CONTRACTORS: POLYGON US CORPORATE (MOISTURE AND CLIMATE MANAGEMENT)

TRUEBECK CONSTRUCTION, A large general contractor on the West Coast, was responsible for building Timberview VIII, an 8-story, mixed-use, multifamily development in Portland, Oregon. The team was determined to ensure that the project was delivered with exceptional quality, so they made moisture mitigation for the construction materials and mass timber products a priority.

CHALLENGE

The design called for its primary structure to be constructed of glulam columns and beams, with Cross-Laminated Timber (CLT) floor/ceiling panels supported by steel brace frames. The team had 2 main concerns. One, the Pacific Northwest's weather

POLYGON CLIMATE CONTROL EQUIPMENT (DESICCANT DEHUMIDIFIER AND INDIRECT FIRED HEATERS) TREAT INTERIOR CONDITIONS OF TIMBERVIEW VIII

Source: Polygon US Corporation; Credit: Kevin Lockard

could slow the drying schedule for materials like paint, drywall, and gypcrete. Two, the climate conditions coupled with incoming moisture-laden materials could affect the mass timber. Overdrying the mass timber could lead to cracking, checking, and delamination, whereas underdrying, or excessive moisture, could extend timelines and lead to staining and mold.

The team considered manually recording moisture content (MC) levels with handheld meters and adjusting climate equipment daily. However, that would have required a dedicated person and been wrought with risk and inefficiency. "It would have been a nightmare to have to do that manually across the entire building," said Jack Doman, project engineer for Truebeck.

SOLUTION

Truebeck consulted Polygon about a climate control system. "It was really important for us to work with a climate control partner who had mass timber experience," said Patrick Valdefiera, project manager at Truebeck. "It was critical to us and the owner to ensure we avoid any issues."

Polygon's engineered solution included sensors and equipment capable of maintaining conditions of 6,575 degrees Fahrenheit and 45 percent to 55 percent relative humidity (RH). Twenty sensors measured and alerted on ambient T/RH with continuous readings of wood moisture content. Data was used to automatically turn on and off a desiccant dehumidifier and indirect fired heaters to optimize drying and heat with the least energy consumed.

The system delivered the conditions, data, and alerts needed to manage moisture for the buildings. "We are tracking conditions every day," Doman said. "I am closely watching humidity fluctuations in the building and planning ahead with activities to make sure things are trending down in an appropriate amount of time. That's the goal: make sure that there isn't a problem, and if the data indicates there could be one in the future, we can minimize it ahead of time—before it impacts the project."

BENEFITS

Efficient approach: Digitizing the moisture reading and piping data to high-performance equipment eliminates manual processes and human error and reduces energy use. It also provides a more comprehensive solution, linking conditions to climate control equipment.

Instant and constant visibility: Continuous monitoring of multiple zones and mass timber points provides a record of changes over time and vital information to manage daily activities and compress the schedule without compromising materials.

Peace of mind: The project team and owner have increased confidence in the quality of the building, knowing that conditions were properly managed and that they have a partner with experience behind them.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.


field edge
Connecting natural resources and regenerative industry-scale projects
Making buildings behave more like plants and industries more like forests
info@fieldedgeconsulting.com
info@singlewidget.com
SINGLE WIDGET

CHAPTER 7: OCCUPANTS

EMILY DAWSON, AIA
OWNER, SINGLE WIDGET | FIELD EDGE

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; improving mental functions, stamina, and focus; improving moods and learning rates; and decreasing 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 connected the use of wood to the support of human health in the built environment.[3] 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 monitored subjects' physiological responses to different ratios of wood surfaces in an environment and found measurable results.[4] 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.

Recovery and Healing

Another emerging area of occupant health is evidence-based design involving analysis of a building's design 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

The COVID-19 pandemic 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 that researchers have been interested in since well before the pandemic, particularly in spaces of commercial food preparation. A 2015 study from Cornell University tested 3 types of pathogenic bacteria on 3 types of surfaces—plastic, varnished beechwood, and untreated beechwood. [7] It found that, at initial "infection" and after 24 hours, bacterial counts were highest on the plastic and lowest on the untreated wood. Likewise, a

3 Michael D. Burnard and Andreja Kutnar, "Wood and Human Stress in the Built Indoor Environment: A Review," *Wood Science and Technology*, 2015, 49, no. 5, pp. 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*, 2007, no. 53, pp. 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*, 2015, 07, no. 04.

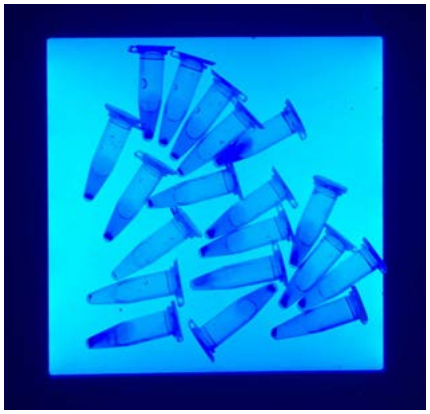


FIGURE 7.2: LAB TESTING VISIBILITY OF MICROORGANISMS LIKE BACTERIA, VIRUSES, AND FUNGI ON WOOD SURFACES

Samples treated with photoreactive PMA dye (Propidium Monoazide) used in PCR (polymerase chain reaction)

Source: University of Oregon, Biology and the Built Environment Center

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 examined "the role of bioactive chemicals in the antiviral action of wood," finding that wood surfaces can be used as "a natural and sustainable barrier against viral transmissions."[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 addressed with findings from experiments that demonstrated that commercial disinfectants in hospitals were as effective at cleaning wood as they were at cleaning plastic.[11]

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 the 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.

8 Muhammad Tanveer Munir, Hélène Pailhoriès, Matthieu Eveillard, et al., "Antimicrobial Characteristics of Untreated Wood: Towards a Hygienic Environment," *Health*, 2019, 11, no. 02, pp. 152–70.

9 Muhammad Tanveer Munir, Hélène Pailhoriès, Florence Aviat, et al., "Hygienic Perspectives of Wood in Healthcare Buildings," *Hygiene*, 2021, 1, no. 1 pp. 12–23.

10 Sailee Shroff, Anni Perämäki, Antti Väisänen, Pertti Pasanen, Krista Grönlund, Ville H. Nissinen, Janne Jänis, Antti Haapala, and Varpu Marjomäki, "Tree Species-Dependent Inactivation of Coronaviruses and Enteroviruses on Solid Wood Surfaces," *ACS Applied Materials & Interfaces*, 2024.

11 Elizabeth DeVere and Diane Purchase, "Effectiveness of Domestic Antibacterial Products in Decontaminating Food Contact Surfaces," *Food Microbiology*, 2007, 24, pp. 425–430.

M.A. Deza, M. Araujo, and M.J. Garrido, "Efficacy of Neutral Electrolyzed Water to Inactivate Escherichia Coli, Listeria Monocytogenes, Pseudomonas Aeruginosa, and Staphylococcus Aureus on Plastic and Wooden Kitchen Cutting Boards," *Journal of Food Protection*, 2007, 70, pp. 102–108.

H. Thormar and H. Hilmarsson, "Killing of Campylobacter on Contaminated Plastic and Wooden Cutting Boards by Glycerol Monocaprate (Monocaprin)," *Letters in Applied Microbiology*, 2010, 51, pp. 319–324.

Hamzah M. Al-Qadiri, et al. "Efficacy of Neutral Electrolyzed Water, Quaternary Ammonium and Lactic Acid-Based Solutions in Controlling Microbial Contamination of Food Cutting Boards Using a Manual Spraying Technique," *Journal of Food Science*, 2016, 81, pp. M1177–83.

A FULL-SCALE MOCK-UP OF THE ALL-WOOD DIAGRID WAS BUILT
Source: StructureCraft; Credit: Graham Handford

CASE STUDY: KU SCHOOL OF ARCHITECTURE AND DESIGN (MAKERS' KUBE)

TRADITIONAL TIMBER JOINERY CREATES LIVING LAB FOR ARCHITECTURE STUDENTS

PROJECT OWNER: UNIVERSITY OF KANSAS

PROJECT LOCATION: 1465 JAYHAWK BOULEVARD, LAWRENCE, KS 66045

COMPLETION DATE: JANUARY 11, 2027

ARCHITECT/DESIGNER: BJARKE INGELS GROUP, BNIM

MASS TIMBER ENGINEER/MANUFACTURER: STRUCTURECRAFT

GENERAL CONTRACTOR: JE DUNN

STRUCTURAL ENGINEER: STRUCTURECRAFT

THE MAKERS' KUBE, designed for the School of Architecture and Design (ARCD) at The University of Kansas, is an iconic 6-story mass timber student space. Along with providing studio space, the KUbe will also serve as a teaching tool, showcasing sustainable practices through its mass timber diagrid design.

Designed in direct response to the needs and wishes of the school's students, faculty, and board starting in 2022, the building consolidates all architecture and design programs into 3 inter-

MAKERS' KUBE IS A COLLABORATIVE SPACE FOR LEARNING AND SHOWCASES SUSTAINABLE PRACTICES

Source: StructureCraft; Credit: Kilograph

THE CONNECTIONS IN THE "MEGA-X" BRACED FRAME ARE DETAILED AS ALL-TIMBER JOINTS, WITH NO STEEL OR ENGINEERED TIMBER SCREWS

Source: StructureCraft; Credit: Kilograph

connected buildings, tying together the existing Marvin Hall from 1908, Chalmers Hall from 1978, and the new 6-story Makers' KUbe. The adjacent Marvin Hall's stone facade and beloved spaces will be historically preserved while Chalmers Hall will be renovated to bring in more daylight.

The campus seeks to embody 4 primary principles: to become an emblem of creativity, to create a connected campus hub to be innovative and future-proof, and to showcase environmental stewardship.

Further sustainable material choices include low-carbon concrete, dry floor build-ups, nonconventional facade materials, and gypsum alternatives throughout the building. These complement the broad sustainability goals and create pause for thought for future users of the space.

"The Makers' KUbe is conceived as a showcase in timber tectonics, traditional joinery, robotic manufacturing, and sustainable materials. The timber bones of the building are exposed by stripping away all applied finishes—elevating structure to expression," Bjarke Ingels said.

The structural engineers posed a question: could the structural frame be 100 percent wood with no steel connection hardware or fasteners? Full-scale connection prototyping and a deep dive into pure timber engineering ensued.

The school and the design team were receptive to the idea, and a full-scale mock-up was created using an exterior glulam diagrid achieved with 100 percent wood connections. It features a bay of the full building, including the architecturally expressive Hero Node and a section of the L2 floor plate.

Notably, the diagrid connections are designed to be all wood; they draw inspiration from traditional Japanese joinery and require a high level of precision in detailing and fabrication. The mock-up was displayed at the 2024 International Mass Timber Conference and was erected in just 8 hours.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

These studies have the potential to significantly increase the adoption of wood in health-care environments. A recent design guide, "Mass Timber Hospital: The Future of Healthcare," was developed by ZGF and Swinerton in partnership with Timberlab Inc., Dengenkolb, Arup, University of Oregon Institute for Health in the Built Environment, PeaceHealth, KPFF, Jensen Hughes, and Pierce McVey to address ways in which mass timber could be adopted for these 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.

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

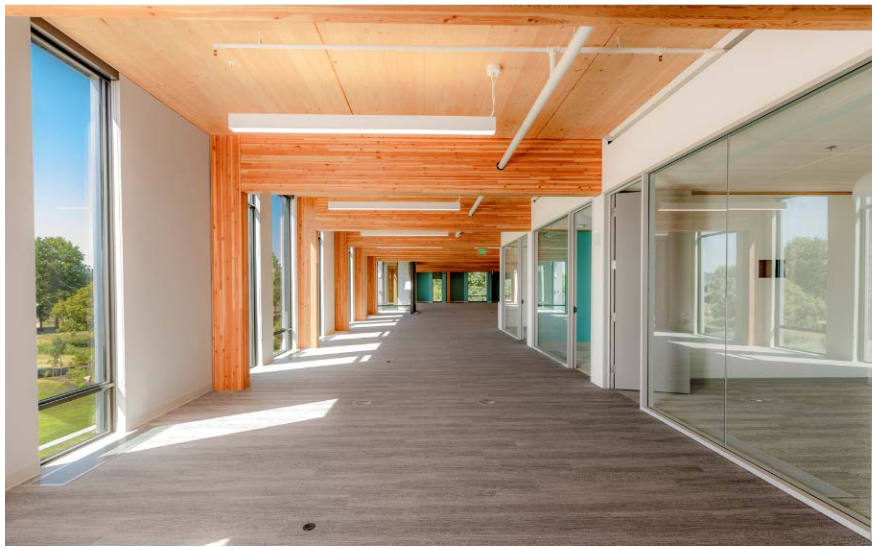
ABOVE — FIGURE 7.3: ASCENT, MILWAUKEE, WI
Source: New Land Enterprises

RIGHT — FIGURE 7.4: PEAVY HALL
Source: Oregon State University
Credit: Josh Partee

spend about 90 percent of their time indoors.[12] 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.

IEQ in relation to occupant comfort is multidimensional, including thermal comfort, indoor air quality (IAQ), acoustics, visual comfort, and safety. In the simplest terms, when people feel

12 Environmental Protection Agency, "Indoor Air Quality Exposure and Characterization Research," 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

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, not everyone can, so achieving this indoors has many benefits to human health.[13] 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 and the distance from exterior walls to the core, so occupants spend most of their time near the perimeter of the building where daylight is most prevalent.

13 Environmental Protection Agency, "Indoor Air Quality (IAQ)," https://www.epa.gov/indoor-air-quality-iaq.

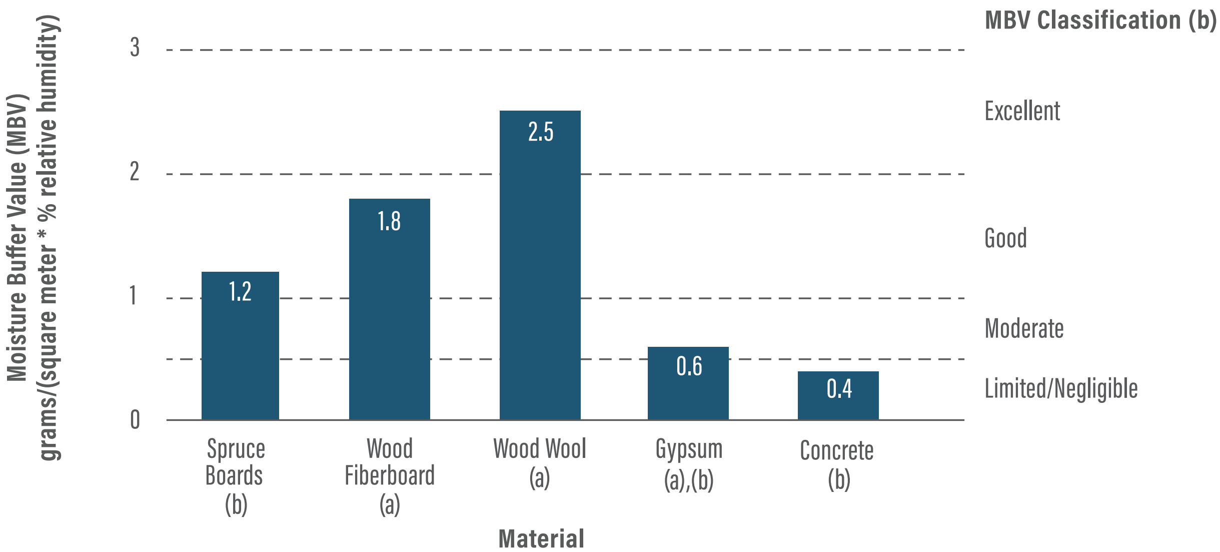


FIGURE 7.7: MOISTURE-BUFFERING VALUES OF COMMON BUILDING MATERIALS

(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).

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 emits terpene-based compounds that contribute to the aromatic properties responsible for the pleasant, relaxing smell that we associate with cut wood.[14] Mass timber panels can use resins that result in virtually no formaldehyde off-gassing; many mass timber products are "Red List Free"[15] and approved for use in certified Living Buildings; and some options, such as Nail-Laminated Timber (NLT) and Dowel-Laminated Timber (DLT), are adhesive-free.

Relative humidity (RH) is the relative measure of water vapor in the air at a given temperature. The optimum range for human health indoors is 40 percent to 60 percent RH, coinciding with the

14 Harumi Ikei, Chorong Song, and Yoshifumi Miyazaki, "Effects of Olfactory Stimulation by -Pinene on Autonomic Nervous Activity," *Journal of Wood Science*, 2016, 62 (6), pp. 568–72. https://doi.org/10.1007/s10086-016-1576-1.

15 Red-list chemicals are "worst in class" according to Living Future, https://living-future.org/red-list/.

least optimal range for microorganisms such as bacteria, viruses, fungi, and mites that may have negative human health impacts. Just as materials with high thermal mass (such as stone or concrete) absorb heat on a sunny day and release it 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). Materials with values over 1 (g/[m²-%RH]) are good, and those 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.

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. Although wood has low density and stiffness that, on its own, readily transmits sound, mass timber can be designed to decouple sound transmission pathways. Adding mass and decoupling to an assembly is an important aspect of acoustic mitigation, and bio-based, low-carbon assemblies designed for deconstruction have demonstrated performance surpassing code requirements in laboratory studies.[16]

Ambient sound experience can be managed with sound-absorbing materials to control reverberation of noise in a space. Architectural finishes, furnishings, and even the occupants themselves can absorb sound. Wood is a porous material, making it less sound-reflective than some other common building materials with smooth, flat surfaces (like stone, concrete, tile, glass, or plastic).[17] That said, smooth, flat surfaces are sound-reflective, and additional elements are necessary to sound-dampen a space.

Thermal Comfort

Wood is not only a natural insulator, but large mass timber panels, when used in exterior building enclosure configurations, can create airtight construction, giving designers increased flexibility when detailing 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 Energy Studies in Buildings Laboratory (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

16 University of Oregon, *Academic Testing of Bio-Based Mass Timber Floor Assemblies*, https://issuu.com/buildhealth/docs/acoustics_testing_for_sustainable_mass_timber_tech?fr=xKAE9_zU1NQ.

17 Soundproof Living, "Sound-Reflecting Materials That Cause Echoes and Reverberations," https://soundproofliving.com/sound-reflecting-materials/.

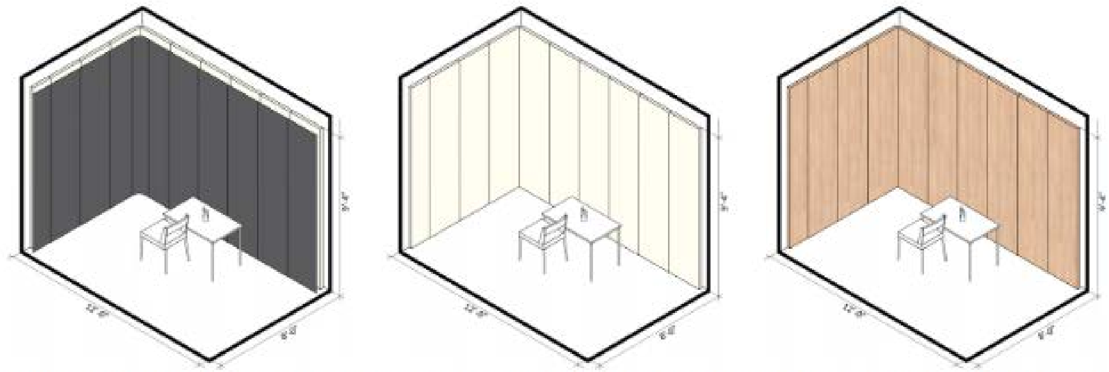
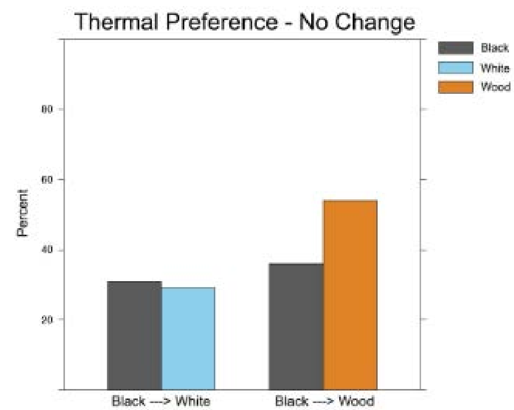


Figure 1. Wall conditions: 1.1 Black curtain (left), 1.2 White painted drywall (center), and 1.3 Wood (right)

FIGURE 7.8: STUDY FINDINGS ON THERMAL COMFORT

Visual effects of wood on thermal perception of interior environments. Denise Blankenberger, Kevin Van Den Wymelenberg, and Jason Stenson, University of Oregon, Eugene, OR, 2019



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

FIGURE 7.9: OREGON CONSERVATION CENTER

Source: LEVER
Credit: Lara Swimmer

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.

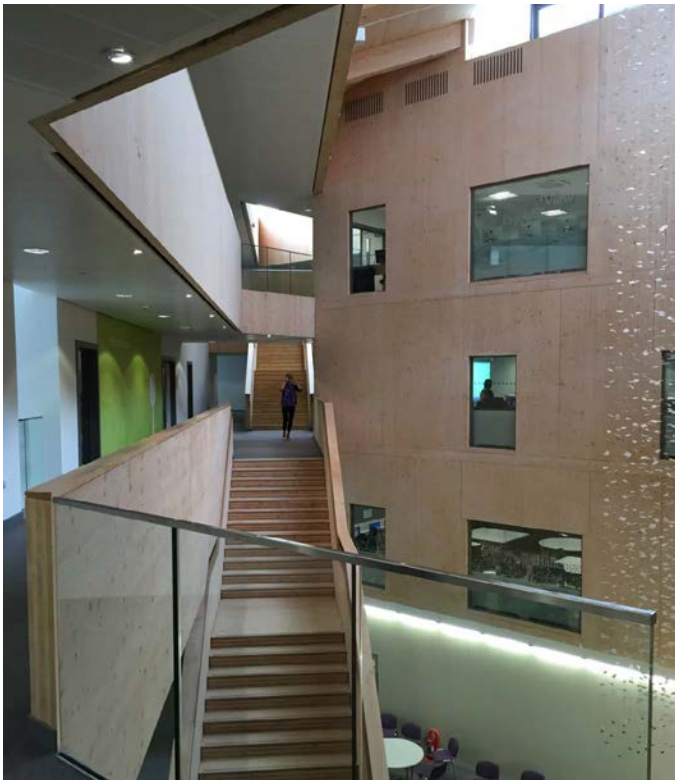
Positive changes in student academic performance and medical patient outcomes are correlated with natural design elements like exposed wood. Benefits are also present in retail and hospitality environments. "Retail customers judge businesses surrounded by nature and natural features to be worthy of prices up to 25 percent higher than businesses with no access to nature." An environment where customers feel both relaxed and stimulated is 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.

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 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 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 because vandalism might 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 that used graphics, words, and quotes to remind students to be peaceful and wise. To the administration's



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

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 found that wood surfaces are less likely to be vandalized than other surfaces.[18]

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.[19]

18 https://www.fastepp.com/news/2022/09/wood-use-in-bc-schools/

19 https://www.terrapinbrightgreen.com/blog/tag/education/

TOP LEFT — THE EXTERIOR OF THE FORTIS BUILDING
TOP RIGHT— THE EXTERIOR OF GNEISS CLIMBING
BOTTOM LEFT — THE EXTERIOR OF RUSTIC REEL

Source: naturally:wood
Credit: Ed White Photograph

CASE STUDY: THE EXCHANGE

THE EXCHANGE MODELS SUSTAINABLE MASS TIMBER CONSTRUCTION

PROJECT OWNER: FACTION PROJECTS INC.

PROJECT LOCATION: 760 VAUGHAN AVE., KELOWNA, BRITISH COLUMBIA, CANADA V1Y 7E4

COMPLETION DATE: MARCH 1, 2024

ARCHITECT/DESIGNER: FACTION PROJECTS INC.

MASS TIMBER ENGINEER/MANUFACTURER: RJC ENGINEERS

STRUCTURAL ENGINEER: RJC ENGINEERS

OTHER CONTRACTORS: GHL CONSULTANTS LTD.

THE EXCHANGE, a mixed-use office and commercial project in downtown Kelowna, British Columbia, exemplifies the innovative use of exposed mass timber in modern construction. Designed to attract tenants with its industrial aesthetic and sustainability, the project bridges historic and contemporary architectural styles, honoring the evolving context of its industrial area.

PROJECT VISION

Located on a strategic 3.5-acre site, The Exchange is part of a broader transformation in Kelowna's north end, which is experiencing an influx of mixed-use developments. This 4-building project includes the first new construction following 2 adaptive reuse initiatives. Its design features an exposed timber structure, open floor plans, and weathered metal cladding, appealing to creative businesses that value a distinctive industrial vibe.

