2021

INTERNATIONAL
MASS TIMBER REPORT

Editing by Self-Publishing Services LLC Formatting by Meld Media
Cover Photo Credit: B&K Structures, UK

978-1-7337546-4-4 (print)
978-1-7337546-5-1 (ebook)

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The work upon which this document is based was funded in part through a cooperative agreement with the US Forest Service, Wood Innovations Grants. The US Forest Service is an equal opportunity provider, employer, and lender.

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On the cover

B&K STRUCTURES, UK

Under its banner of Believe in Better Building (BiBB), BSkyB's new educational facility for graduates, apprentices, and staff reflects the company's aspirations for sustainability. Based at the Campus in Osterley, West London, the 3,800 m² development encompasses a three-story linear building with an additional story accommodating a restaurant and roof terrace—all providing inviting multifunctional amenities.

OPTIMIZED HYBRID STRUCTURE: Mace appointed B&K Structures to provide an optimized hybrid structure for the build, comprising a glulam frame with Cross-Laminated Timber (CLT) floor, roof, and stability walls, together with perimeter wall cassettes. The structure was designed to deliver permanent quality, adaptability, and long-term energy efficiency to meet sustainability objectives. The project was to be completed in time for BSkyB's 25th anniversary celebration, making speed and ease of construction vital. It was important, however, to not compromise on the quality of design and materials.

MAIN CONTRACTOR: MACE
CLIENT: BSKYB
ARCHITECTS: ARUP ASSOCIATES
STRUCTURAL ENGINEER: ARUP ASSOCIATES
STRUCTURAL FRAME PROVIDER: B&K STRUCTURES
PRODUCTS: GLULAM, CLT, STEEL, CASSETTES PANEL SYSTEM

SPONSOR SPOTLIGHT: *Thanks to Weyerhaeuser for their support, which helped make this report possible.*

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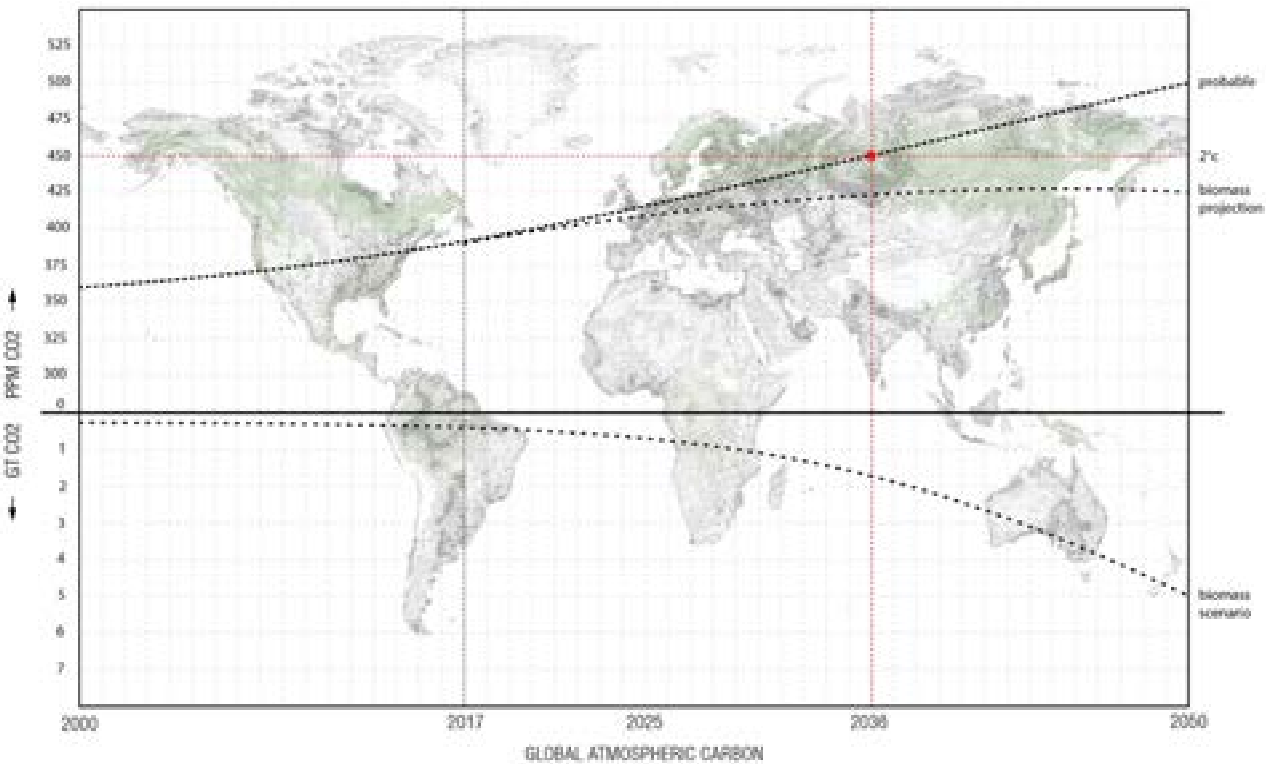
Acknowledgments

The authors would like to thank the following companies and organizations for their contribution of information and insights toward the development of this report and the advancement of the mass timber sector.

TABLE OF CONTENTS

THE MASS TIMBER EFFECT

Globally, the number of mass timber buildings will double every two years. The result is that the North American building industry will store more carbon than it emits by the year 2034.



Mass Timber, Forest Health, and Climate Change

- Carbon emissions are recognized as the leading cause of climate change. Projections suggest that we may experience an irreversible average increase in global temperature of 2 degrees Celsius (approximately 3 to 4 degrees Fahrenheit) within 20 years, at the current rate of carbon release into the atmosphere.
- Carbon emissions from the building sector are a major contributor to the climate change equation, far larger than either the transportation or industrial sectors alone.
- The rapid development of mass timber products is creating more opportunities for the use of wood in place of steel and concrete in commercial and multifamily residential construction.
- Science is demonstrating that substituting wood for steel and concrete in construction can substantially reduce total carbon output and actually reduce existing carbon in the atmosphere through carbon sequestration.
- Accelerating the adoption of mass timber to replace concrete and steel in commercial and multi-family residential construction can effectively reduce the amount of carbon in the atmosphere and have a significant impact on reversing climate change.