INNOVATIVE DESIGN AND CONSTRUCTION

The new structure is a hybrid of mass timber and concrete, incorporating a Nail-Laminated Timber (NLT) floor and roof system, glulam post-and-beam substructure, and a concrete core for stairs and elevators. The ground floor accommodates retail and light industrial spaces, while the upper floors offer office environments. A rooftop patio enhances tenant amenities, providing a space for collaboration and relaxation.

SELF-FABRICATION OF NLT

The developer, also acting as the architect and construction manager, recognized mass timber's potential to meet sustainability and aesthetic goals. The company chose to self-fabricate NLT panels from locally sourced dimension lumber to reduce costs, gain better material control, and support local businesses. This innovative approach served as a proof of concept for future mass timber projects.

Self-fabrication, however, presented design challenges. The team sought a fluted NLT profile for improved aesthetics and acoustics, requiring special approval as an alternative solution. Comprehensive fire resistance and strength analyses ensured compliance with building codes, using prior fire-testing results to inform design choices.

COST CONSIDERATIONS

Although mass timber is often noted for its cost-effectiveness, the developer emphasized a holistic view of project costs. Beyond material expenses, mass timber's quick assembly translates to shorter construction timelines and reduced labor costs. The exposed timber structure eliminates the need for additional finishes, and its aesthetic appeal facilitates faster leasing.

Reactions from tenants of previous mass timber projects influenced design decisions for The Exchange.

SUSTAINABILITY AND ENERGY EFFICIENCY

Minimizing carbon impact is a key focus for the developer. Mass timber, being renewable and possessing low embodied carbon, aligns with their sustainability goals. The Exchange achieved Step 3 of the BC Energy Step Code, the highest standard for nonresidential buildings in the Okanagan region, thanks to its high-performance envelope, including weathering steel and corrugated metal cladding, energy-efficient windows, and superior insulation.

The light-frame wood walls offer lower thermal conductivity—400 times less than steel and 10 times less than concrete—and increased insulation capacity, enhancing the building's overall energy efficiency.

CONCLUSION

The Exchange stands as a model for future mass timber projects, showcasing the feasibility of self-fabrication and sustainable design in urban environments. It demonstrates how mass timber can create appealing, energy-efficient spaces that meet modern tenants' needs while minimizing environmental impact.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

CHAPTER 8: OWNERS AND DEVELOPERS

EMILY DAWSON, AIA
OWNER, SINGLE WIDGET | FIELD EDGE

Many designers and building owners are drawn to mass timber for its environmental merits. Innovators in the building industry recognize that the carbon impact of any investment will likely 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. Beyond aesthetic appeal, consumer support of sustainable forestry practices and policies appears to be pushing the market toward the maximum carbon storage potential of forest products because sustainably harvested wood fits naturally into a circular carbon economy.

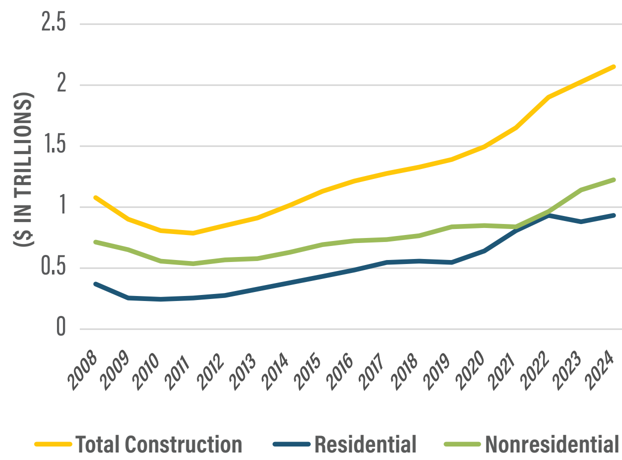


FIGURE 8.1: ANNUAL VALUE OF ALL CONSTRUCTION, 2008–2024

https://www.census.gov/construction/c30/historical_data.html

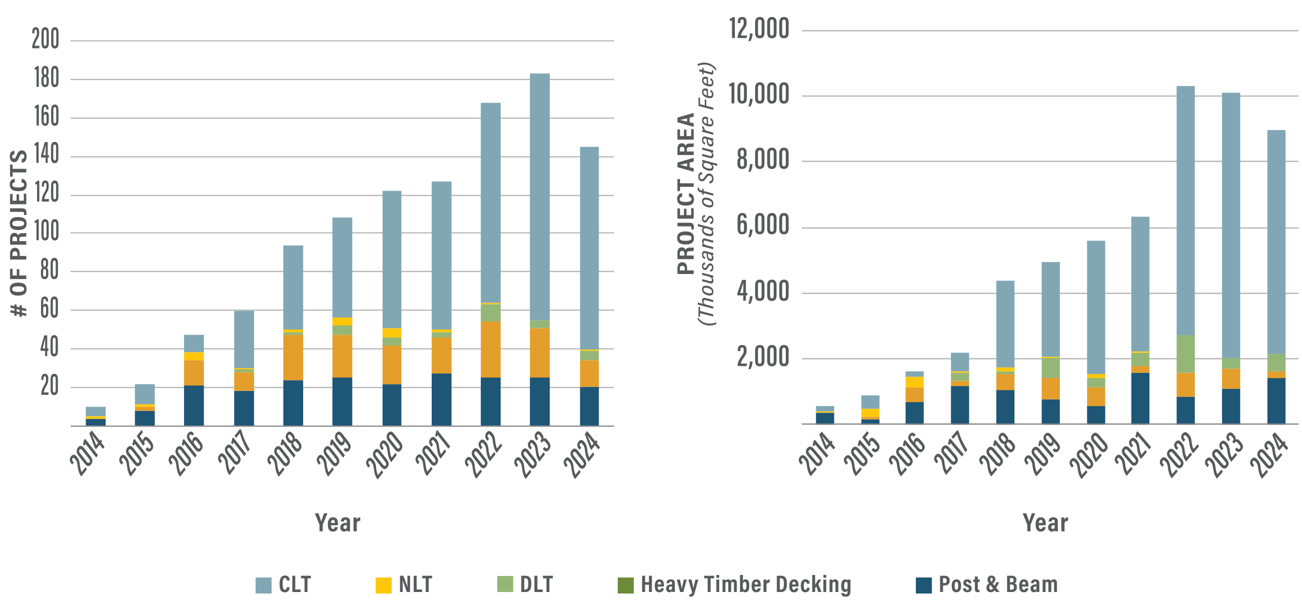
But to meet such ambitious goals, an array of other concurrent advantages must be realized. At this stage in the evolution of mass timber, building owners are true pioneers in adopting a relatively new technology while exploring evolving targets for cost and schedule savings, financing paradigms, and procurement approaches. Although the data that developers typically rely on for pro forma validation is still nascent for mass timber real estate investments, a combination of annual reports, 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 materials like mass timber. According to the *2023 International Report* by global construction consultant firm Rider Levett Bucknall, "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 several years of high global inflation rates, alongside interest rate and energy cost increases, 2023 and 2024 have brought relief. Looking ahead, "global growth is expected to remain stable yet underwhelming," with 5-year projections of 3.1 percent deemed "mediocre compared with the prepandemic average."[2] In the third quarter of 2024, RLB's projections for the US are optimistic, expecting reduced interest rates and declining inflation to contribute to more construction activity.

1 Rider Levett Bucknall, *International Report*, *Construction Market Intelligence*, second quarter, 2023.

2 International Monetary Fund, *World Economic Outlook*, October 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

In 2023, total US construction spending showed the strongest growth compared with other advanced economies, but 2024 yielded more modest growth compared with both Europe and Asia.[3] **Figure 8.1** shows the value of all construction in the United States, $2.15 trillion in September 2024, an increase of about 8.6 percent from 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. It decreased to 43 percent of the market share in 2023 and 2024, indicating a swift rebalancing. Because most residential construction is wood-based, the residential market represents a significant growth opportunity for mass timber. Around one-third of all mass timber projects to date are residential.

8.1.1 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' Wood Products Council, a nonprofit group that provides free project support to the Architecture, Engineering, and Construction (AEC) community on multifamily, institutional, and commercial

3 Deloitte, *2025 Engineering and Construction Industry Outlook*, November 4, 2024.

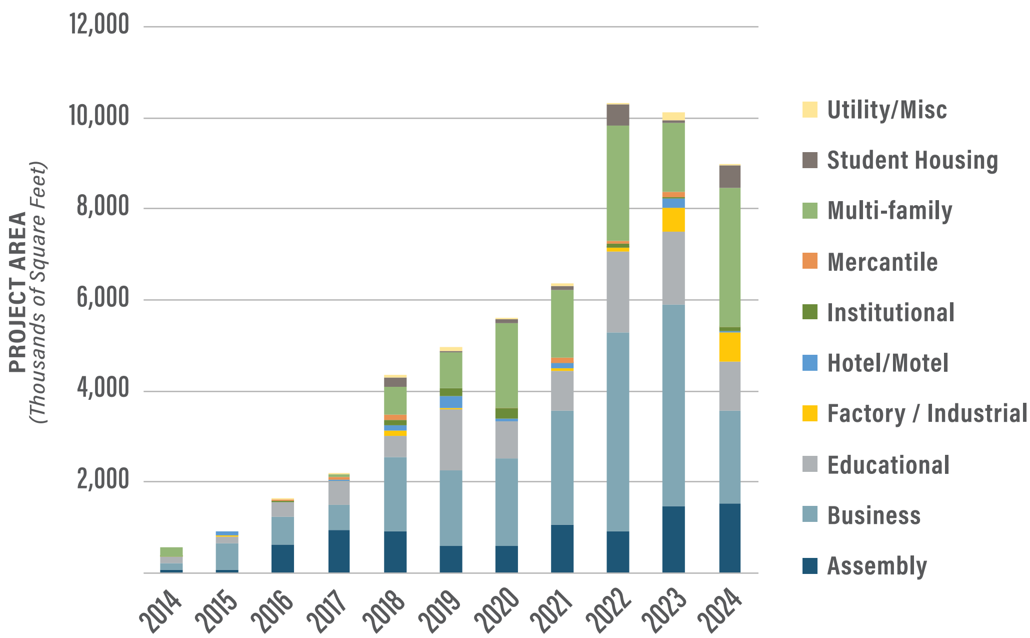


FIGURE 8.4: UNITED STATES MASS TIMBER BUILDING SQUARE FOOTAGE BY OCCUPANCY

Data provided by WoodWorks

buildings. The organization's primary objective is to grow the mass timber market.

For mass timber in the US, 2024 was another year of growth and progress. The number of projects under construction or completed each year continued to grow steadily, increasing by about 10 percent from last year. Despite another year of declines in architectural project billings in the country, and the 18th consecutive month with an Architectural Billings Index score under 50,[4] the number of proposed mass timber projects increased by 8 percent.

Figure 8.2 illustrates the annual number of mass timber construction starts, 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 annual constructed square footage of the buildings in **Figure 8.2**. In 2024, mass timber projects totaled 9 million square feet, an 11 percent decrease from the previous year. The average project size was 62,000 square feet, with CLT accounting for over 76 percent of the total square footage and 72 percent of all projects that broke ground.

Figure 8.4 shows total annual built square footage by building occupancy type. The largest sectors of 2024 were business occupancies, which represented almost 30 percent of square footage, and multifamily buildings at 34 percent.

4 Rider Levett Bucknall, *North America Quarterly Construction Cost Report*, third quarter, 2024.

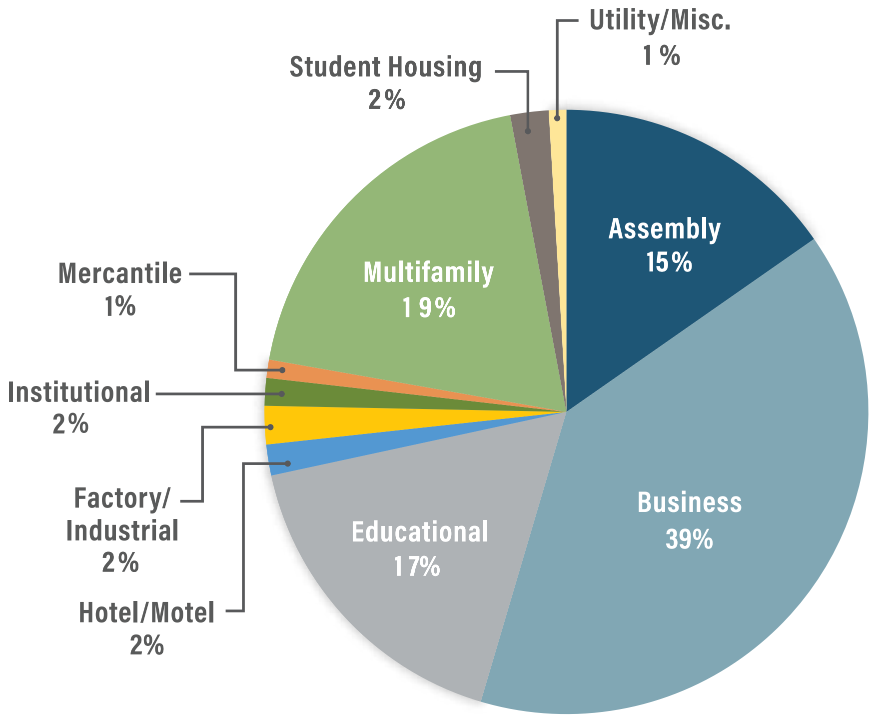


FIGURE 8.5: US TOTAL MASS TIMBER BUILDING SQUARE FOOTAGE BY OCCUPANCY TYPE

Data provided by WoodWorks

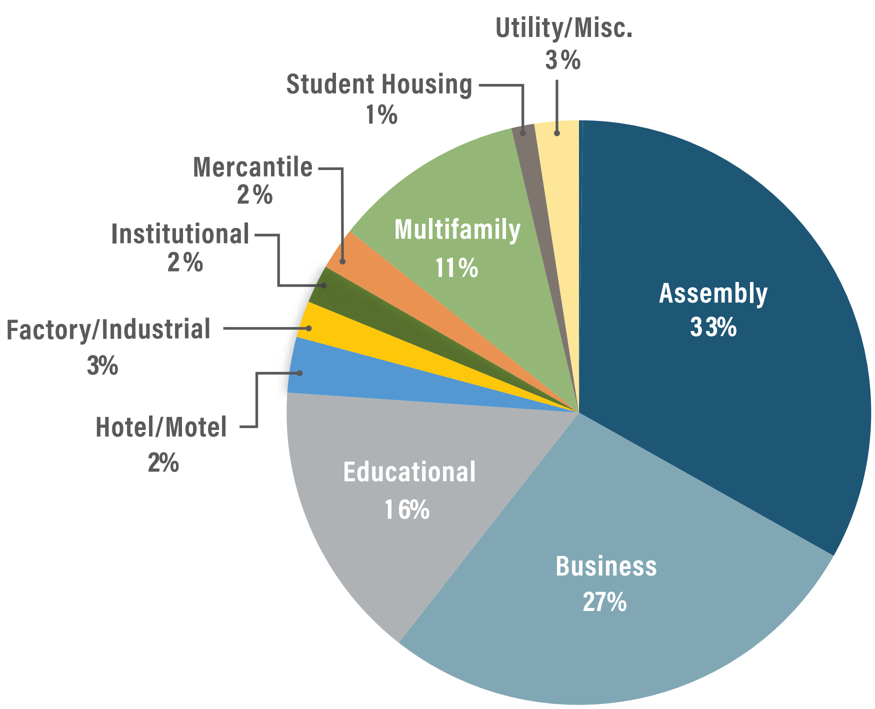


FIGURE 8.6: US TOTAL NUMBER OF MASS TIMBER BUILDINGS BY OCCUPANCY TYPE

Data provided by WoodWorks

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.

Table 8.1 shows the total number of mass timber projects in the US by state. Three states—California, Oregon, and Washington—host over one-third of all constructed projects in the country.

8.2 RATIONALE AND MOTIVATION

In a 2014 survey[5] 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.

At present, 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.

STATE	CONSTRUCTION STARTED / BUILT PROJECTS
AL	13
AR	25
AZ	3
CA	128
CO	36
CT	16
DC	11
DE	2
FL	38
GA	23
HI	3
IA	9
ID	14
IL	18
IN	11
KS	2
KY	9
LA	4
MA	44
MD	8
ME	16
MI	19
MN	14
MO	12
MS	2
MT	20
NC	46
ND	2
NE	7
NH	6
NJ	13
NM	3
NV	1
NY	37
OH	19
OK	4
OR	121
PA	15
RI	8
SC	25
SD	4
TN	17
TX	77
UT	15
VA	18
VT	4
WA	111
WI	29
WV	2
WY	2
GRAND TOTAL	1,086

TABLE 8.1: US MASS TIMBER PROJECTS BY STATE
Data provided by WoodWorks

5 Perkins&Will, *Survey of International Tall Wood Buildings*, 2014.

FIGURE 8.7: LARGE CORPORATE BUILDING OWNERS ARE TURNING TO MASS TIMBER.

Source: Microsoft, Holmes structures
Credit: Blake Marvin Photography

Environmental and carbon sequestration credentials will likely 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 have a place in the carbon markets discussed in chapter 9.

8.3 COST OF CONSTRUCTION

With over 2,200 mass timber projects in the last decade in the US alone,[6] 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[7] 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 efficiencies are also realized. For example, the potential to capture more in lease rates and lower tenant turnover, and the advantage to the building owner's return that results from shortened schedules will not be apparent in a builder's cost estimate, and

6 https://www.woodworks.org/resources/u-s-mass-timber-projects/

7 Emily Dawson, Putting Numbers to "*It Depends*," *International Mass Timber Report*, 2023. The companies that participated reported on commercial projects in the United States in 2023.

VERT WAS CONSTRUCTED AT THE CHELSEA COLLEGE OF ARTS
Source: American Hardwood Export Council; Credit: Petr Krejčí

CASE STUDY: VERT

VERT SHOWCASES RED OAK GLULAM'S ADAPTABILITY

PROJECT OWNER: AMERICAN HARDWOOD EXPORT COUNCIL

PROJECT LOCATION: CHELSEA COLLEGE OF ARTS (TEMPORARY), LONDON (UK), LONDON, SW1P 4JU

COMPLETION DATE: WEDNESDAY, SEPTEMBER 11, 2024

ARCHITECT/DESIGNER: DIEZ OFFICE, OMC°C

MASS TIMBER ENGINEER/MANUFACTURER: NEUE HOLZBAU AG

GENERAL CONTRACTOR: STAGE ONE

STRUCTURAL ENGINEER: BOLLINGER + GROHMANN

OTHER CONTRACTORS: AMERICAN HARDWOOD EXPORT COUNCIL (AHEC, COMMISSIONER), FORWARD STUDIO (ARCHITECTURAL CONSULTANCY), MOLA LEGNO AND THERMORY (TIMBER SUPPLIER)

VERT IS AN experimental structure designed to enhance biodiversity and improve the ecological footprint of cities, while showcasing the potential of red oak glulam. A temporary landmark project for the London Design Festival in 2024, Vert features a series of timber triangles that support suspended biodegradable nets, providing a framework for fast-growing climbing plants.

The triangular design ensures both robustness and modularity, making the structure adaptable to various urban environments. At its base, textile planters nurture a selection of 20 plant species,

VERT'S RED OAK STRUCTURE WAS A KEY FEATURE

Source: American Hardwood Export Council
Credit: Petr Krejčí

enriching local biodiversity while also contributing to temperature regulation in urban spaces.

The choice of red oak, the dominant hardwood species in North American forests, was strategic because of its strength, stability, and underutilization in Europe. This decision aims to expand timber options for construction and to promote the sustainable use of this abundant species, offering an alternative to more commonly used timbers.

A collaboration between the American Hardwood Export Council (AHEC), Diez Office, and OMC°C, the project was developed with expertise from Neue Holzbau, Bollinger + Grohmann, and Forward Studio. Vert pushes the boundaries of red oak glulam, showcasing its structural potential for large-scale applications. The density of red oak allows for smaller cross-sections, minimizing material usage while maintaining high strength.

Performance testing at Bern University has demonstrated that red oak surpasses European oak in tensile strength and structural integrity, making it a superior choice for architectural applications.

Vert also incorporates thermally modified red oak for its decking. This chemical-free modification provides a long-lasting and environmentally friendly solution, reinforcing the project's commitment to sustainability.

Vert's design actively contributes to creating cooler urban environments, with the potential to lower surrounding temperatures by up to 8 degrees Celsius. The plant-covered sails of the structure can generate as much biomass as an 80-year-old tree in a single growing season, casting 4 times more shade than a typical 20-year-old tree. This capacity for biomass production and temperature regulation positions Vert as a vital component in urban ecosystems.

By leveraging red oak—a plentiful yet underutilized species—Vert promotes biodiversity and advocates for a shift toward more sustainable urban planning practices. The project addresses the challenges of rising temperatures and biodiversity loss and serves as a prototype for future urban greening initiatives.

In alignment with the London mayor's climate initiatives, Vert exemplifies an innovative and sustainable solution for cities facing ecological challenges, opening up conversations about what the future could look like. Its approach illustrates the potential for architecture and design to contribute positively to urban environments.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

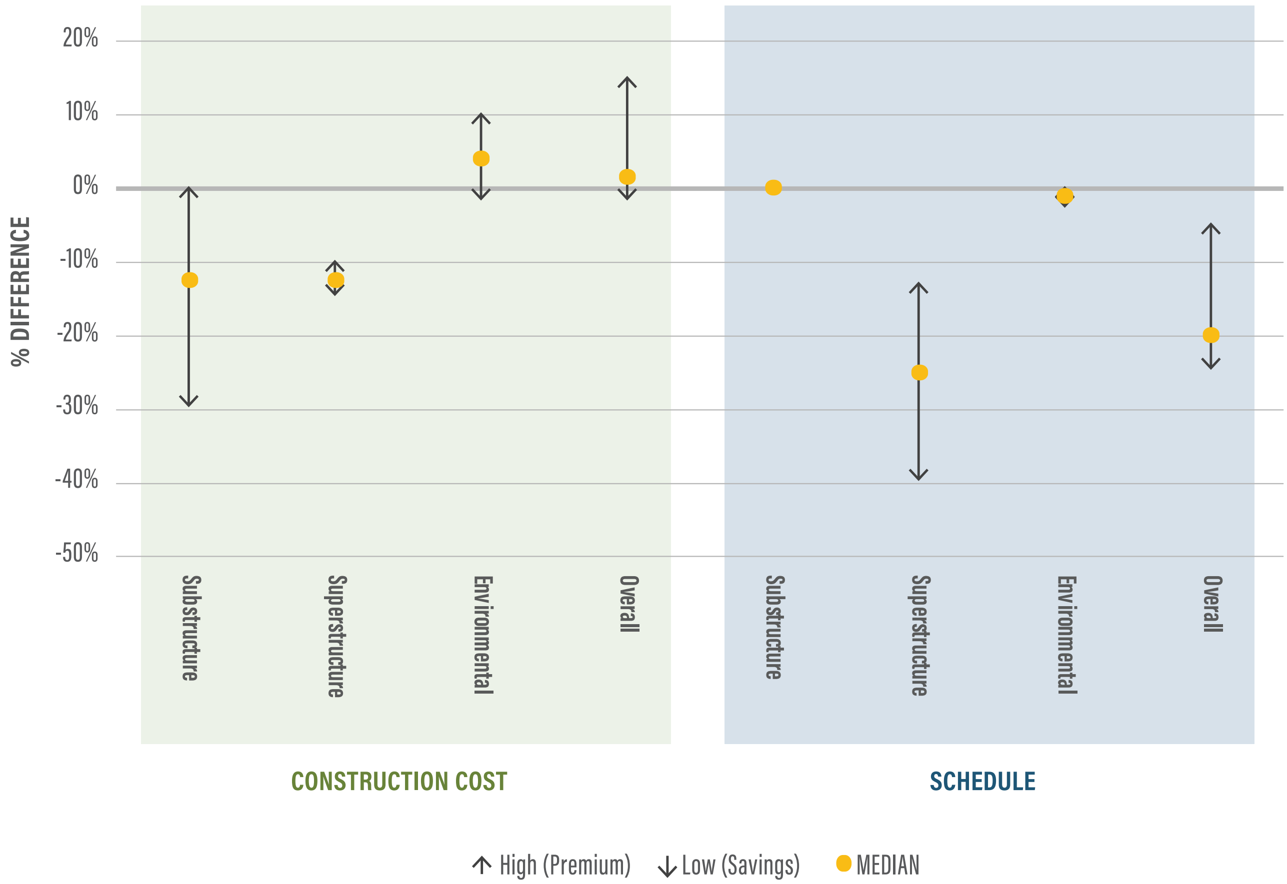


FIGURE 8.8: COST AND SCHEDULE DIFFERENCES BETWEEN MASS TIMBER AND OTHER STRUCTURAL MATERIALS (2023)

Commercial projects in the US

Source: Emily Dawson, Putting Numbers to "It Depends," International Mass Timber Report, 2023.

the building owner can only investigate this impact accurately within their overall pro forma.

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

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

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.[8] The choice of lateral systems matters, too, and it can often drive the overall material and labor premiums. Concrete cores may slow the overall schedule, for example, because mass timber framing might have to pause while the core is constructed. The timing of material procurement, which is often impacted by a fluctuating commodity market, can also be the 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,[9] 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. For example, Hines' T3 Minneapolis has 6 stories of mass timber over a concrete podium. MKA Engineers estimated that the building weighs 60 percent less than an all-concrete structure, and 30 percent less than a

8 https://issuu.com/waughthistleton/docs/think-wood-publication-100-projects-uk-clt

9 https://www.thinkwood.com/blog/4-things-to-know-about-mass-timber

comparable steel structure.[10] 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 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, nonstructural elements such as prefabricated enclosures, building 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.[11] 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 otherwise benefiting the environment in a measurable way.

Rigorous whole-building and structural Life Cycle Analysis (LCA) studies are becoming more common 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[12] 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.[13] Over 99 percent of Platte Fifteen's GWP 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. For existing buildings, upper-level additions such as a penthouse may be possible without altering the foundation.

10 https://www.woodworks.org/resources/how-can-a-developer-owner-get-started-with-mass-timber/

11 https://content.aia.org/sites/default/files/2019-03/Materials_Practice_Guide_Modular_Construction.pdf

12 Carbon Leadership Forum and Center for International Trade in Forest Products, *Life Cycle Assessment of Katerra's Cross Laminated Timber Catalyst Building*, 2020.

13 https://info.thinkwood.com/platte-fifteen-life-cycle-assessment

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 compactly 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 building can be sold. The earlier the building is fully leased, the better the return on the investment.

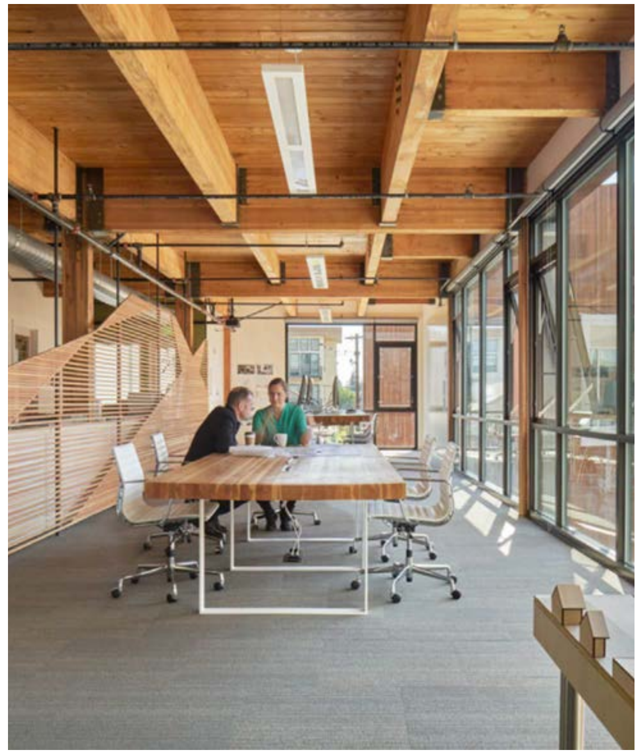


FIGURE 8.10: RADIATOR BUILDING

Source: Andrew Pogue Photography

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 District Office in 2020, and it was 66 percent leased at project completion, more than 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 was leased shortly thereafter. The building has remained completely leased since opening.[14]
- The PAE Living Building, developed by PAE and Edlen & Co., opened in fall 2021 with

14 Interview with a representative of Beam Development.

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
	Manufacturer & Supplier Partner Contacts
	Mass Timber: Shifting Labor from Jobsite to Shop
	Mass Timber Insurance Playbook, UK and US Editions

TABLE 8.2: WOODWORKS RESOURCES FOR BUILDING OWNERS

Source: WoodWorks.org/resources/

88 percent of its office space and 25 percent of its retail space leased.[15]

- 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.[16]
- 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 ground breaking. Even with unprecedentedly high lease rates for the east side of Portland and very little parking, the buildings were fully leased 6 months faster than the pro forma had assumed.[17]

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 would not be cause for the floor-to-ceiling dimensions to be greater (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.

15 Interview with a representative of PAE and Edlen & Co.

16 Interview with a representative of Killian Pacific.

17 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

Construction Risk Reduction

The modularity, precision, and beauty of large engineered timber components have 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 and digital fabrication equipment.

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 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.

FIGURE 8.14: ASCENT IS THE TALLEST TIMBER TOWER IN THE WORLD

Milwaukee, Wisconsin

Source: New Land Enterprises

To date, the tallest completed mass timber buildings are:

- 25 stories, 284 feet (87 meters): Ascent, New Land Enterprises, Milwaukee, Wisconsin (2022), **Figure 8.14**.
- 18 stories, 279 feet (85 meters): Mjøstårnet, AB Invest, Brumunddal, Norway (2019)
- 24 stories, 276 feet (84 meters): HoHo Vienna, Woschitz Group, Vienna, Austria (2019)
- 21 stories, 240 feet (73 meters): HAUT, Lingotto, Amsterdam, Netherlands (2022)
- 20 stories, 239 feet (73 meters): Sara Kulturhus Centre, Skellefeetea, Sweden (2021)
- 22 stories, 231 feet (70 meters): De Karel Doorman, DW Nieuwbouw & WM Projectontwikkeling, Rotterdam, Netherlands (2012)
- 19 stories, 229 feet (70 meters): 55 Southbank, Hume Partners Property, Melbourne, Victoria, Australia (2020)
- 15 stories, 213 feet (65 meters), 36-52 Wellington, Hines, Melbourne, Australia (2023)
- 19 stories, 213 feet (65 meters): Roots Tower, Deutsche Wildtier Stifeetung; Garbe Immobilienprojekte GmbH, Hamburg, Germany (2024)

- 19 stories, 207 feet (63 meters): 1510 Webster, oWOW, Oakland, California (2024)
- 15 stories, 197 feet (60 meters): Abro, Zug Estates Holding AG, Switzerland (2019)
- 18 stories, 190 feet (58 meters): Brock Commons, University of British Columbia, Vancouver, BC (2017)

A growing number of studies and proposals are validating the effectiveness of timber structures up to 35, 40—even 80 stories.[18,19,20,21] In Australia, a 590-foot (180 meters) hybrid timber and steel tower[22] is under construction, and will potentially be followed by a 50-story, 626-foot (191-meter) office building[23] that received permits in late 2023. The latest round of US building code updates, formalized in 2024, increased the 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) has developed resources for project teams pursuing tall mass timber buildings, supported by grant funding from the US Forest Service and Binational Softwood Lumber Council. 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, as well as the technical guidebook, *Tall Timber: Mass Timber for High-Rise Buildings*.

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

18 https://www.woodworkingnetwork.com/news/woodworking-industry-news/worlds-tallest-timber-residential-building-planned

19 https://www.gensler.com/blog/developing-worlds-tallest-net-zero-timber-building-sidewalk

20 https://perkinswill.com/project/canadas-earth-tower/

21 https://perkinswill.com/project/river-beech-tower/

22 https://www.shoparc.com/projects/atlassian-hq/

23 https://grangedevelopment.com/project/c6-south-perth/

procurement.[24] 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 incorporates consultant and key trade input early in the project's development to inform the design. Adequate coordination time before the start of construction reduces costly field labor and project overhead. The advantages to 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.

24 British Columbia Construction Association (BCCA), *Procuring Innovation in Construction: A Review of Models, Processes, and Practices*, 2016.

THE 58,000-SQUARE-FOOT MASS TIMBER WAREHOUSE MIMICS TILT-UP CONCRETE CONSTRUCTION

Source: CD Redding Construction; Credit: Ian Koenig with 365 CREATIVE CO

CASE STUDY: FRERES ENGINEERED WOOD'S PLYWOOD WAREHOUSE

NEW PLYWOOD WAREHOUSE CAN COMPETE WITH STEEL AND CONCRETE

PROJECT OWNER: FRERES ENGINEERED WOOD

PROJECT LOCATION: 47842 E LYONS MILL CITY DR., MILL CITY, OR 97360

COMPLETION DATE: OCTOBER 7, 2024

ARCHITECT/DESIGNER: CROW ENGINEERING

MASS TIMBER ENGINEER/MANUFACTURER: CROW ENGINEERING/ FRERES ENGINEERED WOOD

GENERAL CONTRACTOR: CD REDDING CONSTRUCTION

IN 2024, FRERES Engineered Wood used their patented Mass Ply products to construct a new plywood warehouse, showcasing wood's ability to compete with traditional steel and concrete construction methods for industrial warehouse buildings. The innovative mass timber structure represents yet another sustainable improvement in the larger construction industry.

"As it is now, you only have two opportunities for warehouses: concrete tilt-up construction or

FRERES ENGINEERED WOOD'S PLYWOOD WAREHOUSE, BEFORE CLADDING

Source: CD Redding Construction
Credit: Ian Koenig with 365 CREATIVE CO

THE WAREHOUSE FEATURES A 40-FOOT-BY-48-FOOT GRID

Source: CD Redding Construction
Credit: Ian Koenig with 365 CREATIVE CO

pre-engineered metal buildings," said Kyle Freres, the company's vice president of operations. "There's been a lot of exploration to see if wood can provide a viable alternative to these methods, and the new mass timber warehouse demonstrates that wood can offer a quicker and more effective means of constructing large-format warehouses."

The 58,000-square-foot mass timber warehouse mimics tilt-up concrete construction, but the structural elements are entirely Freres Wood's patented Mass Ply Panels (MPP) and Mass Ply Lams (MPL). The building features a specific 40-foot-by-48-foot grid, with space for 4 truck loading stations, 2 tarping stations, and storage for 6,000 units of plywood.

"Most mass timber projects are built on a much smaller grid and don't have this type of open floor space, so getting this span built in with the structure is unique," Freres said.

In addition to the building's impressive grid span, the construction team was able to save time by installing prefabricated Mass Ply products, thereby cutting costs. In fact, the Freres Wood team estimates the warehouse's mass timber design allowed them to complete the project 3 months faster than they would have with a traditional concrete tilt-up method.

Finally, by replacing concrete and steel construction methods with wood alternatives, Freres Wood avoided approximately 429 metric tons of greenhouse gas emissions, representing a total potential carbon benefit of 1,539 metric tons. These measurements are the equivalent of taking 325 cars off the road for a year or saving the energy necessary to operate 163 homes for a year.

"We are thrilled at the potential for wood to compete directly with concrete and steel industrial building construction in the future," Freres said. "We believe the biophilic nature of all-wood structures has the potential to improve the well-being of those living and working within them. Additionally, we hope these new mass timber designs will support the growing trend toward sustainable, renewable alternatives in the construction industry."

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

- 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."[25]

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 proceeded with the mass timber option. Ensuring premium market 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.

25 Erica Spiritos and Chris Evans, Swinerton Builders, "Mass Timber Construction Management: Economics & Risk Mitigation" (presentation, Mass Timber Conference, 2019).

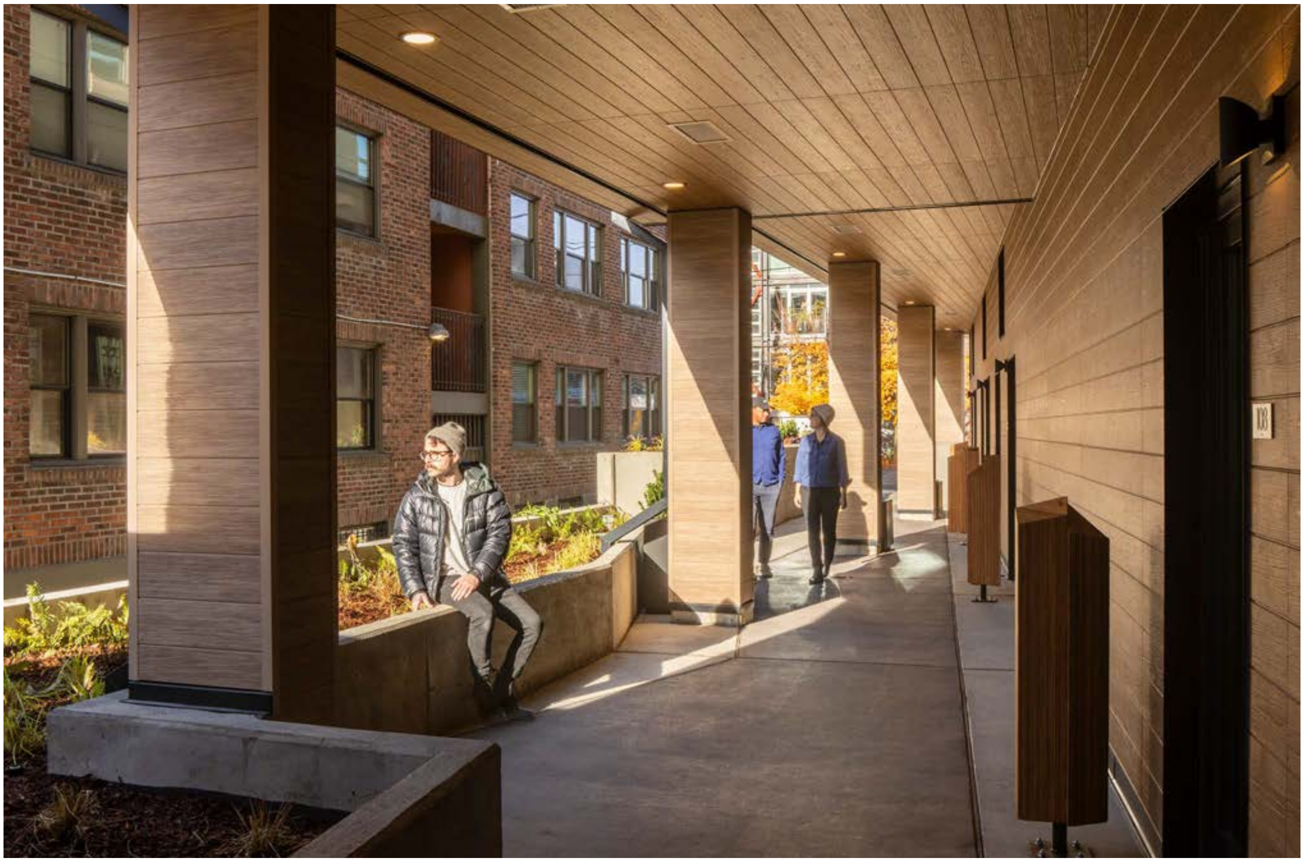


FIGURE 8.15: COMMUNITY ROOTS HOUSING'S HEARTWOOD PROJECT ELECTED FOR A DESIGN-BUILD CONTRACT

Swinerton & atelierjones
Source: atelierjones
Credit: Lara Swimmer

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 streamlined 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. Owners inexperienced with mass timber may have concerns about precluding competitive bids, but the advantages of this approach include design optimization, detailed pricing feedback during design, and early assurances of product delivery dates, all of which positively affect cost and schedule. 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 and 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 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. For insurance underwriters, a lack of data indicates high risk. Without a breadth of experience or data on mass timber buildings, the insurance industry has defaulted to perceive all wood buildings similarly. Mass timber structures are often grouped with light frame structures, despite markedly different performance regarding fire, seismic, and water damage. A 2018 study[26] found that mass timber had yet to be fully recognized by the insurance industry as comparable to a concrete-and-steel structure, and a 2023 Dovetail report[27] lists insurance and project financing as still among the biggest challenges for mass timber's economic competitiveness.

The insurance industry has recently begun to recognize mass timber as a distinct structural building category. Insurance risk classifications are

26 Perkins&Will, *Mass Timber Influencers: Understanding Mass Timber Perceptions among Key Industry Influencers*, October 2018.

27 Dovetail Partners, Kathryn Fernholz, Mark Jacobs, Gloria Erickson, et al., *Mass Timber and Tall Wood Buildings: An Update,* 2023.

defined industry-wide by the Insurance Services Office, a division of Verisk, a global data analytics company. In 2024, Verisk produced a white paper[28] on the need for a new construction classification for mass timber and their intention to add mass timber construction to the 2025 Standard Classification of Property Exposure (SCOPES) revision. This revision will categorize Types IV-A, B, and C as "mass timber construction" and preliminarily defines it as categorized between "non-combustible" and "joisted masonry" construction. Some major insurers have, in the meantime, defined their own categories internally, as a way to meet market demand in the absence of an ISO definition.

Project teams may find support with resources like *The Mass Timber Insurance Playbook*[29] from the UK-based Alliance for Sustainable Building Products, which was recently adapted and published by WoodWorks as *The Mass Timber Insurance Playbook, US Edition*.[30] 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[31] and has increased builders' risk capacity in the mass timber sector. A 2023 article[32] 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.[33] 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 survey[34] by Perkins&Will, the public perceives the following factors to be the greatest barriers to wider adoption of mass timber:

28 Xiaochuan (Lydia) Shi, PhD, CFPS, and Kevin Kuntz, PE, CFPS, MIFireE, UL-CRP - Property, Verisk, *Mass Timber: New Technology Drives a New Construction Class*, 2024.

29 https://asbp.org.uk/project/mass-timber-insurance-playbook

30 https://www.woodworks.org/resources/mass-timber-insurance-playbook/

31 https://www.zurichna.com/knowledge/articles/2021/10/mass-timber-is-taking-root-in-commercial-construction

32 https://riskandinsurance.com/mass-timbers-resilience-makes-it-an-increasingly-popular-choice-but-are-insurers-pricing-its-risks-accurately/

33 Brad Carmichael, Emily Dawson, and Jeff Speert, *Mass Timber Moisture Monitoring and Simulation: A Marine Climate Case Study*, 2022.

34 Shawna Hammon, "Tall Wood Survey," *Perkins&Will Research Journal* 8, no. 1, 2016.

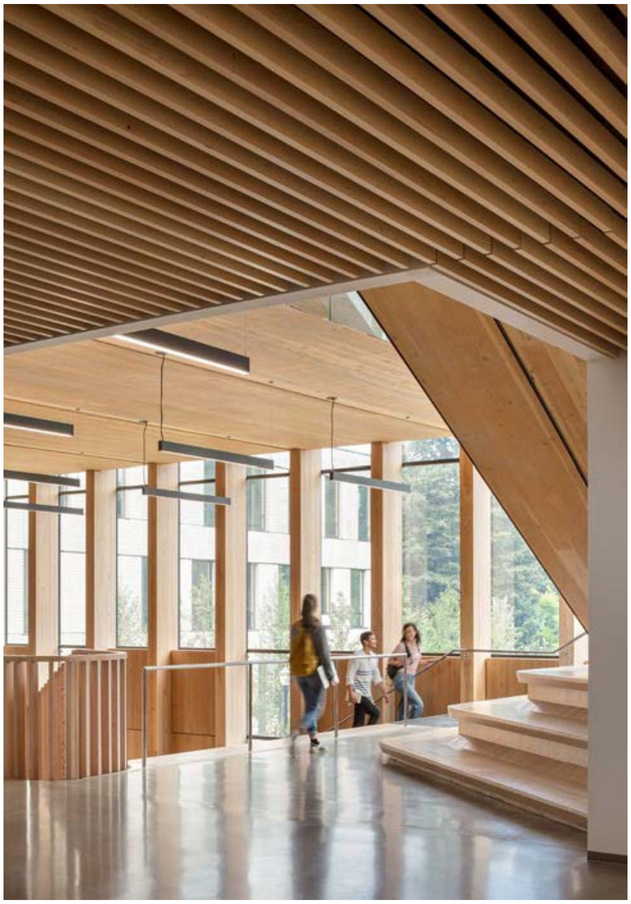


FIGURE 8.16: PEAVY HALL

Source: Oregon State University
Credit: Josh Partee

FIGURE 8.17: TRINITY UNIVERSITY BUSINESS AND HUMANITIES DISTRICT AND DICKE HALL

Source: Lake | Flato
Credit: Robert G. Gomez

- 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.

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, moisture, and pests; 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 building design and architectural detailing—such as overhangs to protect exposed wood elements—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.

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:[35]

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, laboratories, and medical facilities for vibration and impact sound mitigation. These integrated floors may pose challenges to orderly disassembly and may preclude reuse.

Mass timber panels are usually custom-made for specific projects. Markets for blank panels exist for industrial applications, such as construction access mats. 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

35 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.

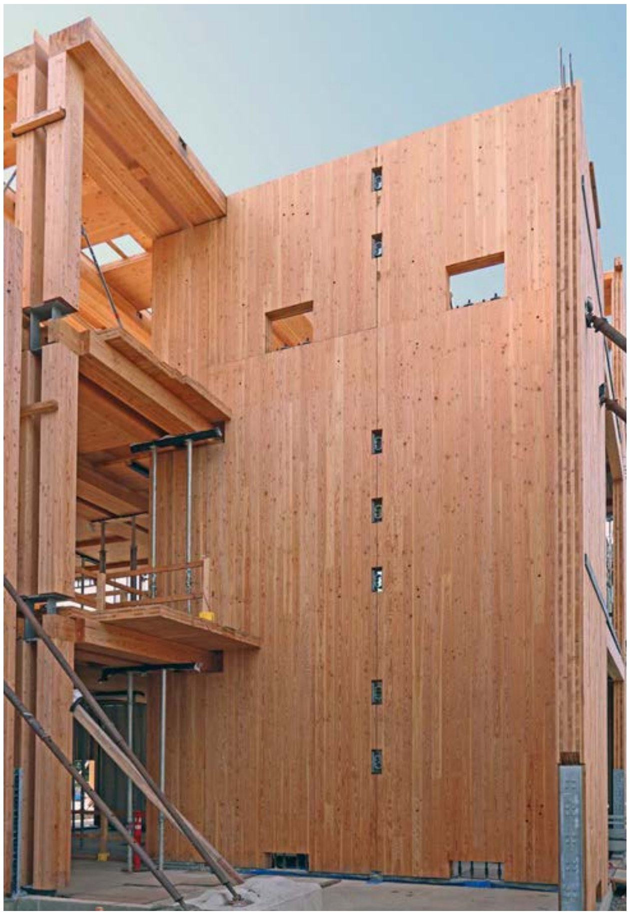


FIGURE 8.18: CLT ROCKING SHEAR WALL

Wall has steel fuses for dissipating seismic forces. Broken fuses are easily replaced.

Source: Project: Oregon State University Peavy Hall Replacement
Credit: Andersen Construction

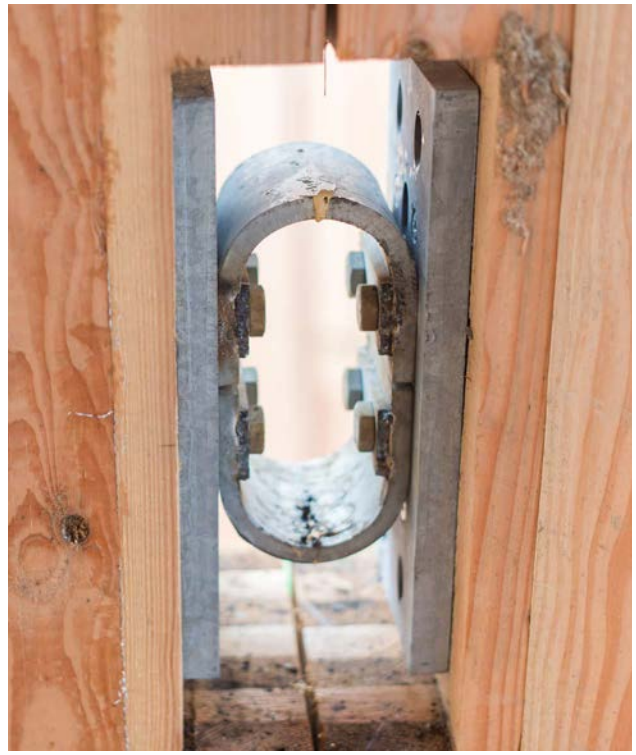


FIGURE 8.19: ROCKING SHEAR WALL FUSE

Source: Project: Oregon State University Peavy Hall Replacement
Credit: Hannah O'Leary

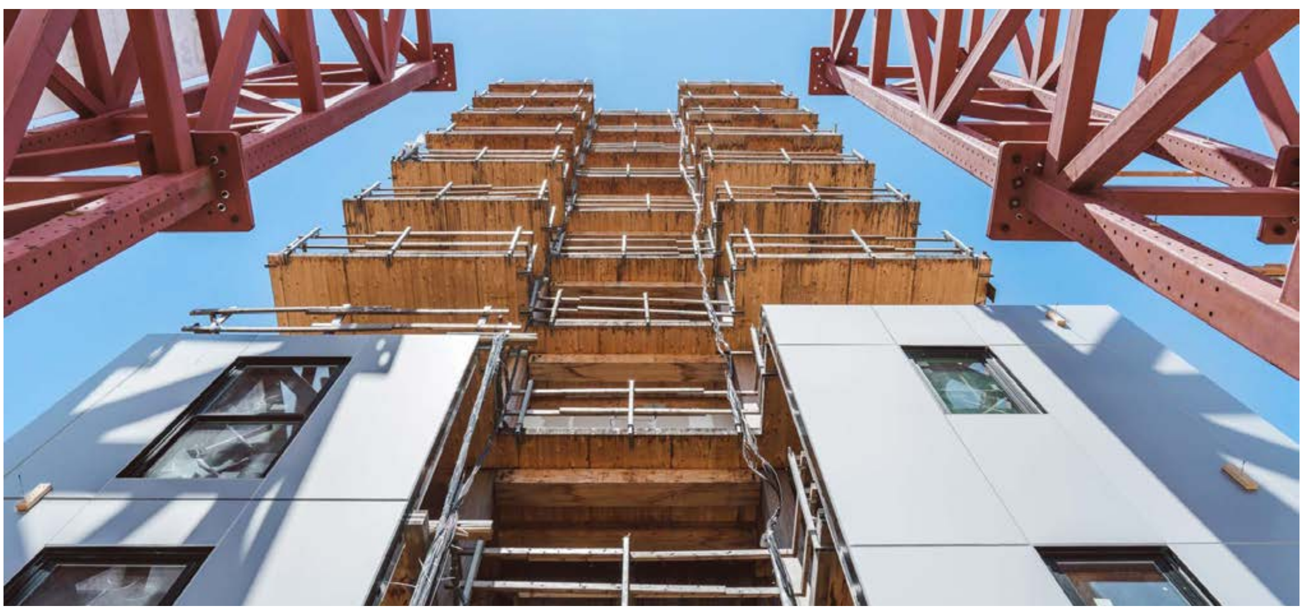
signs of compromise can be more easily replaced. Instead of an entire building being condemned, areas requiring repair can be isolated and retrofitted. In recent years, significant progress has been made in understanding how earthquakes impact mass timber structures and developing strategies to mitigate these effects.