THE GLOBAL MASS TIMBER PANEL INDUSTRY IN 2020

Lech Muszynski[1]

0.0 INTRODUCTION

The mass timber panel industry, most prominently exemplified by cross-laminated timber (CLT), is a new phenomenon. It integrates elements of mass timber design, manufacturing technologies, and construction and has not followed typical commodity-oriented forest products industry models. In fact, it would be difficult to point to an adequate precedent. Organic development of the global mass timber industry over the last 25 years 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. Existing global mass timber operations offer a living laboratory that provides an understanding of both the current state of the industry and its trajectory and future development. Especially important are insights in how newly emerging markets may develop.

0.1 SOURCES OF INFORMATION

The information on the mass timber panel industry presented here is derived from three major sources: 1) industry surveys; 2) targeted site tours of mass timber manufacturing lines; and 3) review of trade journals tracking the development of the industry and public web profiles of mass timber panel companies and hardware manufacturers. Wherever possible, the data obtained from different sources were verified against each other.

To ensure confidentiality, information is presented in aggregate format, and, when discussing regional differences, the data is parsed by large regions that are defined in a way to avoid exposing information from a single manufacturer (**Figure 1**). The regions were decided based on geographic locations and concentration of companies, leading to the division of Europe into two mass timber panel producing regions: Central Europe (sometimes referred to as Alpine Region, which includes Austria, Switzerland, Germany, Italy, and, notably, Czechia); and Other European countries (rarely covered in trade literature summaries). Outside Europe, the mass timber panel producing countries are divided in four large regions: North America (including the US and Canada); South America (including Chile and Brazil); Asia-Pacific (including Japan, Australia, and New Zealand); and Africa, which is represented by one plant in South Africa that agreed to share related information openly [4]. At present, there is not enough data on commercial mass timber panel production in China to include it in the tally.

0.2 CLT AND OTHER EMERGING MASS TIMBER PANEL TECHNOLOGIES IN CENTRAL EUROPE[2]

The report is primarily concerned with CLT because it is the most widely known mass timber panel product. It is comprised of cross-layered pieces of

1 Based on work co-authored with P. Larasatie, J.E. Martinez Guerrero, R. Albee, E.N. Hansen [9][1][13][10][20].
2 This part is an updated version of a content contributed by LM to [1].

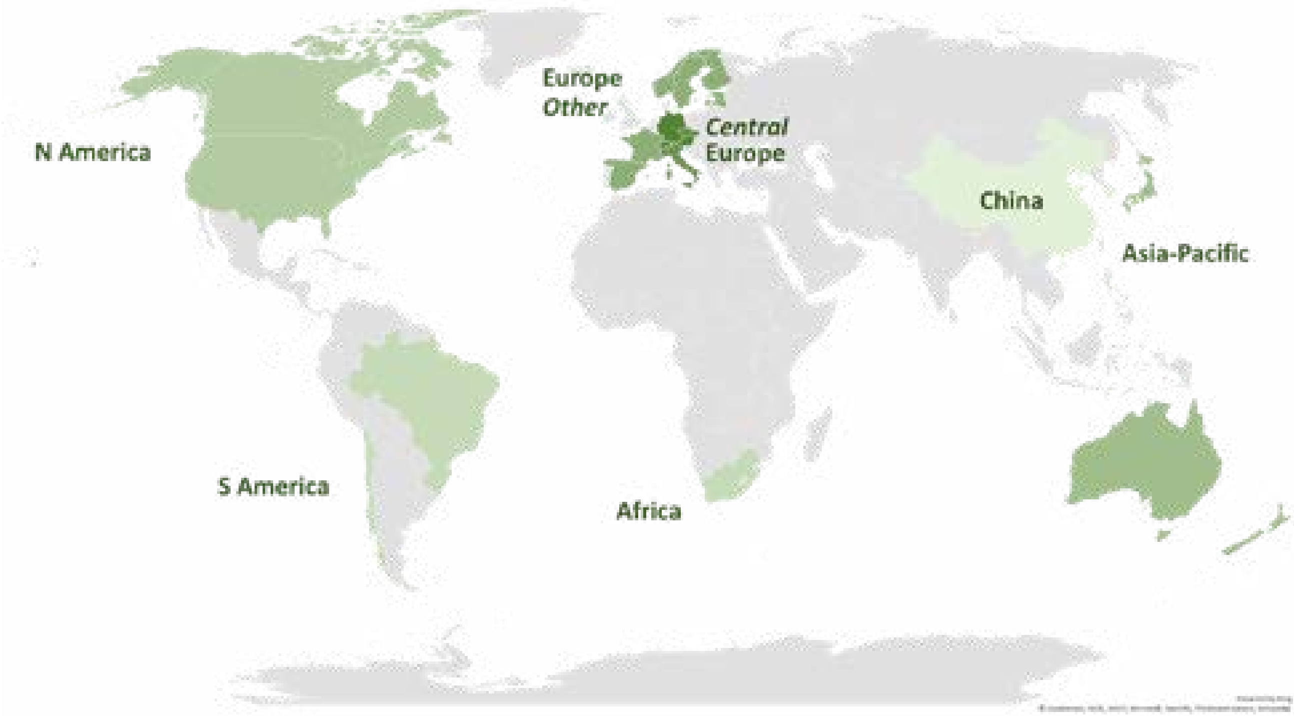


FIGURE 1: MASS TIMBER PANEL PRODUCING REGIONS.

dimension lumber or structural composite lumber (SCL) bound together by structural adhesives [14]. However, one of the interesting developments in the mass timber panel industry is an 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. Although the most obvious distinction among these three is the way the layers are bonded together, they also differ substantially in raw material sourcing, manufacturing technologies, load bearing capacities, and, consequently, in the scope of potential uses. The similarities and differences will be briefly discussed in the sections below.