Completed in 2020, The George W. Peavy Forest Science Center at Oregon State University features the first earthquake-resistant "rocking" shear wall design in North America (see **Figure 8.18**). This 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. If the need arises, the fuses can be easily accessed and are low-cost to replace. Seismic damage is confined to these components.

Recent testing at the NHERI shake table (2022–2023) demonstrated the seismic resilience of a

10-story mass timber building, the tallest mass timber structure ever subjected to seismic shaking[36] (see **Figures 8.20** and **8.21**). A total of 88 tests of varying intensity were conducted to assess the rocking wall lateral system, gravity connection details, and earthquake-resilient nonstructural systems. The results were promising, with only moderate, repairable nonstructural impacts, and no structural member or connection damage. This demonstration also provided the opportunity to study mass timber deconstruction, which facilitated further study of the structural members.

Laura Britton contributed to chapter 8, 2025 edition.



TOP — FIGURE 8.20: NHERI SHAKE TABLE

10-story test structure

Source: Journal of Structural Engineering
Credit: Shiling Pei, et al.

BOTTOM — FIGURE 8.21: NHERI SHAKE TABLE

Source: Timberlab

36 https://ascelibrary.org/doi/10.1061/JSENDH.STENG-13752

CASE STUDY: LIVING IN TIVOLIGASSE

A GREEN OASIS IN URBAN SURROUNDINGS

PROJECT OWNER: PALMERS IMMOBILIEN SE

PROJECT LOCATION: 1120 WIEN, TIVOLIGASSE 11 GESCHWISTER-SPITZER-WEG 2, VIENNA, AUSTRIA 1120

COMPLETION DATE: FEBRUARY 2, 2023

ARCHITECT/DESIGNER: FREIMÜLLER-SÖLLINGER ARCHITEKTUR ZT GMBH

MASS TIMBER ENGINEER/MANUFACTURER: THEURL AUSTRIAN PREMIUM TIMBER

GENERAL CONTRACTOR: HOLZ MEISSNITZER GMBH

STRUCTURAL ENGINEER: HOLZ MEISSNITZER GMBH

LOCATED IN VIENNA'S 12th district of Meidling, Tivoligasse is a perfect example of how urbanization and green spaces are not necessarily mutually exclusive. For Palmers Immobilien, the team from the local architecture studio Freimüller-Söllinger designed an ensemble of 4 loosely positioned buildings on a green deck. This led to the construction of 103 apartments, a supermarket, a bicycle garage, a community room, an underground car park, and an open-air deck right in the middle of the city.

In terms of area densification, an attractive living environment based on a balanced mix of function and free space was created for the residents and their neighbors. The solid timber-frame platform, upon which the preexisting supermarket and its parking spaces are located, forms the central element of the quarter, freeing up the potential of formerly monolithic urban structures in an otherwise dormant inner-city landscape.

TIVOLIGASSE, VIENNA, INCORPORATES GREEN SPACES IN AN URBAN AREA

Source: Kurt Hörbst

To integrate the new building organically among the preexisting structures, the architects opted for an airy design. On the upper levels, residential buildings evolve into a green deck with playfully positioned wooden superstructures. The result is an unusual ensemble, specific to the site, that establishes identity while remaining considerate of the existing visual axes of neighboring structures. The buildings were deliberately rotated slightly into one another to preserve visual corridors from west to east.

TOP — THE BUILDINGS WERE DESIGNED TO RETAIN EXISTING VISUAL CORRIDORS

LEFT — CEILINGS WERE MADE OF VISUAL-QUALITY CLT

Source: Kurt Hörbst

The central element is a flexibly designed wooden structure that enables a wide range of options for residential concepts and free use within the axis setting and subsequent adaptation. THEURL supplied 2,000 cubic meters, or 40 truckloads, of CLTPLUS (Cross-Laminated Timber) elements for ceilings (visual quality) and walls (industrial quality) for the 2 5- and 6-story buildings. Access to the construction site was via a one-way street and, because of the lack of parking, all trucks had to be unloaded as quickly as possible.

One challenge was provided by the unusual vertical loading of all the wall elements and the horizontal loading of the ceiling elements. They had to be delivered overnight to the construction site by 5:00 a.m. because of their protruding width of 2.95 meters. From a structural point of view, the statically required interlocking of the load-bearing wall elements at the rear of the building presented an additional tricky task for Team THEURL. But it was accomplished as confidently as the precision manufacturing for the statically loaded steel elements.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

CHAPTER 9: CARBON CONSIDERATIONS AND MASS TIMBER

EMILY DAWSON, AIA
OWNER, SINGLE WIDGET | FIELD EDGE

ROY ANDERSON, THE BECK GROUP

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 gas (GHG) emissions, as identified in the Paris Agreement of 2015, adds impetus to our transition to nonfossil energy sources. Construction techniques and codes have improved dramatically over the past two decades, contributing to a decline in operational fossil energy use in new buildings. Fossil fuel use can be further reduced by sourcing renewable energy over the lifetime of the building. Using renewable structural materials such as mass timber addresses the embodied fossil carbon and energy footprint of buildings as they are constructed—a valuable savings that's in place before the building is even in use.

The built environment is inextricably connected to natural resources, no matter the choice of materials. The cross-pollination between mass timber project teams and forest resource managers has created an exciting dialogue that could change the way buildings are specified and support the array of forestry professionals—foresters, biologists, hydrologists, silviculturists, fire scientists, carbon scientists, loggers, and many more—who work together to create regenerative, resilient landscapes.

For decades, the Intergovernmental Panel on Climate Change (IPCC) has stated that sustainable forests and wood products are some of the greatest solutions to the climate crisis. Members of the building sector and their clients are also asking crucial questions about the other values and 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 how these values are compatible with producing wood products and creating cities that are carbon sinks rather than sources.

This chapter provides overviews of: (1) the role of forests as carbon *sinks*, 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* benefits 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 carbon sinks, storage, and substitution (also known as "the 3 Ss'[1]").

9.1 SINKS (OR SEQUESTRATION): CARBON IN THE FOREST

The Nature Conservancy (TNC) led a global analysis of the potential for natural carbon storage in 2017;[2] it published a similar one focused on the US in 2018.[3] 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 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 sequestration 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

1 The 3S framework was developed by Climate Smart Forestry Economy Program (CSFEP). Visit https://www.csfep.org/3s-framework for more information.

2 Bronson W. Griscom, et al., "Natural Climate Solutions," *Proceedings of the National Academy of Sciences,* 114, no. 144, 2017. Accessed December 18, 2022, at https://www.pnas.org/doi/10.1073/pnas.1710465114.

3 Joseph E. Fargione, et al., "Natural Climate Solutions for the United States," *Science Advances,* 4, no. 11, 2018. Accessed December 18, 2022, at https://www.science.org/doi/pdf/10.1126/sciadv.aat1869.

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)

Source: US Forest Service Forest and Information Database trees release carbon dioxide back into the atmosphere (see **Figure 9.1**). In the continental US alone, forests store more than 14 billion metric tons of carbon (see **Table 9.1**).

A tree's full life cycle can take hundreds 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, and other factors that shape the evolution of a forest.) Some species—such as quaking aspen, loblolly pine, and lodgepole pine—are relatively short-lived (only 80 years to 140 years). Others—such as ponderosa pine, Douglas-fir, tulip-poplar, Western larch, longleaf pine, cedars, and oaks—can live centuries. These are the potential life spans; however, just as most humans do not live to their full potential life span of 120 years, most trees do not achieve their full potential life spans.

Natural forests can be 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.

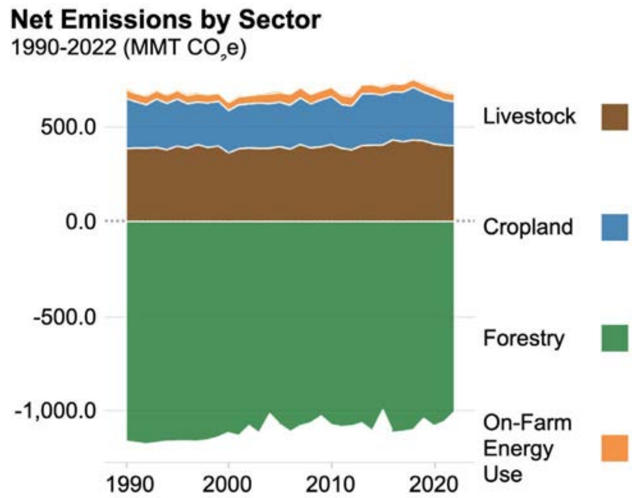


FIGURE 9.1: USDA NET EMISSIONS BY SECTOR

1990-2022 (MMT CO2e)

Source: https://www.usda.gov/AgForestryGHGInventory

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 the tree declines in vigor and parts begin to decay or die. The tree 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

USNR is a comprehensive supplier of equipment and technology for large-scale CLT production, including finger-jointing, material handling, grade sorting, lay-up, and panel pressing.

These systems are expertly integrated to achieve an efficient and automated CLT panel assembly operation. Ask about our controlled migration program that takes you from manual lay-up to a fully-automated system. It's a cost-effective entry point to the global CLT market.

Our patented CLT press has a modular design that allows for infinite expansion along the length. It can grow with your operation, enabling you to meet the needs of the market. *Contact us today to learn more about this techonology*.

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Upgraded Proof Loader Design

New digital design auto-adjusts pressure

USNR's legacy Proof Loader has been upgraded to automatically adjust the pressure when testing the modulus of elasticity (MOE) of boards and end joints in tension laminations.

Gone are the hand cranks and dial indicators of the past. This new digital system shares a PLC with the RF tunnel for a greatly simplified operation.

USNR's Proof Loader tests the proof stress of finger-jointed boards and marks the boards that are deficient. Board attributes are selected through the HMI and set on the machine. Proof loading may be performed on fully cured or partially cured end joints. *Contact us to learn more about our solutions for mass timber production.*

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FIGURE 9.2: FOREST PRODUCTS' CARBON STORAGE

species. A small portion of the carbon will remain in the soil, if undisturbed. Across the landscape, individual stands exist in all these phases.

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,[4] helping to 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 carbon and produce more wood from the same number of acres.

4 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).

THE MARS ARCTIC RESEARCH AND CONSERVATION CENTRE IN CHURCHILL, MANITOBA
Source: James Brittain

CASE STUDY: THE MARS ARCTIC RESEARCH AND CONSERVATION CENTRE

MASS TIMBER AND PREFABRICATION IN NORTHERN CLIMATES

PROJECT OWNER: POLAR BEARS INTERNATIONAL

PROJECT LOCATION: CHURCHILL, MANITOBA, CANADA

COMPLETION DATE: OCTOBER 31, 2020

ARCHITECT/DESIGNER: BLOUIN ORZES ARCHITECTES

MASS TIMBER ENGINEER/MANUFACTURER: HOLZ CONSTRUCTORS

GENERAL CONTRACTOR: HOLZ CONSTRUCTORS

STRUCTURAL ENGINEER: CROSSIER KILGOUR

THIS PROJECT, AFFECTIONATELY known as BASECAMP, is an example of hybrid prefabrication using mass timber, specifically Nail-Laminated Timber (NLT). Fabricated in Winnipeg, Manitoba, by Holz Constructors, it was installed in 2019 in Churchill, Manitoba, the polar bear capital of the world. Churchill is a remote town on the edge of Hudson's Bay, accessible only by ship, plane, or a 16-hour train ride.

With such a remote and challenging site, Holz considered shipping logistics, shifting tundra site conditions, a very short building season, extreme cold, and the notorious high winds off Hudson's Bay that blow sand-like snow particles into any opening as opportunities to overcome.

The client was Polar Bears International (PBI), based in Bozeman, Montana. The client was new to Holz, as was the lead architect, Blouin Orzes Architectes, from Montreal.

THE INTERIOR OF THE CENTRE WITH EXPOSED NAIL-LAMINATED TIMBER (NLT) CEILING

Source: James Brittain

THE INTERIOR OF THE CENTRE WITH EXPOSED NAIL-LAMINATED TIMBER (NLT) CEILING

Source: Holz Constructors

Eleven months after PBI's first email to Holz requesting a proposal, the finished project was delivered.

The fast pace from concept to delivery required collaboration and a high level of trust among owner, architect, and Holz. Holz assisted design architect Blouin Orzes in developing the stunning concept into a final design that prefabbed well. Bathrooms, kitchen, and mechanical rooms were built as PODS . The floors were constructed with NLT panels. The walls and roof were built as panels with exterior and interior finishes factory installed.

Holz requested Baltic birch throughout the interior. This, along with the NLT floors, sped up the schedule, prevented future maintenance issues (no cracked drywall), lowered the client costs, and led to a building that feels warm and invites the community in. The design, strategic use of materials, and prefab approach mean the house is more than just housing for the international team of researchers who study polar bears and how climate change affects them.

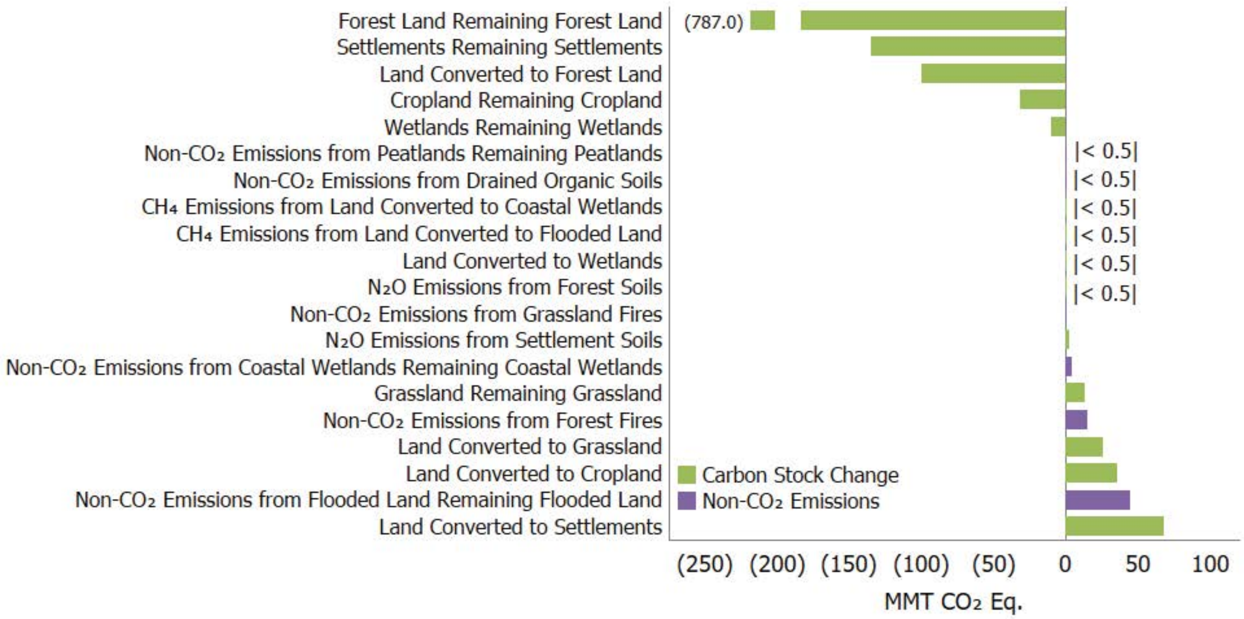
NLT panels painted "Beluga White," in recognition of Hudson's Bay's summer visitors, were used for the level-2 floor and were crucial to the project's success. NLT and Holz's style of hybrid prefab, using panels, PODS, and mass timber were new to the architect. Through careful planning and collaboration, the NLT panels provided a beautiful finish to a space and a unique architectural feature in the small town.

By using NLT panels for the floor and installing a secondary plenum floor above, all the mechanical and electrical were run within the floor, eliminating the need for bulkheads. This also allowed the structure to become weatherproof in less than 2 weeks.

The mechanical and electrical trades got the benefit of a warm and dry building, and they completed their remaining work in less than a week, just having to make final connections. After that, finished floors and the remaining interior finishes were installed. The mechanical trades spent less than a week on-site and didn't need to go back.

This project reaffirmed Holz's practice to use less. It's better for all, including Churchill's polar bears.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.



Note: Parentheses in horizontal axis indicate net sequestration.

FIGURE 9.3: LAND USE, LAND-USE CHANGE, AND FORESTRY (LULUCF) GHG SOURCES AND SINKS

2022 Data
Source: EPA GHG Inventory (2024)

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 9.2**). In addition, at a landscape level, the net impact on the atmosphere is determined by sequestration from changes in carbon across all stands, existing and harvested. US forests currently sequester more than they release[5] due to mortality or harvesting (see **Figure 9.3**).

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[6] (TFD), hosted by the Yale

5 US Environmental Protection Agency, Chapter 6: “Land-use Change and Forestry,” *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2022*. Accessed December 31, 2024, at https://www.epa.gov/system/files/documents/2024-02/us-ghg-inventory-2024-chapter-6-land-use-land-use-change-and-forestry.pdf.

6 The Forests Dialogue, “Climate Positive Forest Products (CPFP),” https://theforestsdialogue.org/initiative/climate-positive-forest-products-cpfp.

School of the Environment. One of its 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 GHG emissions.

Before they met in 2021 and 2022, participants were provided with background papers synthesizing the most recent published research.[7] These papers refer to recently published studies from Europe, North America, and around the world that address wood supply and the carbon benefits of wood versus concrete and steel through the Life Cycle Analyses (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

When forests are not valued as forests, they tend to get turned into something else. Thus, the idea—counterintuitive at first, but economically logical—that the use of forest products contributes 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 rigorous and scientifically informed regulations and net-positive forest growth. The demand for and the value placed on wood products create economic incentives to maintain or expand forests, supporting continuous improvements in management practices.

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 if a new forest is established. Where forest management practices are not regulated for multiple sustainability factors, forest degradation can occur, causing biodiversity loss or a reduction in the ecological resilience of an ecosystem.

A forest sequesters and stores more carbon than any other land use. Keeping US forests intact by reducing unnecessary forest conversion to other land uses and promoting appropriate reforestation can have significant carbon benefits. In 2021, 98.3 million metric tons of carbon were sequestered from lands converted to forests. However, 56.5 million tons were emitted from forestland converted to cropland, and 81.1 million tons were emitted from forestland converted to either urban or rural developments that include housing, according to the Environmental Protection Agency's (EPA) Annual Greenhouse Gas Inventory Report of 2023.

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 prac-

7 Edie S. Hall and Barbara K. Reck, "Current State of Mass Timber and Wood Product Value Chains in Europe" The Forests Dialogue, https://theforestsdialogue.org/sites/default/files/tfd_cpfp_finland_backgroundpaper_2022.pdf.

tice 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.

Forestry Practices

An increased demand for forest products appears to also drive more sustainable forestry practices and outcomes, such as stable or increasing forest stocks and mitigation of severe wildfire risks. 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."[8]

Climate-Smart Forestry

In recent years, the term "Climate-Smart Forestry" (CSF) has emerged. North Carolina State University's website says that CSF enables "forests

8 https://carbonleadershipforum.org/mass-timber-optimization-and-lca/

and society to transform, adapt to, and mitigate climate-induced changes."[9]

How is this done? Modern forestry practices manage for long-term resilience. These approaches protect the carbon stored in the forest and support its ability to store more. They vary by forest type, ecological setting, and disturbance regime. Some talk about "carbon defense" management practices. That might mean favoring better-adapted species and/or reducing forest density, so the remaining trees are better adapted to the increased intensity of natural stressors and disturbances like droughts, wildfires, and insects. It is important to remember that carbon storage is only one metric of many in considering what makes a forest resilient, but it is an important calculation to understand regionally, nationally, and globally.

Some groups advocate for what they call "proforestation" to mitigate climate change. They say mature and old-growth forests should be left alone so they can store more carbon. Deferring harvest might 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 (rather than sinks) because of insect epidemics, wildfires, or a combination of the two. The Society of American Foresters recently released a white paper[10] critiquing the proforestation concept for these omissions.

9.2 STORAGE: CARBON IN WOOD PRODUCTS

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 that the building industry must reach net-zero emissions by 2040 to curb catastrophic climate change.[11] So getting it right is crucial. The engineered properties of mass timber products help meet that goal and open 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 selecting and measuring the carbon impacts of mass timber in building projects. We also discuss how choosing to use mass timber and other wood products, especially at scale as the market sector

9 North Carolina State University Extension Publications, "What Is Climate Smart Forestry? A Brief Overview," https://content.ces.ncsu.edu/what-is-climate-smart-forestry-a-brief-overview.

10 Society of American Foresters, "The Society of American Foresters Develops Resource on Proforestation," https://www.eforester.org/Main/SAF_News/2022/SAF-Develops-Resource-on-Proforestation.aspx.

11 *Architecture Magazine*, The Carbon Issue, January 2020, guest edited by Architecture 2030.

THE EXTERIOR OF HOLGATE LIBRARY BEAMS WITH THE WARMTH OF THE STRUCTURE WITHIN

Source: Bora Architecture & Interiors; Credit: Lara Swimmer

CASE STUDY: HOLGATE LIBRARY

MASS TIMBER PLAYS ROLE IN VIBRANT COMMUNITY SPACE

PROJECT OWNER: MULTNOMAH COUNTY LIBRARY

PROJECT LOCATION: 7905 SE HOLGATE BOULEVARD, PORTLAND, OR 97206

COMPLETION DATE: JULY 13, 2024

ARCHITECT/DESIGNER: BORA ARCHITECTURE & INTERIORS

MASS TIMBER ENGINEER/MANUFACTURER: TIMBERLAB (VDC, FABRICATION OF GL, AND INSTALLATION), KALESNIKOFF (MANUFACTURING OF CLT AND GL, FABRICATION OF CLT)

GENERAL CONTRACTOR: SWINERTON BUILDERS

STRUCTURAL ENGINEER: EQUILIBRIUM ENGINEERS, LLC

MECHANICAL, ELECTRICAL, AND PLUMBING: ARRIS CONSULTING, LLC

THE NEW 2-STORY Holgate Library for Multnomah County Library in Southeast Portland is one of the largest libraries in the county, tripling the size of the original 1971 building to accommodate one of the city's most diverse communities. Boasting a mass timber structure, the library is designed to foster a culture of civic pride, offering healthy and inspiring spaces amply connected to nature that will provide patrons of all ages and backgrounds with an uplifting and welcoming library experience.

Sitting prominently along Southeast Holgate Boulevard, the building is designed as a distinctive inward-folding form along the north and south, framing outdoor spaces and welcoming commu-

INTERIOR SPACES BECOME A STRONG CELEBRATION OF PLACE BY FEATURING PACIFIC NORTHWEST DOUGLAS-FIR

Source: Bora Architecture & Interiors
Credit: Lara Swimmer

THE MAIN READING ROOM ON THE SECOND STORY SERVES A DIVERSE COMMUNITY

Source: Bora Architecture & Interiors
Credit: Lara Swimmer

nities in. Mass timber canopies extend to receive patrons from the parking lot on the north side and Holgate on the south, providing cover from weather at both entry points.

Taking inspiration from the fluttering wings of the butterfly—a universal symbol of resilience, hope, beauty, and transformation—the building is wrapped in custom chevron-patterned metal cladding, creating a calming yet dynamic rhythmic play of light and shadow. Larger areas of glass offer visibility into the children's library and flexible meeting spaces on the ground floor, activating and connecting spaces inside and out.

Using a Design Justice lens, extensive community engagement sessions were held to ensure the building would authentically represent its patrons. This effort resulted in flexible programming and spaces including a large play and learning area for families, a dedicated teen room, and an outdoor plaza for gathering. The community publicly voted on Holgate Library's interior design and exterior color and patterns, as well as the designs of the local artists that will enliven the lobby and exterior. At every turn, the design will reflect its patrons' aspirations to make the new library an inclusive celebration of people and place.

The power of place is strengthened with the use of a Pacific Northwest Douglas-fir timber frame. The timber strategy is a hybrid 1-way/2-way frame. The ground floor is divided into many rooms, minimizing the impact of the several columns required for an efficient 1-way frame. The additional columns also help carry substantial structural loads from the book stacks. The second story benefits from a reduced number of roof-supporting columns by employing girders in the large open reading rooms. The 3-ply Cross-Laminated Timber (CLT) decks carry gravity loads and act as horizontal diaphragms. Buckling Restrained Braces (BRB) serve as the vertical lateral elements and help reduce the overall carbon footprint by 61 percent, compared to conventional steel/concrete construction.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

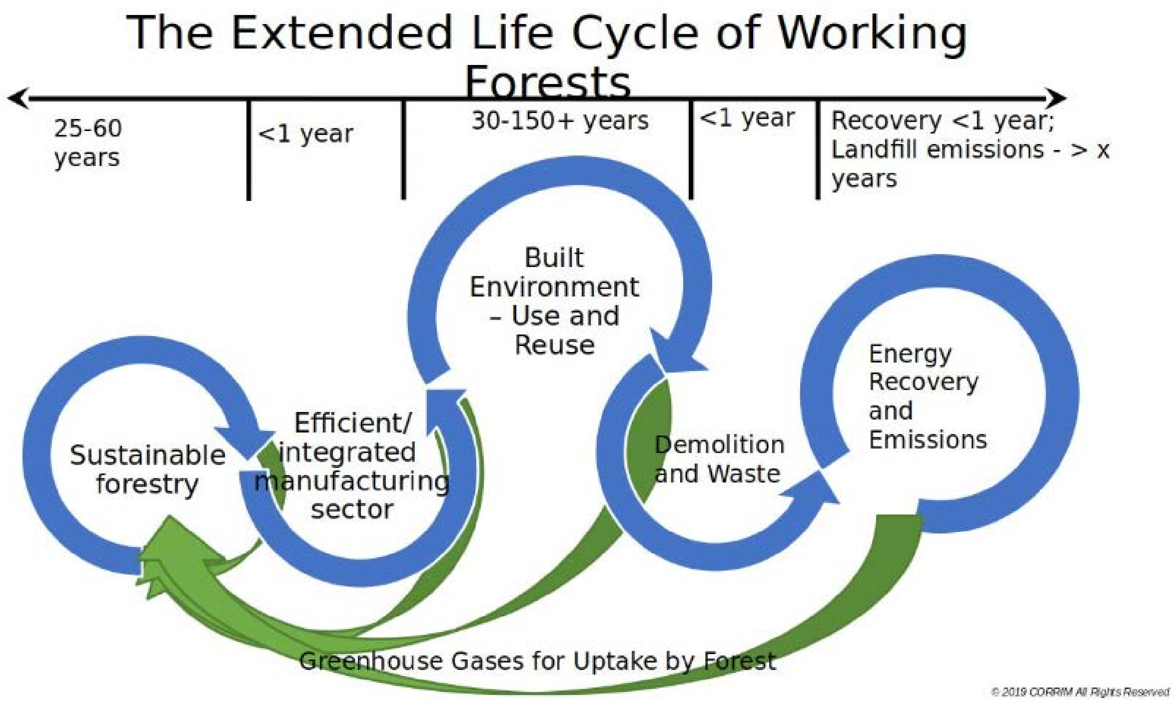


FIGURE 9.4: EXTENDED LIFE CYCLES OF WORKING FORESTS

Source: Reprinted with permission, Elaine Oneil, Consortium for Research on Renewable Industrial Materials (CORRIM), www.corrim.org

grows, 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 9.4**, carbon storage in long-lived wood products can extend the biogenic carbon cycle. Constructing buildings with wood products lengthens the time that carbon is kept in storage. Wooden buildings 1,000-plus years old exist in Europe and Asia. They demonstrate that, with proper protection and maintenance, wood can serve us well.

Biogenic carbon eventually returns to the atmosphere through decomposition or incineration,

12 Science Direct, "Biogenic Carbon," https://www.sciencedirect.com/topics/engineering/biogenic-carbon.

and that may be acknowledged through a complete LCA that illuminates the long-term impacts (spanning at least 100 years). Although 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 years 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, and, therefore, present an opportunity to become carbon storage devices, or carbon banks. To achieve this, the industry must use as many biogenic materials as possible in every building. According to Architecture 2030, buildings are responsible for nearly 40 percent of global GHG emissions. Embodied carbon—i.e., GHGs associated with materials and construction processes throughout the lifetime of a structure—accounts for about 11 percent, most of which (9 percent) is related to the use of concrete, iron, and steel. Embodied carbon, especially up-front emissions associated with manufacturing materials and constructing the building, can be significant. The up-front energy associated with a traditional nonwood building is roughly equal to the energy required to operate that same building for 17 years.

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

13 World Green Building Council, "Bringing Embodied Carbon Upfront," 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/.

building components to a landfill, where LCAs typically assume the wood will decompose. The 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]

9.3 SUBSTITUTION: REPLACING HIGH EMBODIED CARBON/ ENERGY PRODUCTS WITH WOOD

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[16] 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."

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 building industry's carbon goals. Biogenic carbon, discussed in the "Storage" section, 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. For more on these tools, see the "Carbon System Tools" section below.

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 9.5**). We frequently compare wood with these two other materials because the structural system of a building comprises up to 80 percent of its embod-

15 US Environmental Protection Agency, "Decarbonization for Greenhouse Gas Emission and Energy Factors Used in Waste Reduction Model (WARM)," 2019.

16 Galina Churkina and Alan Organschi, "Will a Transition to Timber Construction Cool the Climate?", *Sustainability,* 14, no. 7, 2022.

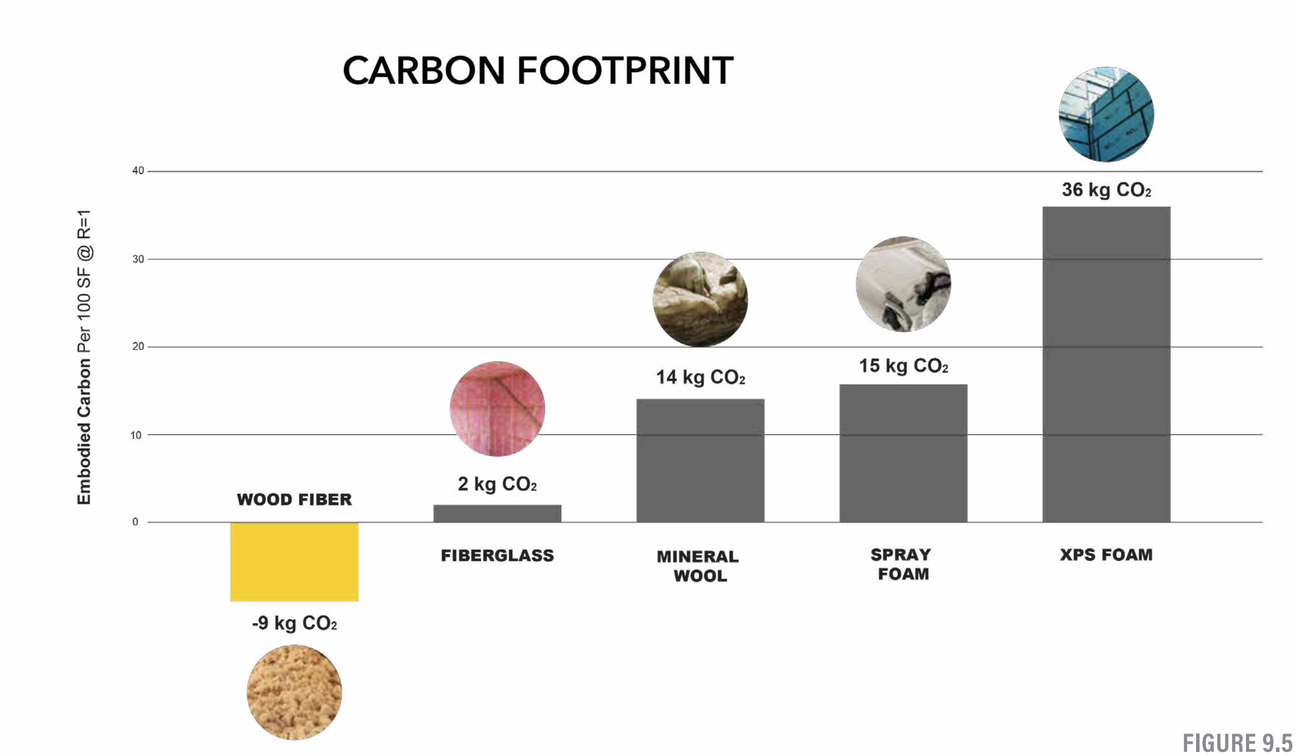


FIGURE 9.5

ied 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."[17] The crucial climate benefits of reduced embodied carbon are achieved while a building is under construction and thus have immediate impacts. Bio-based products also stand apart from other materials in that they store carbon as well, potentially offsetting carbon impacts from other materials.

Short-Lived vs. 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

17 Architecture 2030, "Actions for a Zero Carbon Built Environment: Embodied Carbon," https://architecture2030.org/new-buildings-embodied/.

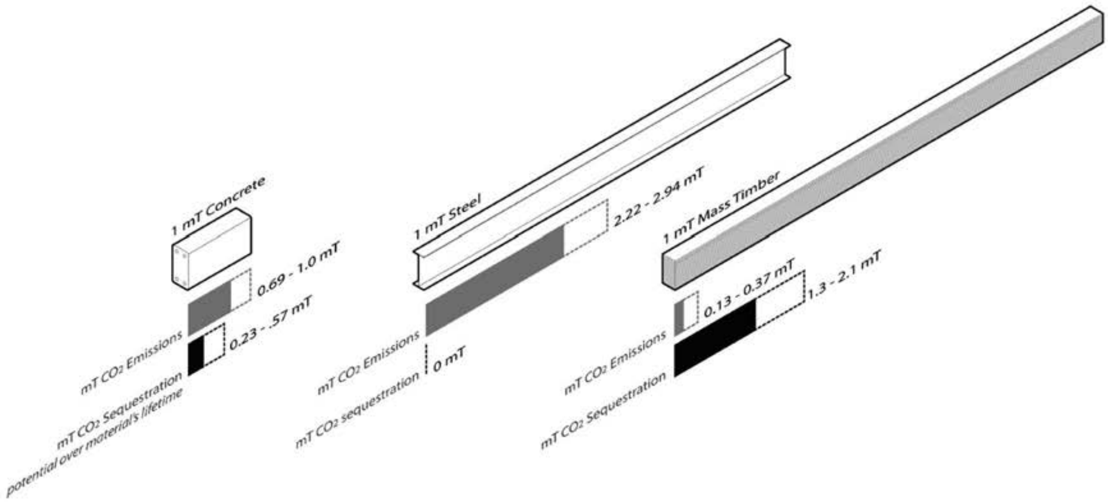


FIGURE 9.6 EMBODIED AND BIOGENIC CARBON IN COMMON STRUCTURAL MATERIALS

Source: Timber City Research Initiative, Gray Organschi Architecture, timbercity.org

sources. Much of the sawdust from sawmills goes into medium- and high-density fiberboard that becomes shelving, tables, and cabinets that 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,"[18] 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 9.6**). 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 desirable construction attributes and applications; 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 percent, according to the US Department of Agriculture (USDA) Forest Products Laboratory. A dam in Georgia was built in 2024 using nanocellulose-infused concrete. The use of biochar to replace coke from fossil carbon, meanwhile, is making steel greener. These opportunities for

18 David Atkins, *2024 International Mass Timber Report*, 2024.

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 that 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, wood products’ carbon is continually replaced by new forest growth, negating the effects of their short lives.

9.4 CARBON SYSTEM TOOLS

Many architects, engineers, and developers who 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?

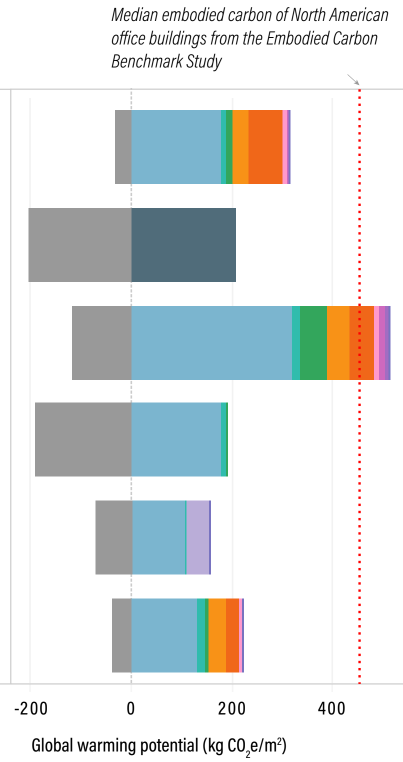
The emotional connection people have with trees and forests may be behind this investigative imperative. As noted earlier, expanding demand can expand the amount of forested land and the amount of carbon stored in the forest per acre or hectare, with longer rotations supported by thinning, especially if market incentives are aligned. Project teams can use established systems and tools such as LCAs, EPDs, forest carbon databases, forest certification systems, and building certification systems to help track carbon impacts.

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 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 forest management and a variety of wood products. 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

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 9.7: 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.

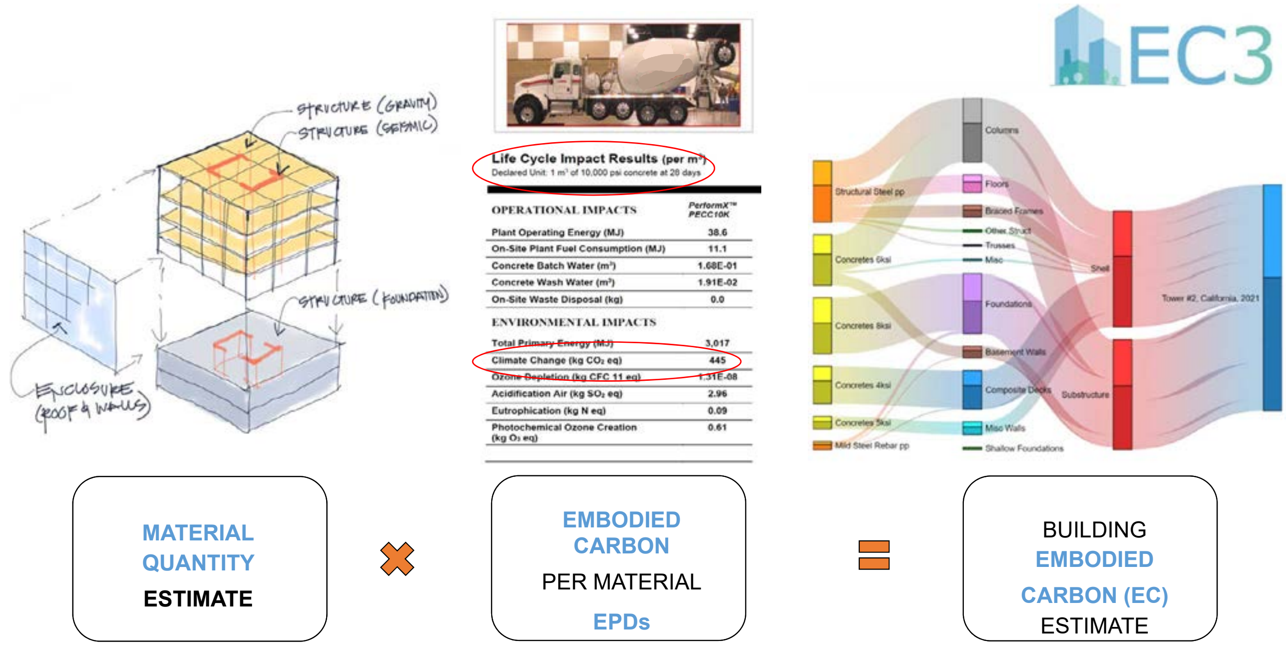


FIGURE 9.8: EC3 LIFE CYCLE ASSESSMENT TOOL

Source: Embodied Carbon in Construction Calculator Carbon Leadership Forum

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 9.7** 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,[19] 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 9.8**. EC3 is a free, open-source LCA tool that was developed by a multidisciplinary team led by the CLF and released in late 2019.[20] 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 GWP. 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

19 KieranTimberlake, "Tally LCA App for Autodesk Revit," https://kierantimberlake.com/page/tally.

20 Carbon Leadership Forum, "Embodied Carbon in Construction Calculator," https://carbonleadershipforum.org/ec3-tool/.

THE BUILDING IS DESIGNED WITH GLULAM POSTS AND BEAMS

Source: VaproShield; Credit: Aaron Gould, VaproShield, director of mass timber

CASE STUDY: MICRON TECHNOLOGY BUILDING

PROTECTING MASS TIMBER FROM MOISTURE INFILTRATION

PROJECT OWNER: MICRON TECHNOLOGY

PROJECT LOCATION: 9600 GODWIN DR., MANASSAS, VA 20110

COMPLETION DATE: OCTOBER 1, 2024

ARCHITECT/DESIGNER: JACOBS

MASS TIMBER ENGINEER/MANUFACTURER: SMARTLAM

GENERAL CONTRACTOR: WHITING TURNER

STRUCTURAL ENGINEER: JACOBS

OTHER CONTRACTORS: SAUTER AND WESTERN WOOD STRUCTURE CARPENTRY PLUS

TO EXPAND ITS Virginia campus sustainably, Micron Technology chose a mass timber structure for its new administrative building and employee cafeteria. The decision reflects a growing preference in the industry for mass timber because of its renewable qualities; low carbon footprint; and the warm, natural aesthetic it brings to interior spaces. The design features glulam posts, beams, and perimeter braces, with a roof topped by 3-ply Cross-Laminated Timber (CLT) panels. This construction choice not only reduces embodied carbon; it also creates a vibrant, light-filled space where employees can relax and recharge.

SLOPESHIELD PLUS ADHERED TO 3-PLY CLT PANELS

Source: VaproShield
Credit: Aaron Gould, VaproShield, director of mass timber

SLOPESHIELD PLUS IS UV-STABLE AND WALKABLE, AND ALLOWS FOR HEAVY MACHINERY

Source: VaproShield
Credit: Aaron Gould, VaproShield, director of mass timber

MANAGING MOISTURE DURING CONSTRUCTION

For a building designed with sustainable materials like mass timber, protection during construction is crucial, especially against environmental factors that can cause moisture damage. Recognizing this, the project team chose SlopeShield Plus SA as a temporary weather and moisture protection solution. The membrane was installed over the roof to shield the timber from rainfall, exposure to ultraviolet radiation, and jobsite conditions while allowing it to breathe and release internal moisture.

Mass timber's sensitivity to moisture buildup can lead to long-term issues like mold growth, decay, and staining, compromising its beautiful natural aesthetic. SlopeShield Plus SA provided the essential dual function of blocking external water while enabling vapor to escape, thus keeping the timber dry and free from moisture buildup.

MANAGING MOISTURE AFTER CONSTRUCTION

SlopeShield Plus SA remains permanently adhered to the wood deck, performing as a continuous vapor-permeable air barrier membrane. Using SlopeShield Plus SA in the finished roof system as a continuous air barrier achieves long-lasting roof durability by reducing air and moisture infiltration by over 90 percent. Within the finished roof system, SlopeShield Plus promotes long-term integrity of the deck through premium moisture management technology.

By choosing SlopeShield Plus SA, the Micron expansion project protected this mass timber roof during the crucial construction phase, ensuring the structure remained dry and intact. The membrane's ability to provide temporary weather protection, combined with its vapor permeability, safeguarded the building materials while allowing for smooth, uninterrupted construction. As a result, the new cafeteria building is ready to serve employees, offering a beautiful, naturally lit space with an exposed timber interior, all while benefiting from the long-term durability of VaproShield's air barrier and moisture protection solution.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

the product's EPD. EPDs report on five 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—product-level EPDs for wood products are available through the American Wood Council (AWC) and the Canadian Wood Council (CWC). Using a 2023 Wood Innovations Grant, AWC recently launched an expanded Life Cycle Survey to collect life cycle impact data from wood product mills across the US. This expansion will lead to more representative and stronger datasets.

One of the most demanding EPD labels is "Declare"; it identifies the most dangerous "Red List" ingredients and clearly states when products are free of them (see Adhesives, section 5.1). Many mass timber products have Declare labels that can be found by searching the database.

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 a USDA sponsored forest and wood product carbon platform (beta),[21] the databases mindfulMATERIALS,[22] Carbon Smart Materials Palette,[23] and the organizational tool EPD Quicksheet.[24]

USDA-Sponsored Forest Carbon Data Platform

Although representing just one metric of sustainable forest management, the carbon sequestration impact of a forest and the carbon storage in wood products is important to understand for project—and industry—impact tracking. The transparency and fidelity of this data was recently improved when, in the spring of 2024, the USDA published the second edition of *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity Scale Inventory*, providing forest landowners with the methods and tools needed to assess the GHG footprint of their operations. Alongside this development, the USDA also entered into a public-private partnership with a group of forest sector organizations to build a digital platform with multiple user-friendly tools providing transparent, high-integrity forest and manufactured forest product carbon data using the USDA's entity-level guidance. The platform will serve as the primary means by which methods and data from a USDA-developed forest carbon Measurement, Monitoring, Recording, and Verification (MMRV) system are delivered in a consolidated, user-friendly format.

21 US Endowment for Forestry and Communities, "Forest & Wood Carbon Data Platform," https://www.usendowment.org/what-we-do/ecosystem-markets/forest-wood-carbon-data-platform/.

22 Spec Matters, "Mindful Materials," https://specmatters.com/mindful-materials/.

23 Carbon Smart Materials Palette, "Materials Palette," https://materialspalette.org/palette/.

24 Architecture 2030, "EPD Quicksheet," https://architecture2030.org/epd-quicksheet/.

Forest Certification Systems

Project teams have many options when it comes to sourcing wood from sustainable and responsible sources. Products from responsible sources are from geographic areas in compliance with an independently certified procurement standard or from geographic areas with programs that implement best management practices. Some teams may choose wood products from trees grown on private lands through forest certification systems like the Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), the American Tree Farm System (ATFS), the Canadian Standards Association Sustainable Forest Management (CSA-SFM), or products that adhere to independently certified procurement standards. Independently certified procurement standards include FSC Controlled Wood and SFI Fiber Sourcing. To qualify for either standard, a manufacturer must have a system that verifies its logs are coming from forests with certain management practices and environmental conservation assurances.

For private and public lands that require an outcome-based approach to meet their goals, certification systems might not be an ideal fit. US state-owned and -managed forests can be certified, and some choose to do so (Wisconsin, Minnesota, Michigan), while certification is too burdensome for others. Federal lands cannot be certified. Laws and regulations for forest management on federal public land in the US are among the most rigorous in the world. For wood products from other US forests, the National Association of State Foresters examined best management practices and wrote a report categorizing each state's regulatory, quasi-regulatory, and voluntary compliance regimes. State-based compliance programs are typically based on either proprietary certification standards or public legislative and regulatory processes. To qualify as "responsible," the best management practices must protect water quality and ensure all fiber comes from known and legal sources. To date, Oregon is the only state to officially have an approved state-based compliance program, though other states are eligible.

Finally, there are international standards that govern forest carbon considerations in mass timber products. For example, the ISO, a consensus-based technical standards body out of Geneva, Switzerland, has developed ISO 13391 to provide an international standard for calculating carbon balances (emissions, storage, and displacement factors) related to the harvesting and manufacture of wood and wood-based products.

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 9.9**), which requires that 100 percent of the embodied carbon emissions impacts associated with the construction and materials of a 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, 170 ZCB Standard projects have been completed, and 593 are emerging.[25] 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.