0.2.1 NAIL-BONDED SOLID WOOD WALL

A nail-bonded solid wood wall, or Massiv-Holz-Mauer (MHM), is a massive, prefabricated CLT panel with layers made of rough sawn boards that are bonded with nails. 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 each other. The nail-bonded MHM (literally mass-wood-wall) technology might have predated the development of the adhesive-bonded CLT, but the real breakthrough came with a solid wood wall system patented in Germany in 2005[8][9]. MHM is fabricated on small-scale, turnkey, three-step Hundegger production lines. The lines consist of specialized molders to produce longitudinal grooves on one side of the laminations, an automated lay-up and nailing station, and a 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 mm or 10/16 inch). The intended use of this product is as load-bearing and division walls for low-rise buildings in moderate exposure to moisture (below 20%) and at low to moderate exposure to corrosion [9].

There are more than 30 licensed MHM plants across Europe, and in 2017, the latest assessment, their total output was about 73 thousand cubic meters (or over 56 MMBF *of the North American dimensional lumber equivalent) [21].*

0.2.2 DOWEL-BONDED CLT

Dowel-bonded CLT is a massive, prefabricated cross-laminated panel with layers of rough sawn boards bonded with hardwood dowels. This is the latest of the CLT products and should not be confused with one marketed in North America as Dowel-Laminated Timber (DLT), for use as beams and floor panels in timber structures, where all layers are oriented parallel to each other. The low moisture content and tight fitting of the dowels at the time of assembly assures a durable tight connection once the dowels swell as they gain moisture in the ambient conditions. The panels are assembled in highly automated lines. Only two commercially successful systems are known to date: 1) developed by Thoma Holz100 (or Wood 100) company in Austria [10]; and 2) developed by Swiss industrial hardware manufacturer TechnoWood [11]. By mid-2019, TechnoWood had installed 8 highly automated lines in Europe. Unlike other CLT products, some layers of the dowel-bonded CLT are arranged at 45 or 60 degrees to the surface layer direction. The dowel-laminated CLT panels are intended for use as load-bearing wall, floor, and roof panels in low-rise (up to 4-story) timber structures [12].

0.3 SUPPLY CHAIN AND MARKET STRUCTURE[3]

It is important to stress again that the mass timber industry is an exception to the traditional commodity-oriented forest products industry at large, even if one compares it to other sophisticated Engineered Wood Products (EWP) such as glulam, Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL), or I-joists.

0.3.1 GENERAL COMMENTS

All structural CLT panels discussed here are specialty products, by which we understand that all panels are custom produced and fabricated for specific projects. If one does not count glulam decks and unidirectional Nail or Dowel Laminated Timber panels (NLT/DLT), prefabricated mass-timber structural panels have no serious precedent in timber construction, offering new opportunities in design and construction to professionals intimately familiar with the products. It is, however, very similar to the precast concrete industry in that it produces premanufactured components and delivers them to address specific project requirements.

Historically, however, companies have had strong incentives 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 of the industry, and panel production becomes a stage in a process that begins with project commission and ends with closing the shell of a building. In reality, the level of vertical integration varies substantially, both among and within the three products discussed.

3 This part is an updated version of a content contributed by LM to [1].

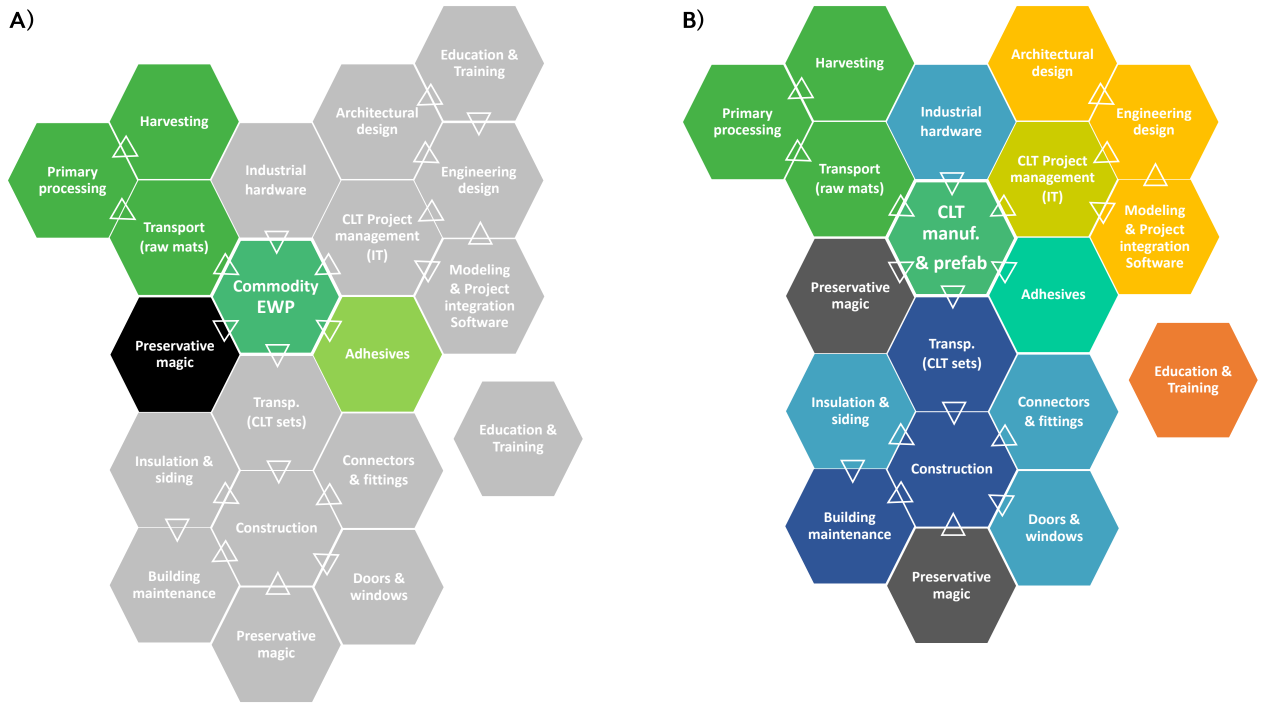


FIGURE 2: TYPICAL SUPPLY/VALUE CHAIN MODEL OF AN EWP COMPANY (A) COMPARED TO A POSSIBLE SUPPLY/VALUE CHAIN OF A CLT COMPANY WHERE THE FINAL PRODUCT IS A BUILDING (B).