FIGURE 9.9: ILFI'S ZERO CARBON CERTIFICATION REQUIRES EMBODIED CARBON DISCLOSURES

These certification programs, where wood products are concerned, often connect with forest management certifications, and they can be relevant if project teams are sourcing fiber from privately owned and managed forest lands in circumstances where certification is used. Certifications can be a way to quickly communicate to stakeholders the connection between sustainably managed forests and the use of wood in new and creative approaches.

Keep in mind that many small, family forest owners do not certify their lands because of the cost, complexity, administrative burden, and the diversity of landowner objectives. These landowners make up 56 percent of timberland ownership in the US (almost 290 million acres). Even though many of these lands are not certified, most are subject to wood fiber sourcing certification at the mills that purchase the landowners' timber. US federal timberlands are not certified, but this does not mean they are not being sustainably managed. In 2007, the Pinchot Institute conducted a study of 5 national forests and found their management practices met many of the certification requirements in terms of forest planning, and protection of threatened and endangered species.

The goal for these systems, and of many other types of land managers including US state, federal, and tribal lands, is to 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.

25 New Buildings Institute, "Getting to Zero Buildings Database," https://newbuildings.org/resource/getting-to-zero-database/.

CHAPTER 10: THE GLOBAL MASS TIMBER PANEL INDUSTRY IN 2024

AN INSIGHT INTO BASIC LOGISTICS

LECH MUSZYŃSKI
PROFESSOR, OREGON STATE UNIVERSITY

MATTHEW SPARR

The purpose of this chapter is to present the updates in the North American mass timber industry described in previous chapters in a broader global context. The discussion is restricted to the sector related to mass timber panel (MTP), leaving out glulam, Laminated Veneer Lumber (LVL) elements, mass timber trusses, and other products established earlier. The context is necessary to avoid overinterpreting phenomena observed on the relatively small number of MTP operations in North America or giving undue weight to the uneven pace of developing production capacity or the rate of attrition.

In this broader perspective, the MTP industry that requires integrating elements of mass timber design, manufacturing technologies, and construction 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 important to keep in mind that the MTP industry is 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. Thirty years after its inception, the industry is still young and struggling to find 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 3 major sources:

- Industry surveys[1]
- 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, data obtained from different sources were verified against each other.

1 Albee, R.R. MS thesis, Oregon State University, 2019. 114 pp.; Larasatie, P., R.R. Albee, L. Muszyński, J.E. Martinez Guerrero, and E.N. Hansen. Proc. World Conference on Timber Engineering, WCTE 2020, 2021. 8 pp.; Larasatie, P., L. Muszyński, and E. Hansen. Proc. XV World Forestry Congress, 2022. 5 pp.

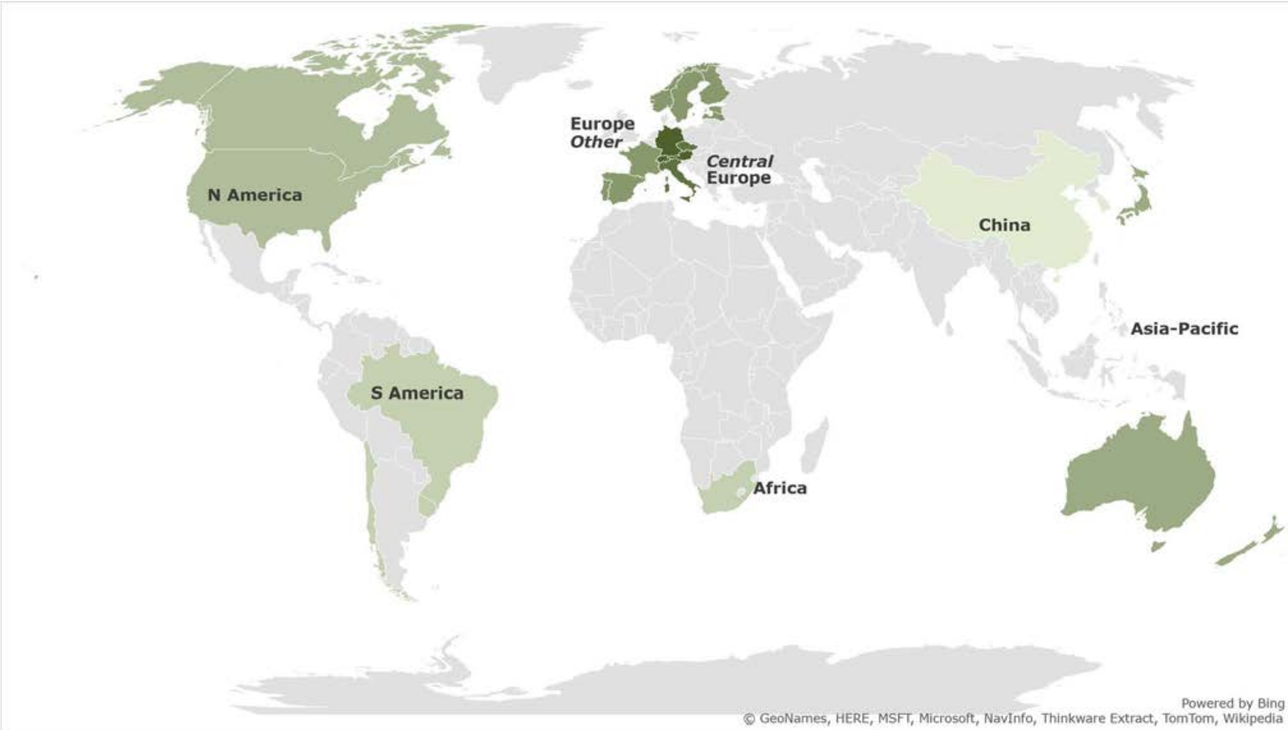


FIGURE 10.1: MTP-PRODUCING REGIONS

To ensure confidentiality of the 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-producing countries are divided into 4 large regions: North America (including the United States 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.[2] 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

2 Smily, J. XLam SA, personal contact. October 5, 2023; XLam, accessed Jan. 12, 2025, at https://xlam.odoo.com/; van der Hoven, M., personal contact. Jan. 8, 2025; Mass Timber Technologies, accessed Jan. 6, 2025, at https://www.masstimbertech.co.za/.

audiences in journal papers, conference presentations, and proceedings publications.[3]

10.2 CLT AND OTHER EMERGING MTP TECHNOLOGIES[4]

Most of the data presented in this chapter refers to Cross-Laminated Timber (CLT), adhesive-bonded cross-laminated panel, because it is the most widely known MTP product. ANSI/APA PRG 320-2019[5]—the North American product standard published by the American National Standards Institute (ANSI) and the Engineered Wood Association (APA)—defines CLT as a "prefabricated engineered wood product made of at least 3 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)[6] or panels built from LVL as structural CLT under PRG 320. Although, in principle, this general definition agrees with that proposed in the European standard EN 16351:2021,[7] some European products might not qualify as structural CLT under PRG 320 because of restrictions on the thickness of laminations and discrepancies in structural lumber grading rules.

An interesting development 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.

3 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. Technical Report of the Joint Institute for Wood Products Innovation, submitted to the California Board of Forestry and Fire Protection: Agreement #9CA04450, 2020. 116 pp.; Muszyński, L., E. Hansen, B.M.S. Fernando, G. Schwarzman, and J. Rainer. BioProducts Business 2 (8): 77–92.; Albee, R. R., L. Muszyński, E. N. Hansen, C.D. Knowles, P. Larasatie, and J.E. Guerrero. Proc. World Conference on Timber Engineering, proceedings of the WCTE 2018, 2018. 6 pp.; Muszyński, L., P. Larasatie, J.E. Martinez Guerrero, R. Albee, and E.N. Hansen. Proc. 63rd International Convention of Society of Wood Science and Technology, 2020. 8 pp.; Muszyński, L., P. Larasatie, E.N. Hansen, E. Bright, T. Barnett, J.E. Martinez Guerrero, and R. Albee. Proc. FPS International Conference on Wood Adhesives, Portland, Oregon, 2022; Muszyński, L., P. Larasatie, E.N. Hansen, J.E. Martinez Guerrero, and R. Albee. Proc. 64th 2021 International Convention of the Society of Wood Science and Technology, 2021. 29–43.; Muszyński, L., E.N. Hansen, and P. Larasatie. Proc. 65th 2022 International Convention of the Society of Wood Science and Technology, 2022. 6 pp.; Muszyński, L., M. Riggio, M. Puettmann, A. Dodoo, L. Schimleck, and N. Ahn. In: Shahnoori S., and Mohammadi M., eds. Proc. 2nd International Conference on Circular Systems for the Built Environment, Eindhoven, 2022. pp. 55–62.; Ahn, N., C. Bjarvin, M. Riggio, L. Muszyński, L. Schimleck, C. Pestana, A. Dodoo, and M. Puettmann. Proc. World Conference on Timber Engineering, WCTE 2023, 2023. 7 pp.; Muszyński L.: In R. Anderson, E. Dawson, D. Atkins, L. Muszyński, C. Rawlings, E. Spiritos, B. Beck: 2024 International Mass Timber Report. FBN. ISBN: 979-8-9902000-0-5 (ebook), pp. 252-277.

4 Based on author's contribution to 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. Technical report of the Joint Institute for Wood Products Innovation, submitted to the California Board of Forestry and Fire Protection: Agreement #9CA04450, 2020. 116 pp.

5 ANSI/APA. ANSI/APA PRG 320-2018. APA, The Engineered Wood Association, Tacoma, Washington. p. 46.

6 Freres Wood, 2023. Accessed Oct. 1, 2024, at https://frereswood.com/products-and-services/mass-ply-products/mass-ply-panel/.

7 CEN EN. 16351:2021. p. 11.

TIMBER IS A PROMINENT FEATURE OF THE REC CENTER'S DESIGN

Source: Populous; Credit: Conor Culver

CASE STUDY: AURORA SOUTHEAST RECREATION CENTER AND FIELDHOUSE

TIMBER ROOF EMULATES EASTERN COLORADO PRAIRIE'S ROLLING HILLS

PROJECT OWNER: CITY OF AURORA

PROJECT LOCATION: 25400 E. ALEXANDER DRIVE, AURORA, CO 80116

COMPLETION DATE: JANUARY 1, 2023

ARCHITECT/DESIGNER: POPULOUS

MASS TIMBER ENGINEER/MANUFACTURER: MERCER

GENERAL CONTRACTOR: SAUNDERS CONSTRUCTION

STRUCTURAL ENGINEER: MARTIN/MARTIN

THE "CANYON ROOF" of the Southeast Recreation Center is a stunning architectural feature, showcasing gracefully undulating glulam beams that appear to float above a glass clerestory encircling the structure. This design element beautifully mimics the rolling grassland prairie surrounding the site, infusing the building with a sense of nature and warmth through its timber construction.

This project was designed to offer users unique opportunities not found in similar facilities. A winding "figure 8" running track connects various areas of the building, fostering a sense of connection among different workout spaces. Inspired by Colorado's many hiking trails, the track features gentle elevation changes achieved through sloping ramps, simulating a trail running experience in a climate-controlled environment available year-round. These hills and elevation changes provide a new challenge for users, offering a more dynamic experience than the typical flat, oval tracks found in gymnasiums.

TOP — CARE WAS TAKEN TO CONCEAL MECHANICAL, ELECTRICAL, AND PLUMBING (MEP) SYSTEMS, ALLOWING THE VIEW OF THE TIMBER ROOF TO BE LESS OBSTRUCTED

BOTTOM — THE UNDULATING ROOF EMULATES THE NEARBY ROLLING HILLS

Source: Populous
Credit: Conor Culver

The fire protection system was cleverly integrated to blend seamlessly with the structure. Fire sprinkler pipes were installed directly against the glulam beams, painted to match the wood, and sloped with the roof structure, effectively hiding them from view and avoiding the look of a typical suspended fire protection system.

Lighting was designed to highlight the beauty of the wood, with up-lighting emphasizing the color and finish. Main lighting elements were installed along the glulam beams, drawing attention to the primary structural components and enhancing the overall aesthetic.

The community has responded positively to this project, appreciating the unique experience it offers compared to other centers used for community events, sports leagues, or daily workouts. Beyond its aesthetic appeal, the center's practical space planning and functional program usage provide users with a multitude of options, including the innovative figure-8 undulating track.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

Nail-Bonded Solid Wood Wall

A nail-bonded Solid Wood Wall, or as it is known in Central European markets, Massiv-Holz-Mauer (MHM), which translates literally to "massive wood wall," is a large prefabricated cross-laminated panel with layers made of rough-sawn boards bonded with nails.[8] 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 cross-laminated panel technology might have predated the development of adhesive-bonded CLT, but the commercial breakthrough came with the Solid Wood Wall system patented in Germany in 2005.[9] 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 where there is moderate exposure to moisture (below 20 percent) and low to moderate exposure to corrosion.[10]

There are 30 licensed Solid Wood Wall plants across Europe,[11] and in 2024, when the latest assessment was done, the total output in Central Europe was about 50,000 cubic meters (over 21.2 million board feet [MMBF] of the North American dimensional lumber equivalent),[12] a decrease from the 55,000 cubic meters (23 MMBF) estimated in 2022.[13]

Wood100, the Dowel-Bonded CLT

Dowel-bonded CLT—marketed as Wood100, Nur-Holz (which means "only wood"), and various local brand names[14]—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), where all layers are oriented parallel to each other and intended for use as beams and floor panels in timber structures. The low moisture content and tight fitting of the dowels at the time of assembly ensure a durable, tight connection once the dowels gain moisture in ambient

8 MHM, 2023. Accessed Dec. 30, 2024 at https://www.massivholzmauer.de/en/about-us/sales-offices/locations/mhm-producers.html.

9 MHM, 2023 (cited above)

10 MHM, 2023 (cited above)

11 MHM, 2023 (cited above)

12 Jauk, G. 2024. *Timber-Online*. Accessed Dec. 30, 2024, at https://www.timber-online.net/.

13 Jauk, G. 2022. *Timber-Online*. Accessed Oct. 1, 2023, at https://www.timber-online.net/.

14 Thoma. Accessed Jan. 12, 2025, at https://www.thoma.at/en/. Nägeli. Accessed Jan. 12, 2025, at https://www.naegeli-holzbau.ch/appenzellerholz.html#technische-daten. TechnoWood AG, 2023. Accessed Dec. 30, 2024, at https://www.technowood.swiss/en/loesungen/tw-concept-line/.

conditions 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;[15] (2) a system developed by Swiss industrial hardware manufacturer TechnoWood AG;[16] and (3) Rombach Nur-Holz, which operates out of the Black Forest region in Germany and uses threaded hardwood dowels as connectors.[17] By the end of 2024, 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 a 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.[19]

10.3 SHIFTS IN GLOBAL PRODUCTION DISTRIBUTION

Since the publication of the first global survey,[20] 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.

At 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.[21]

The annual global output of CLT in 2024, which we can attribute to 111 specific production lines, is nearly 2.3 million cubic meters (a 13 percent increase from 2.0 million cubic meters estimated for 2023). The annual global per-shift capacity in 2024 is about 1.87 million cubic meters (over an 11 percent increase compared to 1.68 million cubic meters estimated for 2023).

That number includes a 1.3 million cubic meter capacity increase predicted by Gert Ebner of the Timber-Online.net trade journal, based on a list of pending and announced new and expanding CLT production projects for years 2020 to 2024,

15 Thoma. Accessed Jan. 12, 2025, at https://www.thoma.at/en/.

16 TechnoWood AG. Accessed Dec. 30, 2024, at https://www.technowood.swiss/en/loesungen/tw-concept-line/.

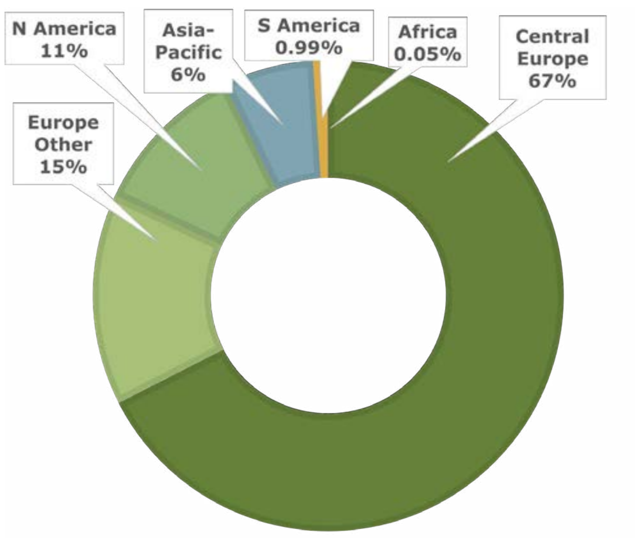
17 Rombach Nur-Holz. Accessed Jan.12, 2025, at https://www.nur-holz.com/en/.

18 Jauk, 2022, cited above.

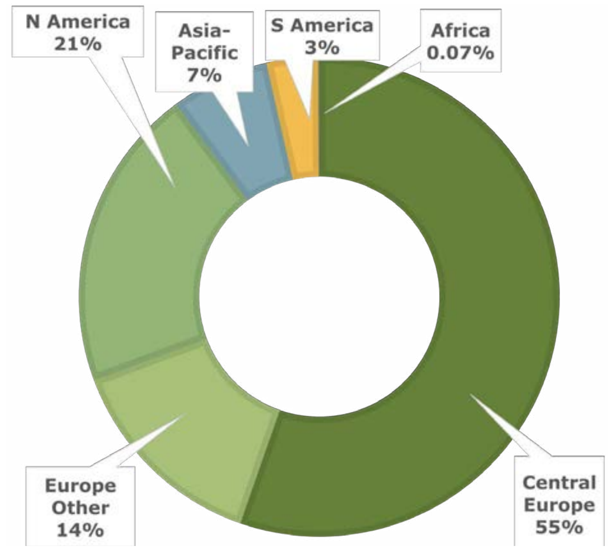
19 TechnoWood AG. Accessed Jan. 12, 2025, at https://www.technowood.swiss/en/loesungen/tw-concept-line/TW-Portfolio_ANSICHT_-4.pdf.

20 Albee, R.R., 2019, cited above; Muszyński, L., P. Larasatie, J.E. Martinez Guerrero, R. Albee, and E.N. Hansen, 2020, cited above.

21 Weinberg, C., 2021. The Information. Accessed June 1, 2021, at https://www.theinformation.com/. Guzely, E., 2021. Timber-Online.net. Accessed Aug. 5, 2021. O'Brien, F., 2023. Western Investor. Accessed April 26, 2023, at https://www.westerninvestor.com/.



(A)



(B)

FIGURE 10.2: REGIONAL DISTRIBUTION OF THE TOTAL GLOBAL CLT OUTPUT VOLUME (A) AND PER-SHIFT CAPACITY (B)

Based on Larasatie et al., 2021, cited above.

mostly in Central Europe.[22] Considering known CLT operations, for which the produced volumes/capacities are unavailable or outdated, it is likely that, by the end of 2025, global annual output will reach 2.8 million to 3.4 million cubic meters, even as the increased capacity does not immediately translate into a proportional increase in the production output.

Manufacturers of mechanically bonded cross-laminated panels like Solid Wood Wall, Wood100, and Nur-Holz (45 lines, mainly in Central Europe, are not included in the distribution graphs in **Figure 10.2**) likely contributed another 70,000 cubic meters of structural panel products to the MTP market in 2024 (the time of the most recent tally).[23]

The combination of the steady addition of production capacity in Europe and the recent troubles in the North American CLT industry continues to shift the global distribution of adhesive-bonded CLT production (**Figure 10.3**). The Alpine region in Central Europe still accounts for over 68 percent of the output (the estimated share increased from 65 percent last year) and 56 percent of the annual per-shift capacity. All European manufacturers combined contribute more than 82 percent of the adhesive-bonded CLT volume to the global construction market and 100 percent of the dowel- and nail-bonded cross-laminated panels. Austria alone contributed about 38 percent of the total output and continues to lead the global industry. A difficult-to-assess portion of that volume is being exported to overseas markets, where European companies successfully compete with local CLT manufacturers on quality and price of the products and projects, despite existing tariffs, transportation costs, and differences in building codes.

22 Ebner, G. 2022 Timber-Online. (Jan. 18.) Accessed Feb. 10, 2022, at https://www.timber-online.net/wood_products/2022/01/sustained-clt-boom.html.

23 Jauk, 2024, cited above.

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*, (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) **

**MHM. Accessed Jan. 12, 2025, at https://www.massivholzmauer.de/en/contact/find-a-manufacturer/partner.*

***Rombach Nur-Holz, cited above.*

In the same time frame, North American CLT production shrank from 17 percent of the global volume in 2020[24] to 11 percent in the current tally, with an equally substantial reduction to the per-shift capacity, down from 28 percent in 2020 to 20 percent in 2023. It should also be noted that, in North America, 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 such as Austria, Australia, Czechia, France, Germany, Japan, Indonesia, New Zealand, and Norway. Although

24 Muszyński, L., 2021. In Anderson R., E. Dawson, L. Muszyński, B. Beck, H. Hammond, B. Kaiser, and C. Rawlings, 2021. 2021 International Mass Timber Report.

the attrition rate in the North American MTP production capacity seems high, the underlying systemic factors for the state of the industry in the region are still awaiting a comprehensive analysis. 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 unscathed.

10.4 RAW MATERIAL SOURCING

Raw material use must be considered separately for the 3 types of cross-laminated 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[25] 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; for the transverse pieces, it is No. 3 (see chapter 3, "Raw Materials," for additional details).

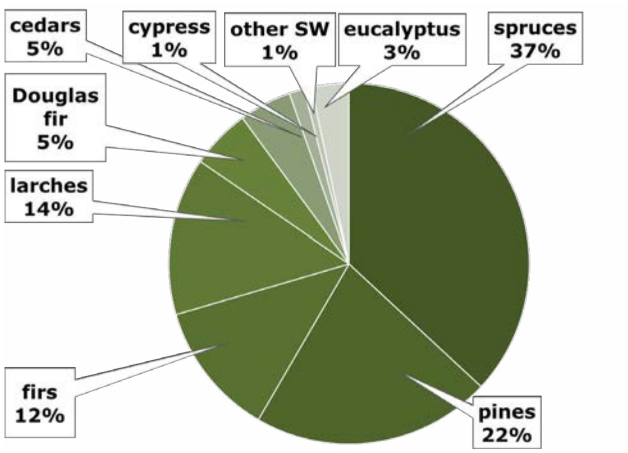
Although both grades allow a certain amount of wane, and PRG 320 allows gaps between adjacent lamination edges (up to ¼ inch, or 6.4 millimeters), manufacturers tend to use perfectly square pieces and eliminate all gaps because wane pockets and gaps in the panels form water catchment wells at construction sites. It follows that logs with diameters too small to produce a substantial volume of lumber free of wane might not be favored unless the laminations are finger-jointed from square sections of lumber produced from small logs. Some European CLT companies join clear square sections as short as 600 millimeters (or about 2 feet).

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.[26] 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.

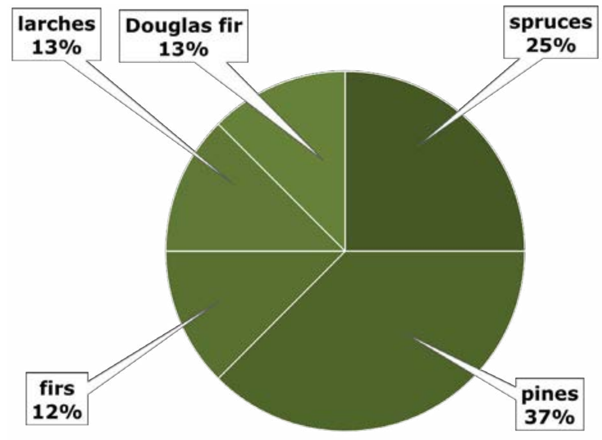
Solid Wood Wall panels use relatively thin, rough-sawn boards rather than nominal 2-by stock. The surface is not considered for visual quality. That means there should be greater potential to use lumber of lower quality than that required for adhesive-bonded CLT. However, the nailing patterns require 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 grain 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 a thin continuous bitumen sheet for

25 ANSI/APA. ANSI/APA PRG 320-2018 2018. APA, The Engineered Wood Association, Tacoma, Washington. p. 46. (The newest update of the standard is expected in the first half of 2025.)

26 For instance: OIB. European Technical Assessment, ETA-15/0760, by Austrian Institute of Construction Engineering (OIB), Austria, 2017. 24 pp.



(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.

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 intended for visible surfaces in structures (with the dowel pattern contributing to the visual appeal). Also, bonding with dowels requires wide-face lumber (likely more than 200 millimeters, or 8 inches) to allow 2 rows of dowels in each surface lamination. This likely limits the prospect of using 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.