Another common theme is the existence of intrinsic barriers that prevent commoditization of massive CLT panels, even in the most-developed markets. The principal issues are the large dimensions (up to 13 feet x 65 feet) and mass (up to 5.5 metric tons), as well as the embedded value of individual panels. Currently, it simply does not make much sense for anyone in the industry to carry the cost of the intermittent storage and the waste generated if standard-sized panels would have to be substantially trimmed for specific projects. Producing prefabricated panels, finished for a specific design and on-time delivery to the construction site, is, for the time being, the most efficient solution. There are, however, companies that are starting to offer prefabrication services on "commoditized panels," but it remains to be seen how they will fare. This issue is further discussed in Chapter 4.

Because of these circumstances, the mass timber panel industry is still—and may remain for the foreseeable future—a specialty industry, with products delivered to the market not as panels but as building shells or even finished buildings.

Compared to Engineered Wood Products (EWP), therefore, the value chain of mass timber panel products is much more complex. It necessarily involves architectural firms that serve as sort of external project acquisition gates to the process, civil engineering offices, and project management on one side; and specialized connectors manufacturers, insulation and siding products, and construction crews on the other (**Figure 2**).

Most CLT and all dowel-bonded CLT producing companies show some level of vertical integration within their complex value chains. The most common model is integrating the engineering detailing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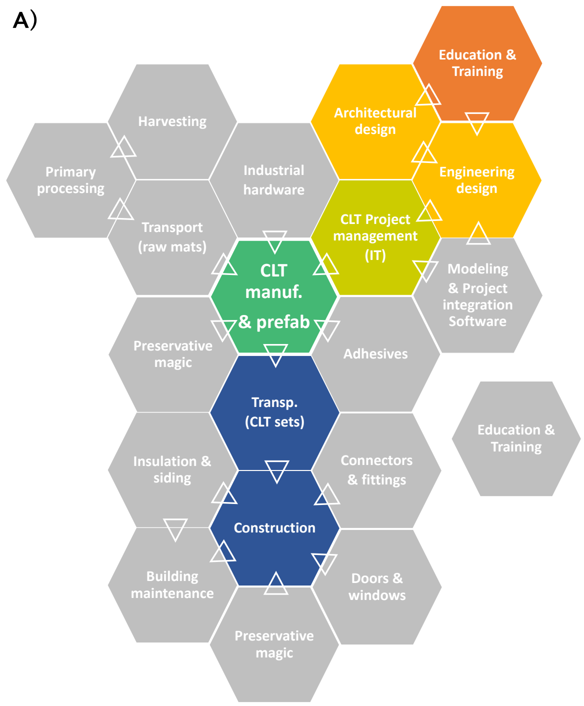

FIGURE 3: A COMMON SCHEME OF VERTICAL INTEGRATION OF CLT COMPANIES (A) AND AN EXAMPLE OF A VERTICAL INTEGRATION OF COMPANIES SPECIALIZED IN BUILDING WITH CLT, THOUGH NOT PRODUCING PANELS, LIKE EURBAN [13] (B).

services and a level of project management, while other services are outsourced to closely allied partner companies familiar with the technology. However, there are companies that offer architectural design offices; transportation; construction services (**Figure 3a**); customized connectors, pre-installation; and, in one case, custom manufacturing of their own windows/doors, floor finishes, insulation, and external siding [1][4]. Some companies own forestlands and sawmills [9]. On the other extreme, there are also a few small-scale companies that focus exclusively on fabricating panels for external orders, outsourcing all other functions to the parent companies. Examples may be found in Japan and Finland.

A quite famous example of a vertically integrated company offering construction services in mass timber panels sourced from external manufacturers is Eurban, which operates in Great Britain (**Figure 3**). To-date, Eurban claims 311 mass timber/CLT projects realized in the UK, all from imported CLT prefabricated specifically for the projects [13]. Although this may be an indicator of 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.

0.4 RAW MATERIAL SOURCING

Raw material use has to be considered separately for the three types of mass timber panels defined above (CLT, MHM, and dowel-bonded CLT).

CLT production in North America is regulated by a prescriptive ANSI/APA PRG320 standard [14] that regulates the grades and dimensions of lumber used as lamstock. The minimum requirement for the layers aligned with the principle loading

A)

B)

FIGURE 4: A SECTION OF MHM SHOWING LONGITUDINAL GROOVES IN LAMINATIONS INTENDED TO ENHANCE THE THERMAL-INSULATION PROPERTIES OF THE PANELS [19] (A) AND A DOWEL LAMINATED PANEL SHOWING THE 60-DEGREE LAYER

Photo Credit: L.Muszynski

direction is visual grade No. 2 or better, and for the transverse pieces No. 3 or better (see Chapter 3 for additional details). While both grades allow certain amount of wane, manufacturers tend to use perfectly square pieces because wane pockets in the panels form water catchment wells at construction sites. It follows that logs with diameters too small to produce a substantial volume of lumber free of wane may not be favored.

MHM and dowel-bonded CLT, on the other hand, are not regulated by any product standards. In some European countries, they can be used in low-rise structures based on European Technical Approval certificates issued to individual manufacturers (see, for instance, reference [9]). The panels are not nearly as airtight as adhesive-bonded CLT, and so wane is not perceived as a substantial problem.

MHM uses rough sawn boards rather than nominal 2x stock. The surface is not considered for visual quality. That means that there should be greater potential for utilization of lumber of lower quality than that required for adhesive-bonded CLT. It also makes it more likely for this technology to be able to utilize lumber sawn from small-diameter logs. Laminations are grooved on one side along the grains to increase the thermal insulation of the panel (**Figure 4a**). The final thickness of grooved laminations is about 16.5 mm (10/16 inch).

Dowel-bonded CLT uses rough sawn lumber in core layers, but dressed lumber is needed for the face layers that often are meant to be visible in structures. Also, bonding with dowels requires wide-face lumber (likely more than 8 inches) to form two rows of successful dowel bonds in each surface layer. This likely limits the prospect of utilizing small logs (**Figure 4**).

There is no magic in the species selection for mass timber production. Manufacturers tend to tar-

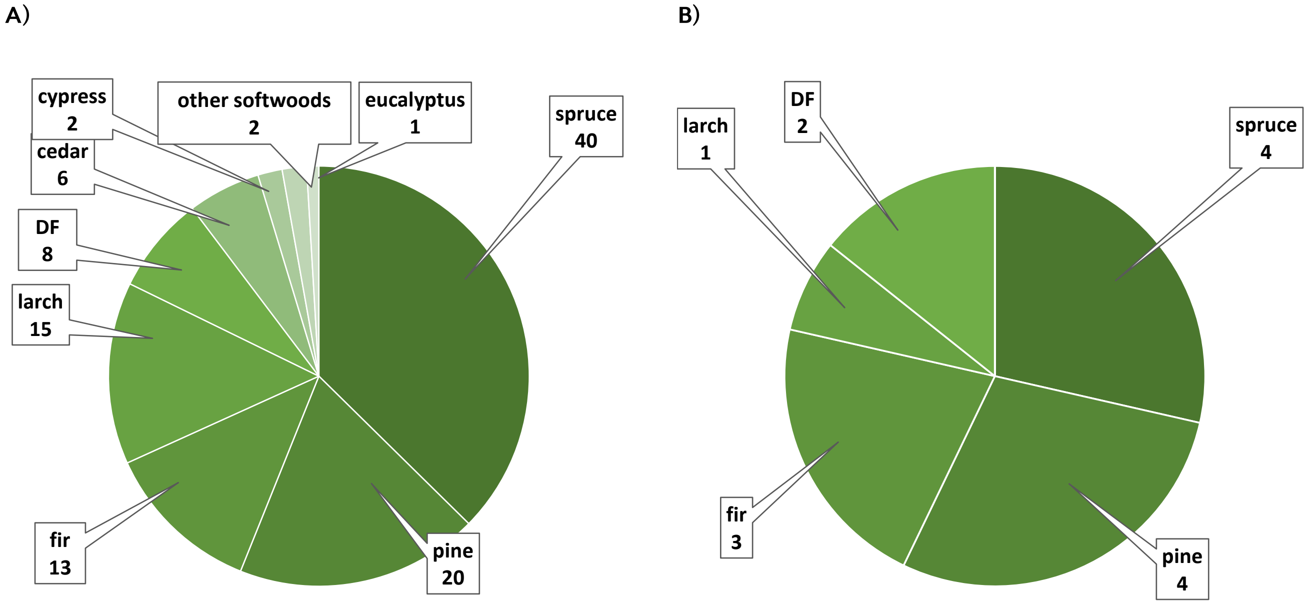

FIGURE 5: NUMBER OF COMPANIES REPORTING USING SPECIES GROUPS (E.G. SPRUCES, PINES, AND FIRS ETC. RATHER THAN SPECIFIC SPECIES) GLOBALLY (A) AND IN THE US (B). NOTE THAT NOT ALL COMPANIES REPOST SPECIES USED IN THEIR MASS TIMBER PANELS. *DF* STANDS FOR DOUGLAS FIR.

get structural grade softwoods available in their region, with some manufacturers occasionally importing lumber from markets that are afar if the prices are favorable. Although we do not have precise information on the volumes 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 groups of species. That is the use of spruces, pines, and firs in general, rather than specific species, as shown in **Figure 5**.

It should be noted here that in most countries outside the Alpine Region, growth of the CLT industry has been encouraged by governments motivated by the desire to find a stable, economically viable outlet for substantial volumes of domestic lumber of lesser quality. The incentive programs used as a tool in these campaigns vary by country in terms of scale, specific form, and duration, and not all are equally successful.

0.5 DIVERSITY IN TECHNOLOGY AND PRODUCTION LINES

Ownership of CLT plants ranges from family enterprises to international holdings. Press types and sizes vary greatly (there is no size standard for CLT panels). And, as mentioned, most CLT companies show some level of vertical integration within their complex value chains.

The scales of operation and the levels of automation vary greatly. Annual production volumes of CLT plants across the globe varied from less than 500 m^3 to over 125,000 m^3 (**Figure 6a**), while the annual per-shift capacities varied from less than 500 m^3 to 110,000 m^3 (**Figure 6b**). Over the past three years, however, an increasing number of new CLT plants have opted for specialized off-the-shelf equipment solutions, characterized by a high capacity, a high level of automation, and an option for full integration of entire lines. These two graphs indicate that not all companies utilize

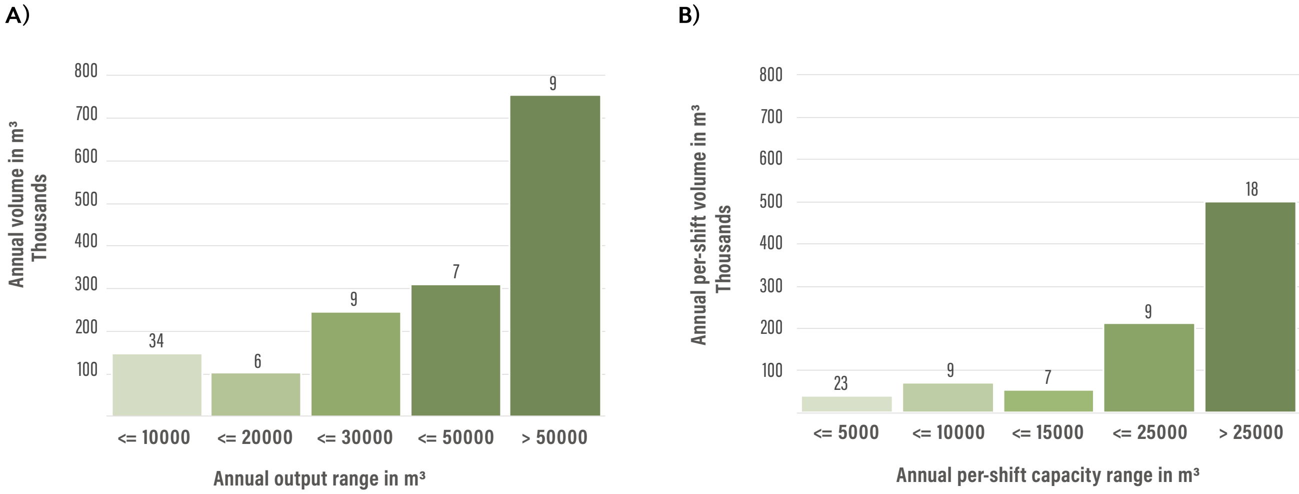

FIGURE 6: ANNUAL PRODUCTION VOLUMES (A) AND ANNUAL PER-SHIFT CAPACITY (B) ALLOCATED TO CLT LINES REPRESENTING A RANGE OF PRODUCTION CAPACITY. THE NUMBER OF PRODUCTION LINES IN EACH CATEGORY PROVIDED ABOVE THE BARS. [4] UPDATED.