In terms of species selection, manufacturers tend to target the structural-grade softwoods available in their regions, with some manufacturers occasionally importing lumber from external—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 82 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. Manufacturers in the Far East still rely largely on imported structural lumber for their CLT production.

CLT PANELS THAT HAVE BEEN TREATED TO STAY FREE OF DECAY AND WOOD-DESTROYING ORGANISMS INSIDE FINISHED AIRPORT

Source: Mitsubishi Estate

CASE STUDY: SHIMOJISHIMA ISLAND AIRPORT

TREATMENT ENSURES SUSTAINABILITY THROUGH DURABILITY

PROJECT OWNER: SHIMOJI ISLAND AIRPORT

PROJECT LOCATION: TROPICAL ISLAND (SHIMOJI) NEAR OKINAWA, JAPAN, SAWADA-1727, IRABU, MIYAKOJIMA, OKINAWA, JAPAN, 906-0507

COMPLETION DATE: MARCH 1, 2019

ARCHITECT/DESIGNER: NIKKEN SEKKEI LTD.

MASS TIMBER ENGINEER/MANUFACTURER: YAMASAMOKUZAI CO. LTD.

GENERAL CONTRACTOR: MITSUBISHI ESTATE CO. LTD.

CROSS-LAMINATED TIMBER (CLT) is a relatively new construction method that allows multistory construction using solid wood instead of concrete or steel. Because a natural organic material is used, durability against mold and wood-destroying organisms is a concern. Even if it were possible to permanently keep the wood dry to prevent wood-rotting basidiomycete fungi, some pests can attack wood that is wetted temporarily (e.g., mold fungi) or even relatively dry wood (e.g., drywood termites).

CLT PANELS INSIDE THE FINISHED AIRPORT
Source: Mitsubishi Estate

Borates—especially polyglycol borates for dry wood—have the advantage of being effective against both decay fungi and insects at low retentions, and even are bait toxicants against subterranean termites at low retention. Such approaches have been successfully used in residential construction in the US for decades. The use of an inorganic salt as the active ingredient is also good in topical applications where organic systems can be destroyed by ultraviolet light during construction.

Even non-wood-destroying insects such as psocids and cockroaches can be controlled via the use of borate-treated wood. Borates have low acute mammalian toxicity and are globally available from a number of suppliers. Using topical treatments also ensures that all of the construction components are treated (the mass timber itself but also framing and plywood and other SKUs that typically go into a building), and borates have the unique advantage of diffusing into even refractory wood species.

In this project, topical treatment was carried out using a 40 percent DOT glycol borate diluted at a 1-to-1 volume dilution in water (Bora-Care to equal a 23 percent DOT solution concentration). A 0.8 percent didecyl dimethyl ammonium chloride (1 percent as Mold-Care, available commercially from Nisus Corporation) was added as a surface moldicide. The diluted material was applied with roller coating at Yamasamokuzai Co. Ltd., the CLT manufacturer.

An application of 300 milliliters per square meter was used in compliance with Japan Wood Protection Association requirements to treat 6,000 cubic meters of CLT. This concentration and application rate was chosen to help drive diffusion over time, to protect against subterranean termites and other wood-destroying organisms, to enhance spread of flame performance, and to supply some reservoir to compensate for dilution because of diffusion into the wood.

The inaugural direct flight from Narita to Shimojishima occurred on March 30, 2019, and many more flights will be able to land in an airport that is sustainable because of its durability—effectively storing carbon and remaining free of decay and drywood termites and other wood-destroying organisms for decades to come. If mass timber, especially CLT, is to gain the position it deserves in future construction, it is essential that long-term durability is addressed, as suggested by wood experts globally. This project has shown that it is relatively easy and cost-effective to achieve.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

An interesting example of such trends is pilot-scale operations in Tasmania and South Africa that successfully built CLT panels using plantation eucalyptus species. It is also worth noting that the new edition of the ANSI/APA PRG 320 standard for structural CLT, expected in 2025, is likely to allow lamstock from hardwood 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 might consider appearance, sustainability, emissions regulations, carbon dioxide footprint, etc.; performance, which might consider bond integrity and fire performance; and ease and cost of application, e.g., plant logistics, curing dynamics, and open time versus press time.

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 (17 percent use nails and 8 percent use hardwood dowels) with the share of products with mechanical binders produced and installed in buildings (combined 3 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 (PU) adhesive systems, which now include Elastan TLP, a new product developed for use in CLT manufacturing by BASF. Even though the new product has been introduced in just 3 plants owned by a single European company, the impact of that decision may be appreciated when the Elastan TLP PUR segment is set apart from other PUR products on graphs in **Figure 10.5**. The adhesive can now be found in 5 percent of CLT panels produced on the planet in 2024.

Taken together, PUR systems are used by 46 percent of companies around the globe and are found in nearly 73 percent of the cross-laminated MTPs produced in 2024 (fractions for PUR and TLP PUR segments in the graphs combined). The share of melamine-based systems (melamine formaldehyde [MF] and melamine urea formaldehyde [MUF]) reached about 12 percent (by volume produced) because of 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 HB X 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 3 percent of the global output of MTP produced and installed, reflecting the preferences of manufacturers operating in Japan.

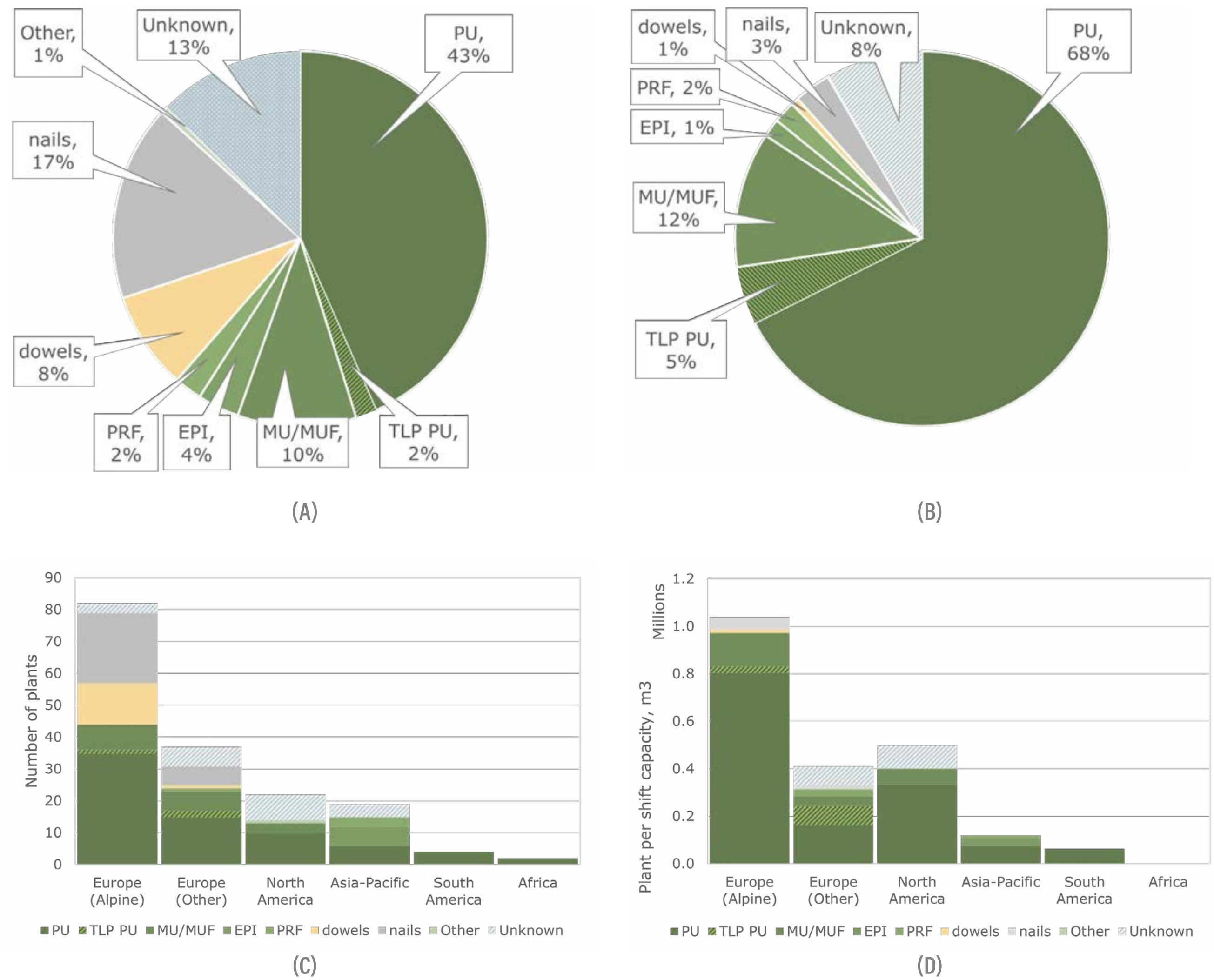


FIGURE 10.5: USE OF BINDERS IN GLOBAL MTP PRODUCTION: (A) USE OF GLOBAL BINDERS BY NUMBER OF PLANTS, (B) SHARES OF PRODUCT VOLUMES USING SPECIFIC BINDERS, (C) USE OF BINDERS BY NUMBER OF PLANTS IN MTP-PRODUCING REGIONS, AND (D) SHARES OF PRODUCT VOLUMES USING VARIOUS BINDER TYPES BY REGION.

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 the selection of binders (adhesives and mechanical) may be motivated by a variety of factors, the market is shaped by the choices of the biggest European producers. Although most new developments happen in that region, trends are difficult to appreciate, given the long history and number of plants installed when PUR appeared 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. The addition of the Elastan TLP PUR system demonstrates that new adhesives 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[27]

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.[28] Arguably, the first patent describing layered CLT composite bonded *with suitable cement* was issued to 2 residents of Tacoma, Washington, back in 1923.[29]

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 backgrounds in the forest products sector. It seems a natural and logical course of events.

The organic development of the global MTP industry since the early 1990s has produced a 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 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."[30] 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.[31] 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

27 Based on author's contribution to Muszyński, L., E.N. Hansen, and P. Larasatie. Proc. 65th 2022 International SWST Convention, 2022. 6 pp.

28 Wikipedia. Accessed June 4, 2022, at https://en.wikipedia.org/wiki/Plywood.

29 Walsh, F.J., and R.L. Watts. US Patent 1,465,383, patented Aug. 21, 1923.

30 Ferdinando, J., 2022. Accessed May 29, 2022, at https://www.investopedia.com/terms/c/commodity.asp.

31 Ferdinando, 2022, cited above.

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 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 2 large dimensions, change the game and move the concept into scantly 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.[32] 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,[33] 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

32 E.g., Albee, R.R., 2019, cited above; Larasatie, P., R.R. Albee, L. Muszyński, J.E. Martinez Guerrero, and E.N. Hansen, 2021, cited above; Larasatie, P., L. Muszyński, and E. Hansen, 2022, cited above; Muszyński, L., E. Hansen, B.M.S. Fernando, G. Schwarzman, and J. Rainer, 2017, cited above; Muszyński, L., P. Larasatie, J.E. Martinez Guerrero, R. Albee, and E.N. Hansen, 2020, cited above; Muszyński, L., P. Larasatie, E.N. Hansen, E. Bright, T. Barnett, J.E. Martinez Guerrero, and R. Albee, 2022, cited above; Muszyński, L., P. Larasatie, E.N. Hansen, J.E. Martinez Guerrero, and R. Albee, 2021, cited above.

33 Muszyński, L., P. Larasatie, E.N. Hansen, J.E. Martinez Guerrero, and R. Albee, 2021, cited above.

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.[35]

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 production logistic challenge. The spaces must be within range of an overhead crane, and although flat-stacking panels is easy, it precludes quick access to all but the top panels.

It is easy to imagine that 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 the desired characteristics, or specialized storage hardware enabling quick access. Although such concepts are being offered by industrial hardware manufacturers serving the MTP industry,[36] we are not aware of any unit in this capacity planned for installation.

The existence of independent MTP fabricators 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 the overflow of production related to large projects, sending large, blank panels to another location 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

34 Ferdinando, 2022, cited above.

35 Muszyński et al., 2021, cited above.

36 Minda. Accessed Jan. 12, 2025, at https://www.minda.com/en/solid-wood-industry/high-bay-warehouse.

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 costs 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, chemical, and general construction industries.[37] 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.

37 E.g., Sterling Solutions. Accessed Jan. 12, 2025, at https://www.sterlingsolutions.com/sterling-locations/.

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.[38] 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, 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, MARKET STRUCTURE, AND LOGISTICS[39]

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.

The actual level of vertical integration varies substantially, both among and within the 3 products discussed.

More than a third of the respondents to OSU surveys owned sawmills, project transportation fleets, building engineering offices, and/or construction crews.

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,

38 Bhandari, S., M. Riggio, S. Jahedi, E. Fischer, L. Muszyński, and Z. Luo. Journal of Building Engineering 68(A), January 2023: 105485.

39 Based on author’s contribution to Muszyński, L., P. Larasatie, E.N. Hansen, J.E. Martinez Guerrero, and R. Albee, 2021, cited above.

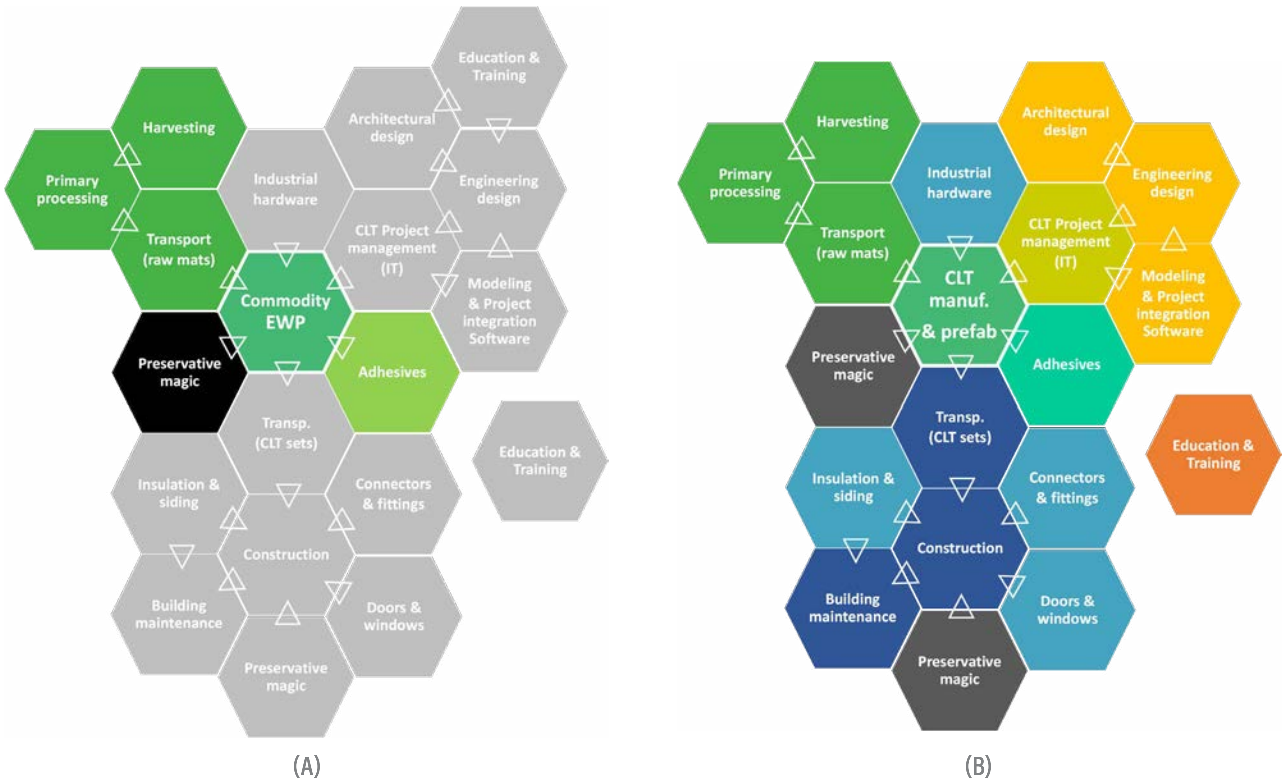


FIGURE 10.6: TYPICAL SUPPLY/VALUE CHAIN MODEL OF AN EWP COMPANY (A) COMPARED TO A POSSIBLE SUPPLY/VALUE CHAIN OF A CLT COMPANY WHERE THE FINAL PRODUCT IS A BUILDING (B).

the products delivered to the market are not panels but building shells, or even finished buildings.

Compared to other types of engineered wood products (EWPs), 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 manufacturers of specialized connectors, insulation, and siding products, and construction crews on the other (**Figure 10.6**).

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 to integrate 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 10.7a**); customized connectors and preinstallation; and, in one case, custom manufacturing of their own windows/doors, floor finishes, insulation, and external siding.[40] Some companies own forestlands and sawmills.[41]

40 Albee, 2019, cited above; Muszyński et al., 2017, cited above.

41 Larasatie et al., 2021, cited above.

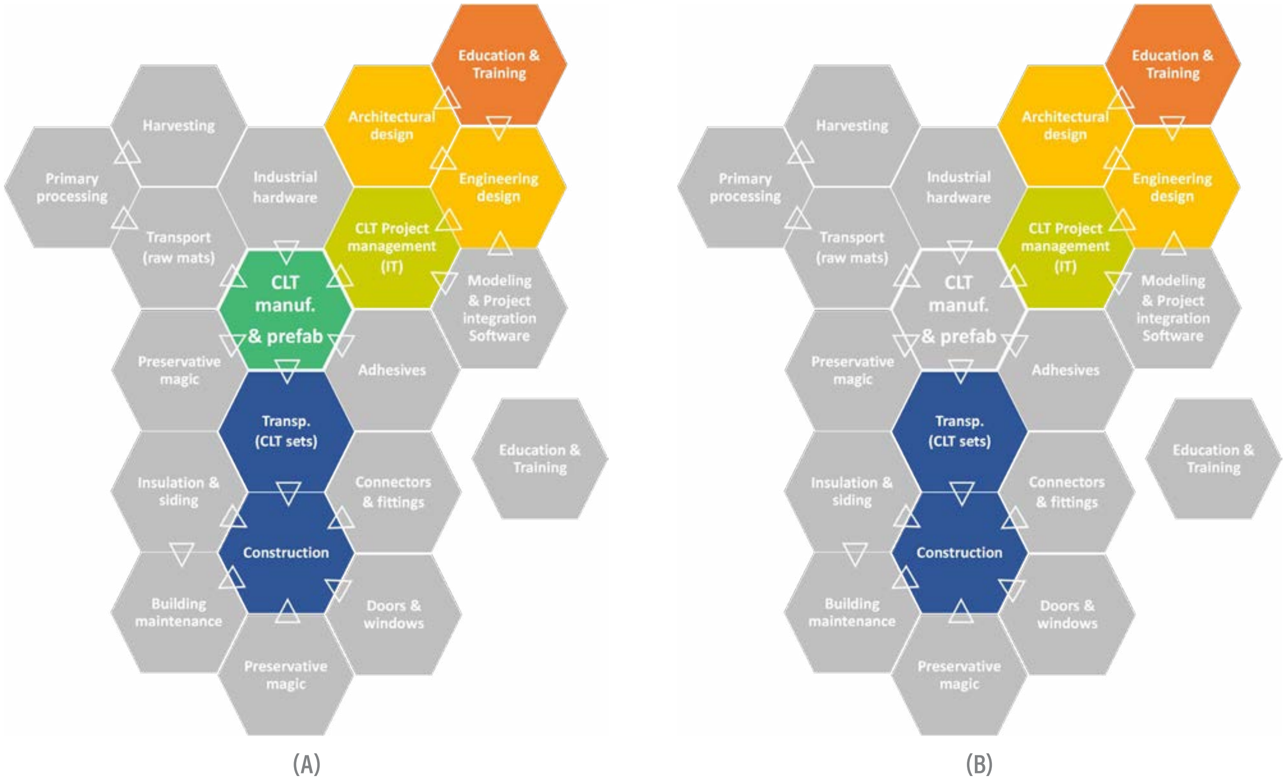


FIGURE 10.7: A COMMON SCHEME OF VERTICAL INTEGRATION OF CLT COMPANIES (A) AND AN EXAMPLE OF A VERTICAL INTEGRATION OF COMPANIES SPECIALIZING IN BUILDING WITH CLT, THOUGH NOT PRODUCING PANELS, LIKE EURBAN (B)

Muszynski et al., 2021, cited above

On 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.

British company Eurban was one of the earliest examples of a vertically integrated company offering panelized construction services but outsourcing the production and fabrication of MTPs (**Figure 10.7b**). Eurban mass timber/CLT projects realized in the United Kingdom use imported CLT prefabricated specifically for the projects.[42] 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 BASIC LOGISTICS[43]

One of the less discussed aspects of the MTP industry is its peculiar logistic calculus. Although projects are being routinely shipped, even on long-distance intercontinental routes, it is still not clear what the optimal location for a manufacturing operation would be along its complicated supply and value chains. However, we believe that

42 Eurban. Accessed Jan. 12, 2025, at http://www.eurban.co.uk/.

43 Based on Sparr M., L. Muszyński, 2024, cited above.

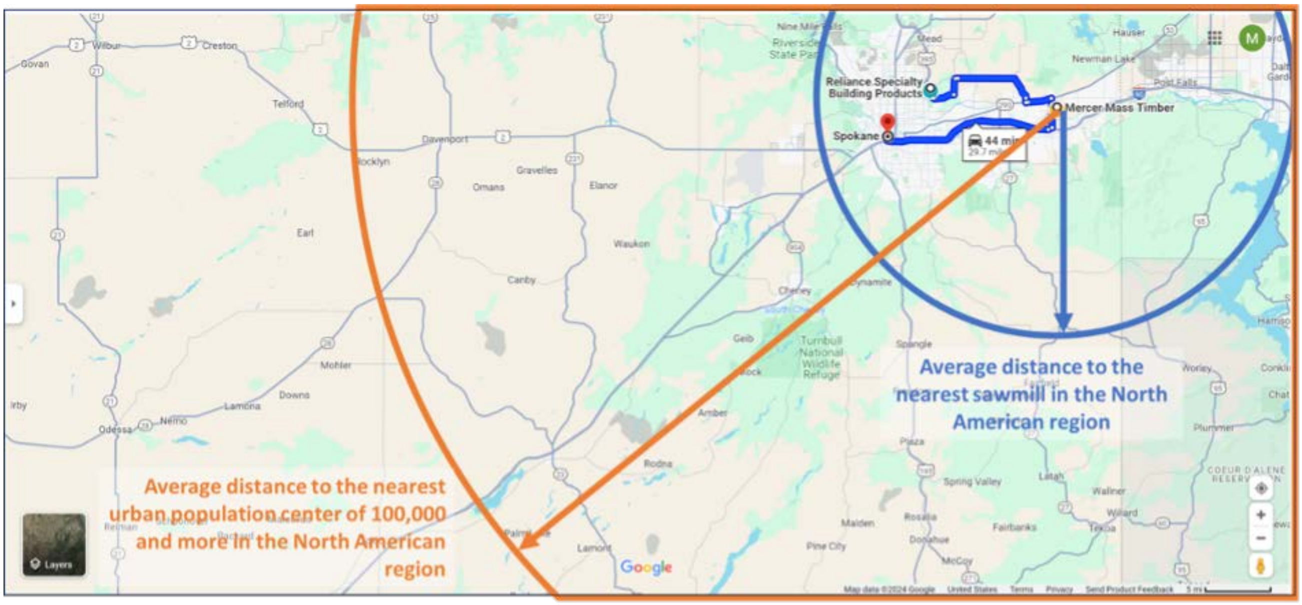


FIGURE 10.8: AN EXAMPLE OF A CLT MANUFACTURING PLANT LOCATION INDICATING ACTUAL DISTANCES TO THE NEAREST SAWMILL AND TO THE NEAREST URBAN POPULATION CENTER OF 100,000 OR MORE; THE BLUE CIRCLE INDICATES THE AVERAGE DISTANCES TO THE NEAREST SAWMILL, AND THE ORANGE LINE, THE AVERAGE DISTANCE TO THE CLOSEST URBAN CENTER FOR ALL MTP PRODUCTION LINES IN THE REGION (NORTH AMERICA)

clues can be inferred from an analysis of existing global mass timber operations.

For this exercise, known locations of MTP manufacturing facilities across the globe were used to identify locations of the closest urban centers with a population over 100,000 and the closest sawmill. Driving distances were determined using Google Maps functions. Sawmill locations in non-English-speaking countries were found by searching for a range of possible synonym keywords in the local languages, then confirming the location with a satellite picture (looking for log yards) and related company web pages.

An example of a CLT manufacturing plant location indicating driving distances approximated by Google Maps tools to the nearest sawmill and the nearest urban population center over 100,000 is shown in **Figure 10.8**.

In addition, the reference distances, or the mean distances to the nearest sawmill (marked as a blue circle on **Figure 10.8**), and to the nearest urban center of 100,000 or more for regions (marked as an orange circle on **Figure 10.8**) were calculated and compared to the global average in **Figure 10.9a**. For broader context, total populations within the reference distance from the manufacturing lines were also determined using Global Human Settlement Layer (GHSL), reflecting European program Copernicus data[44] applied in the maps.ie web tool.[45] The mean distances for regions were compared to the global average (**Figure 10.9b**). Fractions of MTP lines within the reference distance (cutoff radius) from the nearest

44 GHSL: Global Human Settlement Layer. Accessed June 1, 2024, at https://human-settlement.emergency.copernicus.eu/.

45 Maps.ie. Accessed June 1, 2024, at https://www.maps.ie/population/.

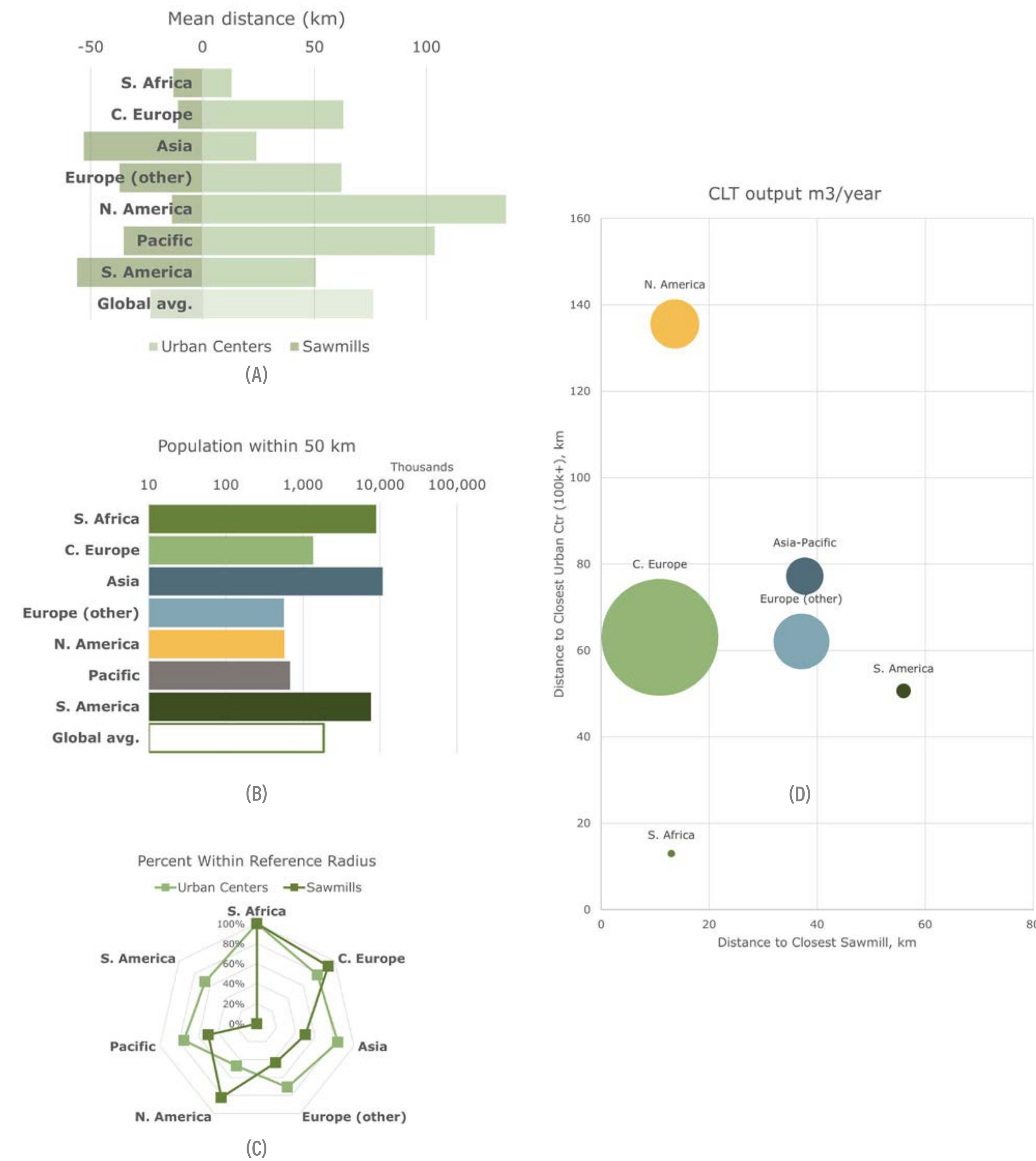


FIGURE 10.9: MEAN DISTANCES TO THE NEAREST SAWMILL (BLUE BARS) AND THE NEAREST URBAN CENTER OF 100,000 OR MORE FOR REGIONS COMPARED TO GLOBAL AVERAGE (A), TOTAL POPULATIONS WITHIN THE REFERENCE DISTANCE FROM THE MANUFACTURING LINES IN REGIONS COMPARED TO GLOBAL AVERAGE (B), PERCENT OF LINES WITHIN THE REFERENCE (CUTOFF) DISTANCE FROM THE NEAREST SAWMILL AND URBAN CENTERS IN REGIONS (C), AND COMPARISON OF MEAN ANNUAL OUTPUT (THE SIZE OF THE BLOB), CORRELATED WITH THE MEAN DISTANCES TO THE NEAREST SAWMILL AND POPULATION CENTER BY REGIONS (D)

sawmill and urban centers in regions are shown in the graph in **Figure 10.9c**. Finally, the blob-graph in **Figure 10.9d** represents a comparison of mean annual output, represented by the size of the blob, correlated with the reference distances to the nearest sawmill and population center.

Although the method is somewhat crude and the detailed analysis is pending at the time of the publication, the following major observations can be offered:

1. The locations of the CLT manufacturing plants between the nearest population centers and nearest sawmills vary substantially across the global CLT manufacturing regions.
2. Except for plants in continental Asia, on average the CLT plants tend to be closer to the nearest sawmills than to the nearest population centers. (Distances to the nearest sawmills could not readily be found for CLT plants in China.)
3. The total population within the mean average radius to the nearest population center varies significantly by region (exceeding 1 million in Asia, Central Europe, South America, and South Africa).
4. There is no apparent correlation between the distances from the CLT plants to the nearest sawmill/urban center and the average annual production volume in the region.
5. In the most successful Central European region, the average distances from the CLT plant to the nearest sawmill (11 kilometers) and to the nearest population center (63 kilometers) are somewhat shorter than the global mean distances (23 kilometers and 76 kilometers, respectively) and substantially shorter than outside of that region (56 kilometers and 84 kilometers, respectively). North American companies, on the other hand, tend to be much farther from the nearest urban centers (136 kilometers) than companies in other regions (global mean is 76 kilometers).

10.8 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 10.10a**), while the annual per-shift capacities vary from less than 500 cubic meters to 70,000 cubic meters for structural products and to 110,000 cubic meters for commodity access and rig mats (**Figure 10.10b**). The bars show estimated volumes of finished products contributed by manufacturers in 2024 in 5 volume segments (**Figure 10.10a**) and volumes produced by manufacturers in 5 annual per-shift capacity segments (**Figure 10.10b**). The numbers above the graphs indicate the number of manufacturing lines in each segment for which the relevant volumes and capacities are known at the time of the publication.

Compared to the 2024 tally presented last year, more lines are producing less than 10,000 cu-

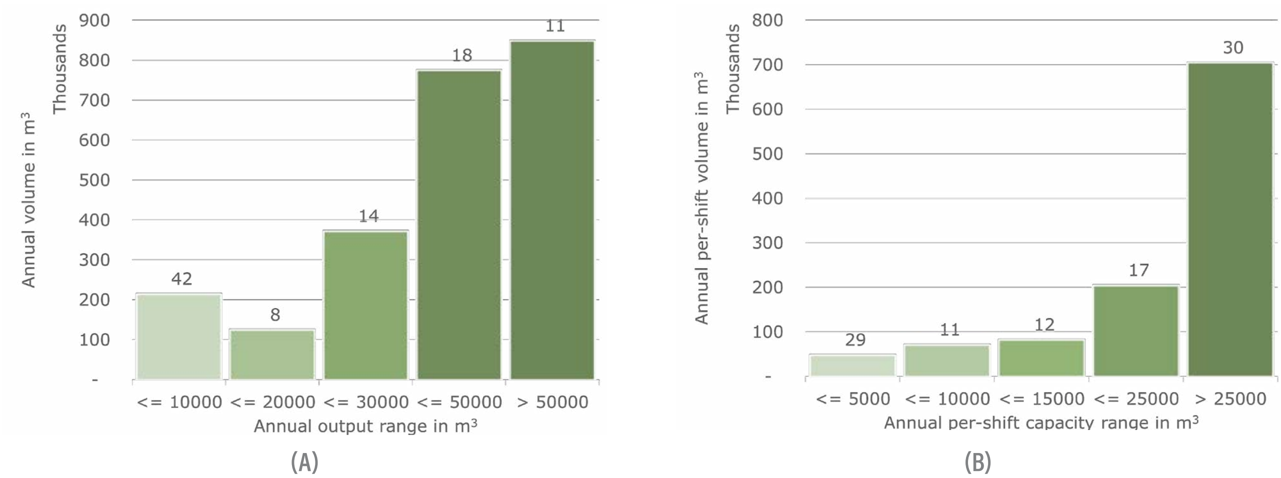


FIGURE 10.10: ANNUAL PRODUCTION VOLUMES (A) AND ANNUAL PER-SHIFT CAPACITY (B) ALLOCATED TO CLT LINES REPRESENTING A RANGE OF PRODUCTION CAPACITY REPRESENTED BY BARS; THE NUMBER OF PRODUCTION LINES IN EACH CATEGORY IS PROVIDED ABOVE EACH BAR

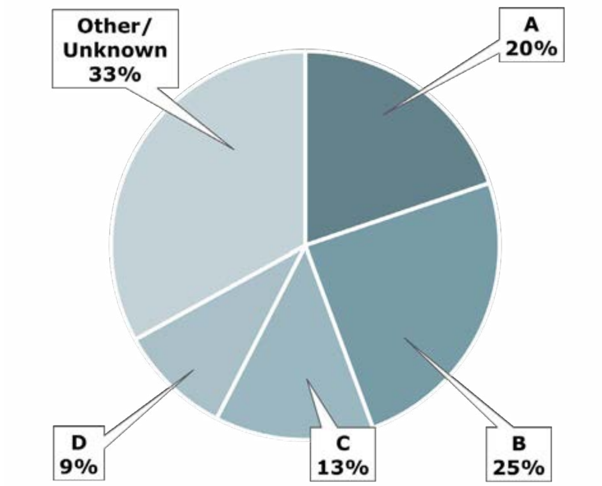
Based on Muszyński et al., 2017, cited above.

bic meters of CLT (45 today compared with 38 reported in 2024), probably marking new lines gradually increasing their production toward the nominal per-shift capacity and lines recovering from disruptions. The increase in number of lines contributing between 30,000 and 50,000 cubic meters in 2024 (19 today compared with 14 reported in 2024) is likely showing the other side of this process: companies reaching their potential. However, the graph in **Figure 10.10b** indicates that the majority of the new lines aim at production in the highest-capacity segment.

It should be noted, however, that not all companies use their production capacity to the same degree. This is consistent with the noncommodity character of the industry. Full saturation of any line's potential requires securing a steady stream of projects and executing them with high efficiency.

This efficiency is sought through increasing levels of smart automation of the manufacturing process and high levels of integration of internal line logistics. Almost all new CLT plants added in the past 5 years have opted for specialized equipment solutions offered by an increasing number of dedicated hardware manufacturers and integrators. Close collaboration between CLT manufacturers and industrial hardware companies brings innovative solutions aimed at reducing bottlenecks and waste. At least 4 of the new lines launched in Central Europe opted for edge-bonding entire layers before lay-up, trading additional hardware for cuts in lay-up time and trimming losses, and a much simplified final pressing operation. Before, just one company had practiced such a solution.

Two out of three presses installed are fabricated by one of four specialized European manufacturers (**Figure 10.11a**). A similar proportion of all installed CNC centers we know about are fabricated by just two leading European manufacturers (**Figure 10.11b**). That trend applies to the oldest and largest CLT companies as they gradually upgrade their lines or add new lines to meet the increased demand for capacity.



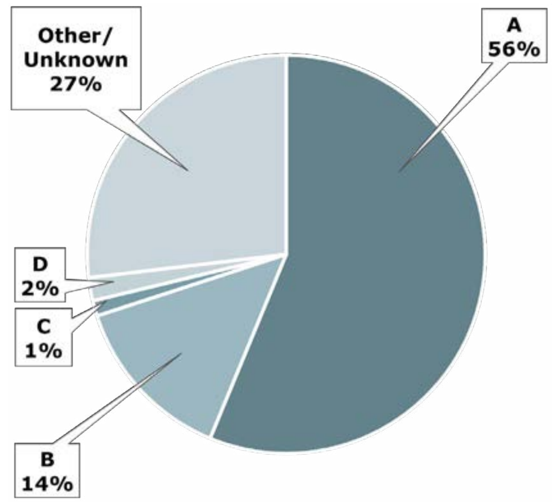


FIGURE 10.11: SHARES OF KNOWN CLT LINES EQUIPPED WITH PRESSES (A) AND CNC FINISHING CENTERS (B) MANUFACTURED BY THE 4 LEADING PROVIDERS OF PRESS LINES AND COMPLETE TURNKEY INTEGRATED PRODUCTION LINES

An increasing number of companies build and operate new plants in different locations, including some that are expanding to foreign markets within Europe. We know of one Austrian company acquiring an existing CLT plant in Canada. With the major Alpine players being very successful in pursuing projects in foreign markets outside Europe, it is reasonable to assume that intercontinental investment is not far away.

10.9 GAUGING MTP POTENTIAL IN REGIONS[46]

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 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.[47]

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. The differences may be indicative of the potential development of the MTP industry in these other regions.

46 Eurban. Accessed Jan. 12, 2025, at http://www.eurban.co.uk/.

47 Muszyński, L., 2021, cited above.

10.10 SUMMARY AND CONCLUSIONS

Overall, the global CLT industry continued growing production capacity, though the growth was somewhat slower than in the past decade. Fewer new lines have been announced. In the North American region, recovery from the setbacks experienced in 2021 to 2023 that led to closures, suspensions, or reorganizations of 3 major CLT-producing companies has been slow but steady. A new high-capacity line has been announced in the Pacific Northwest.

The global MTP industry still seems to be far from maturity, and the actual impact on the construction sector lags far behind the hype in the excited communities along its supply chain. Most of the industry is still serving the higher end of the construction market, which seems less vulnerable to the tectonic shifts in global economies triggered by the global pandemic, war in Ukraine, and other disruptions. However, the volatility touches some elements of the complex supply and value chains of the global MTP industry more than others.

10.11 ACKNOWLEDGMENTS

This project was funded by the US Department of Agriculture's (USDA) Agricultural Research Service (ARS) program. Additional support was provided by the TallWood Design Institute and Softwood Export Council. The authors also acknowledge the support of Dr. Xu Fang (Softwood Export Council, China), Ms. Tomoko Igarashi and Mr. Yuichi Hayashi (American Softwoods, Japan), and Mr. Günther Jauk (Holzkurier/Timber-Online), and all the mass timber panel companies that agreed to host a site tour or grant an interview.

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After harvest: Vaagen Timbers

THE MƏXIŁP HOME IS CONSTRUCTED WITH CLT WALLS AND GLULAM ROOF AND FLOOR
Source: CedarStone Design & Build; Credit: Vignesh Madhavan

CASE STUDY: MƏXIŁP HOME

MƏXIŁP HOME: PIONEERING SUSTAINABLE HOUSING IN PACIFIC NORTHWEST

PROJECT OWNER: ERIC NILL

PROJECT LOCATION: 2578 HARRIS ALLEY, EUGENE, OR 97402

COMPLETION DATE: JUNE 26, 2024

ARCHITECT/DESIGNER: CEDARSTONE DESIGN & BUILD

MASS TIMBER ENGINEER/MANUFACTURER: VAAGEN TIMBERS

GENERAL CONTRACTOR: CEDARSTONE DESIGN & BUILD

STRUCTURAL ENGINEER: ASPECT STRUCTURAL ENGINEER

MECHANICAL, ELECTRICAL, AND PLUMBING: CLIMATIZE, ADVANCED ENERGY SYSTEMS, SIGNATURE PLUMBING

THIS MASS TIMBER house marks the debut of the Məxiłp Home as part of the preapproved accessory dwelling unit (ADU) program for the City of Eugene, Oregon. This is a significant milestone as it is the first Cross-Laminated Timber (CLT) home to be preapproved as an ADU in Eugene. The Məxiłp Home, which draws its name from the Syilx word for “cedar,” is a testament to CedarStone’s commitment to sustainable building and cultural heritage as an Indigenous-owned company.

This innovative project is a collaboration between CedarStone and Advanced Energy Systems, a re-

LEFT — THE INTERIOR OF THE MƏXIɫP HOME
RIGHT — MƏXIɫP HOME IS THE FIRST CLT HOME TO BE PREAPPROVED AS AN ADU IN EUGENE, OREGON
Source: CedarStone Design & Build; Credit: Vignesh Madhavan

nowned Oregon-based solar photovoltaic company. The Məxiɫp Home has been awarded Earth Advantage Platinum and Net Zero Energy certifications, setting a new standard in energy-efficient housing.

Supported by the Northwest Native Chamber and the National Association of Minority Contractors, CedarStone designed and built the home with a truly craftsmanlike interior. Creative detailing celebrates the mass timber structure. Cherry spline details and trim, concealed electrical systems, a design that harnesses natural light, ventilation, and a layout to support healthy family life over many generations are some of the design moves that make the home so beautiful. It features Shou Sugi Ban siding, metal roofing, graphite polystyrene (GPS) insulation, and a finished colored slab-on-grade foundation. Durability, longevity, beauty, health, safety, constructability, and affordability are all layered into this project.

The Məxiɫp Home is constructed with CLT walls and glulam roof and floor, and all panels had to be carefully maneuvered down the narrow alley access, requiring additional innovation with regard to installation. The structure was erected in 3 ½ days.

This mass timber house is a prototype for what CedarStone has in store. CedarStone is currently opening a facility to streamline many of the processes that went into this Harris Alley build via increased and improved methods of prefabrication.

This case study has not been fact-checked, but it has been edited for length, clarity, grammar, and style.

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 we chose to address what we feel were 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 https://masstimberconference.com/report/.

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 we 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 and 9 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 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 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 for more details.

carbon storage — the carbon stored in wood as it's used in a building. Refer to chapter 9 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 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 parks, 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 — having the ability to absorb moisture from the environment. Refer to chapters 5 and 7 for more details.

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 — a 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, multi-trade 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 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 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 Life Cycle Analysis (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

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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.

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Emily is a mass timber architect advancing structural technology through built and industry-scale projects. Her mission is to make buildings behave more like plants and industries more like forests. The last half of her 22 years in practice has focused on mass timber and modular structural systems. Leading innovation in multiple sectors has given her a broad view of the industry and a passion for breaking boundaries. She writes the building industry and carbon chapters for the annual *International Mass Timber Report*. Emily owns and runs her product innovation company, Single Widget, and her consulting firm, Field Edge, out of Portland, Oregon.

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Will is passionate about strategy and aligning teams to get them from A to B. Working with his clients wakes him up at strange hours with a huge grin on his face. After a decade managing international campaigns for nonprofits and foundations, Will founded +coordinates in 2002. He has served as a program officer at the David and Lucile Packard Foundation, a campaign manager at World Wildlife Fund, and was the founding executive director of #forest proud from 2017-2020, where he conceived and implemented video feature projects highlighting the work of Susan Jones, Michael Green, Katerra, Sidewalk Labs, and the Freres Brothers.

LECH MUSZYNSKI

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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.

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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.

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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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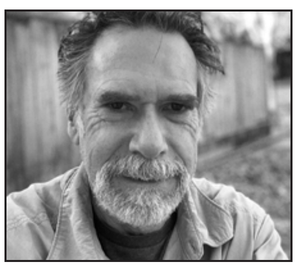

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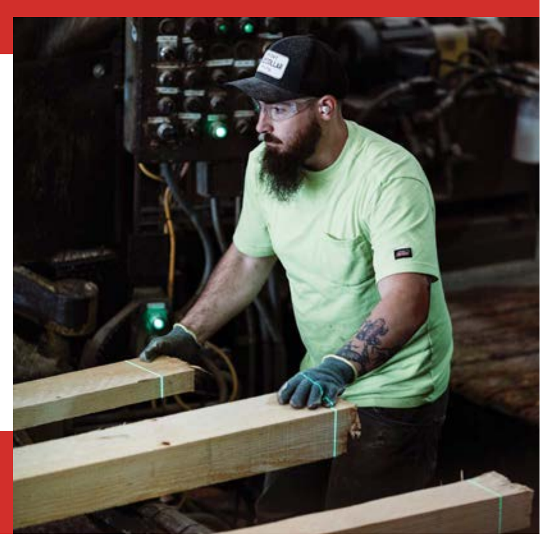

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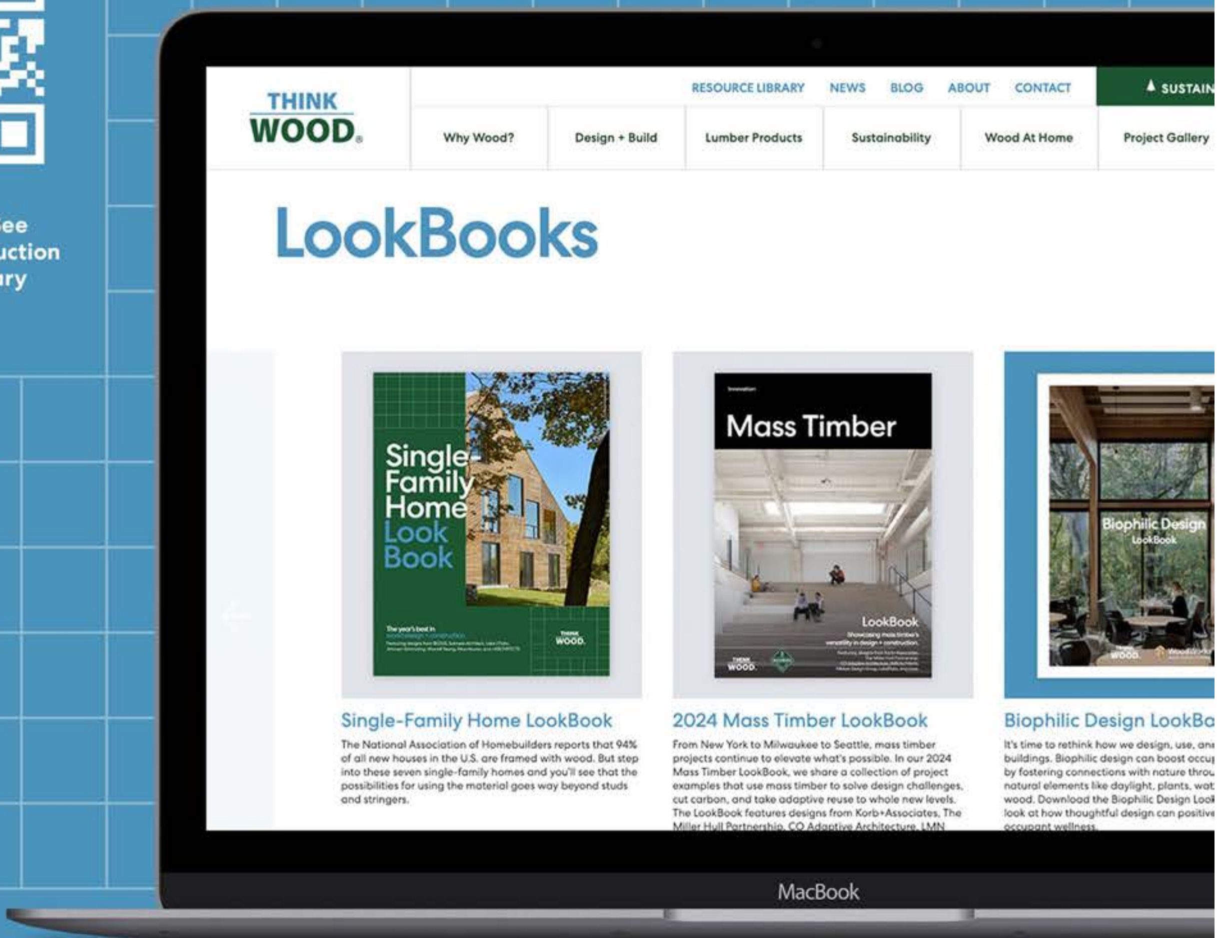

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