their production capacity to the same degree, consistent with the non-commodity character of the industry. This particularly applies to a number of high-capacity plants that were launched in 2020 but did not reach their full production potential in their start-up year or because of pandemic-related issues. Also, the little difference between the a and b figures, suggests that, on average, mass timber plants are currently operating on a one-shift basis.

Currently, two out of three of all presses installed are fabricated by four specialized European manufacturers (**Figure 7a**). Nearly four out of five of all installed CNC centers we know about are fabricated by three leading European manufacturers (**Figure 7b**). As a result, many of the new production lines launched since 2017 are rather similar. That trend applies to the oldest and largest CLT companies in Alpine Europe as they upgrade their lines to meet the demand for increased capacity.

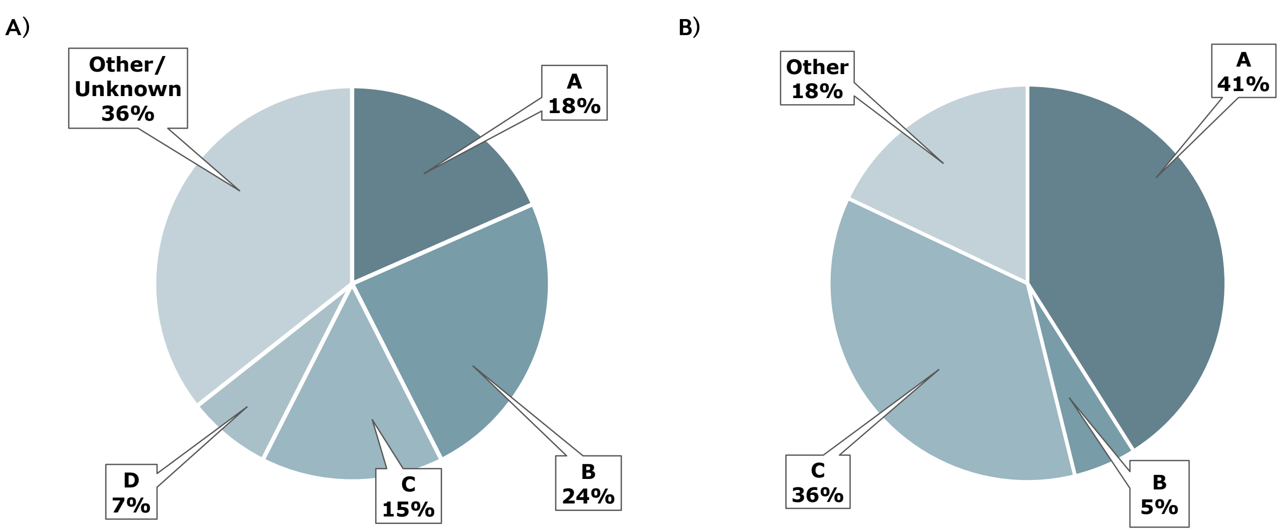

FIGURE 7: SHARES OF KNOWN CLT LINES EQUIPPED WITH PRESSES (A) AND CNC FINISHING CENTERS (B) MANUFACTURED BY THE FOUR LEADING PROVIDERS OF PRESS LINES AND COMPLETE TURNKEY INTEGRATED PRODUCTION LINES.

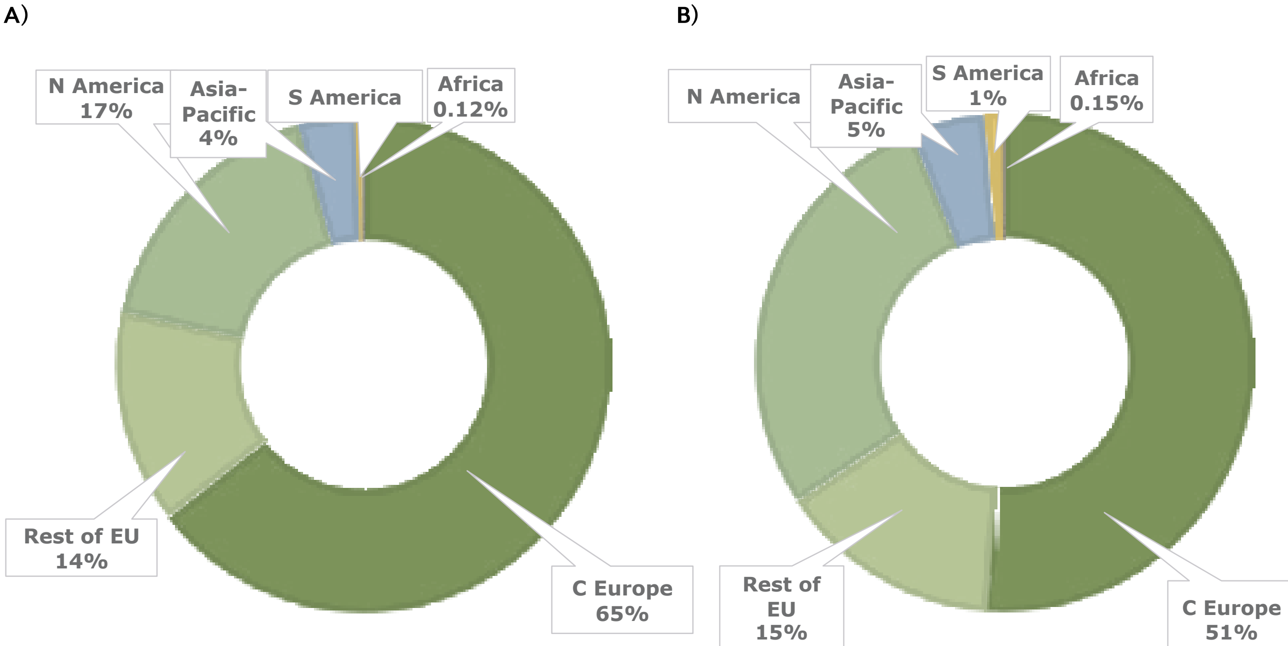

FIGURE 8: REGIONAL DISTRIBUTION OF THE TOTAL GLOBAL CLT OUTPUT VOLUME (A) AND PER-SHIFT CAPACITY (B) (BASED ON [4], UPDATED).

Even though some companies operate more than one line under the same roof, few decide to build another plant in a different location, and even fewer build new production lines in foreign markets. This is true even for the major Alpine Region players that are very successful in pursuing projects in foreign markets. An almost proverbial example is the activity of leading Austrian companies in the Australian market.

“Adhesive-free” cross-laminated panel products that use alternative panel integration systems are on the rise. In Europe, there are about 30 licensed manufacturers of nail-bonded CLT panels marketed as MHM [18] and no fewer than 10 lines producing dowel-bonded panels[10][11].

Since the publication of the first global survey [1], substantial production capacity has been added outside the core Alpine Region of Europe, including new plants in South Africa, Chile, and Brazil, a pilot plant in China, and two short-lived lines in Indonesia. The only continent where no new CLT plants have come online or have at least planned in 2020 has been Antarctica, though we may be reminded that some mass timber panel producing countries have their claims to the frozen continent.

The annual global output of CLT in 2020 that we can attribute to 76 specific production lines is about 1.56 million cubic meters. The global annual per-shift capacity in 2020 is about 1.22 million cubic meters. The Alpine Region still accounts for over 70 percent of the output volume (Jauk, 2019) and nearly 65 percent of the annual per-shift capacity (**Figure 8**). Considering known CLT operations for which the produced volumes/capacities are outdated or currently unavailable, and the number of high-capacity plants that, by pre-pandemic standards, should had reached full capacity in 2020, it is likely that by the end of 2020 the global annual output would have reached 2.0-2.2 million cubic meters.

It should be noted that in North America, a difficult to assess portion of this volume is produced as nonstructural panels for the industrial (access and rig) mat market.

Other mass timber panel manufacturers like MHM, dowel-bonded, cross-laminated panels, and a few other similar products, taken together have likely contributed another 75 thousand cubic meters of panel products to the mass timber panel market in 2019. Figures for 2020 are uncertain.

0.6 MARKET STRUCTURE[4]

As previously described, all structural CLT panels discussed here are specialty products, by which we understand that all panels are custom produced and fabricated for specific projects. Prefabricated mass timber structural panels have no precedent in timber construction, offering new opportunities in design and construction to professionals intimately familiar with the product. It is, however, very similar to the precast concrete industry that produces pre-manufactured components and delivers them to address specific project requirements. And just like in the precast industry, as the market matures, some standard products opportunities will likely emerge. Historically, however, there have been strong incentives for companies to control the project acquisition process by integrating certain levels of architectural and engineering design services, project management, and, quite often, construction services or construction supervision. In this regard, buildings are the actual product of the industry, and panel production becomes a stage in a process that begins with the project commission and ends with closing the shell of a building. In reality, the level of vertical integration varies substantially both between and within the three products discussed.

Although much has already been said about the positioning of CLT in the market, MHM and dowel-bonded, cross-laminated panels deserve a separate note.

0.6.1 MHM

Most of the MHM plants currently in operation are small-scale turnkey, three-step MHM production lines licensed by Hundegger. In contrast to the adhesive-bonded CLT, there is not much space for diversity in terms of the production processes, levels of automation, scales of operation, and products. MHM is intended mainly for walls and roof elements but is inappropriate for floors. Manufacturers, therefore, cannot offer complete MHM-based building solutions. Not much is currently known, however, about the market strategies or degrees of vertical integration in MHM-producing companies. There are more than 30 licensed MHM plants across Europe, and the latest assessment of their total output in 2018 was about 73 thousand cubic meters (or over 56 MMBF of North American dimensional lumber equivalent).

0.6.2 DOWEL-BONDED CLT

To our knowledge, there are 10 operating commercial dowel-bonded CLT lines, 8 of which are turnkey automated lines installed by Swiss hardware company TechnoWood. That does not leave much space for diversity. Because dowel-bonded CLT can be used as load-carrying walls and floors, manufacturers can offer complete building solutions, giving them a strong motivation for in-

4 Based on LM contribution to [1].

tegrating design and construction services. Some companies mount windows and doors in prefabricated panels before sending them out to the construction site. The actual level of vertical integration is not known for the moment. The rough estimate of total production in 2019 is about 30 thousand cubic meters (or nearly 23 MMBF of North American dimensional lumber equivalent).

0.7 MARKET AWARENESS[5]

Commercial recognition of the massive CLT panels presented above varies by product and by region.

0.7.1 CLT

CLT has the best market awareness of these three, particularly in the Alpine Region, where the technology has been present for decades. Companies in other regions still spend substantial resources on education and developing local markets. That applies both to Europe outside the Alpine Region, and to other CLT producing regions. At this stage, large Austrian companies operating in foreign markets are perceived by the local manufacturers as allies in developing the market, even as they are competitors in the same local project pool. Market readiness in North America is still a work in progress.

0.7.2 MHM

MHM is much less known in Europe than CLT, and virtually unknown in other regions. The operation tends to be very local. Our assumption is that the recognition of the umbrella Hundegger license and the marketing skills of local manufacturers decide the success of individual operators. Local investors in North America would have to be educated on the potential of the MHM technology and alerted to substantial differences in its capacity compared to adhesive-bonded CLT. (It cannot be used as floors or in high-rise structures, and it's probably not good for seismic or high wind load applications either.)

0.7.3 DOWEL-BONDED CLT

Dowel-bonded CLT is the newest of these products. Although it is not widely known outside the Alpine Region of Europe, its use is not much different from that of adhesive-bonded CLT, except that it is not suitable for tall timber structures. (Seismic and high wind load performance are unknown). Dowel-bonded CLT is marketed to high-end investors, to whom the "100 percent wood" appeal justifies higher cost of the material. Manufacturers, however, claim that in the long term, the technology may compete with adhesive-bonded CLT on cost as well. This is because rough sawn lumber may be used in production, and adhesives are not required.

The international market potential of massive CLT panels must be considered in the context of these technologies not being involved in commodity markets.

0.7.4 CLT AND DOWEL-BONDED CLT

The end products are buildings/structures or "projects." In absence of specific data at hand, anecdotal evidence should be sufficient to show that projects are relatively easy items to export: Binderholz and KLH, two Austrian leaders of the CLT industry, are shipping projects from

5 This part is an updated version of a content contributed by LM to [1].


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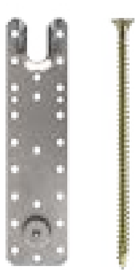

their land-locked Alpine country to Australia, Asia, Oceania, and North America. It should be said, however, that the export potential for dowel-bonded CLT is purely hypothetical. As of today, we are not aware of any dowel-bonded CLT projects that have been executed outside Europe.

0.7.5 MHM

Because this product cannot be used as floors, it is much harder for manufacturers to sell complete projects based on this technology alone. To our knowledge, the focus of this industry is local. We are not aware of MHM-based projects crossing borders.

0.8 CARBON STORAGE[6]

All three types of panels store carbon embedded in the lumber making up the layers of these panels. However, the life cycle of the nonstructural access mats (CLT and nail-bonded CLT) is relatively short compared to the structural elements, which are designed for at least 50 years of service. It should be also noted that the carbon balance is less favorable in the nail-bonded CLT because a substantial number of aluminum nails are present, and in the CLT bonded with petroleum-based adhesives. Trials with bio-based adhesives are currently being conducted. Dowel-bonded CLT is marketed as 100 percent wood product. The utilization of the waste stream generated in production is discussed separately below. Eventually, the carbon balance of entire buildings will depend on contributions from other building and finishing materials being used along with the cross-laminated panels.

Nail- and dowel-bonded CLT utilize raw sawn lumber and can tolerate the substantial presence of wane and surface issues. The elimination of an aggressive planing step, necessary in adhesive-bonded CLT, may weigh favorably in their carbon balance.

0.9 GAUGING MTP POTENTIAL IN REGIONS[7]

Gauging the current and future CLT market in individual regions or countries is notoriously difficult. This is because of the substantial differences that exist 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, but the density of the population and myriad other factors also could be considered. Here we use a simple and manageable approach: creating estimates. A very rough estimate may be arrived at, however, by using a set of substitute gross indicator metrics widely available for individual countries and possible to summarize for regions. For instance, while GDP per capita may be a readily available measure of a country's economic output that accounts for the size of its population, 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.

The metrics used in this study include the volume of softwood production [15], GDP [20], population density (based on 2018 population and area data [15]), number of CLT lines, estimated annual CLT output volume in 2020, and CLT per-

6 This part is an updated version of a content contributed by LM to [1].
7 This part is based on [4] (updated).

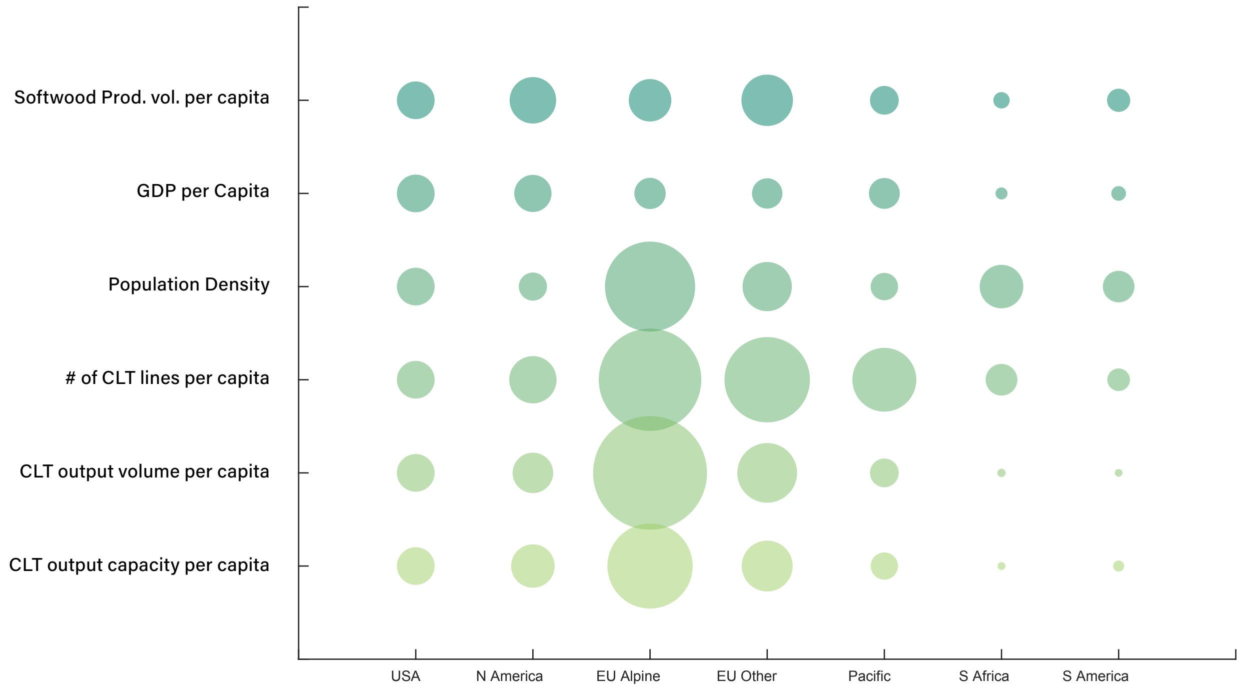

FIGURE 9: A COMPARISON OF SELECTED SOCIOECONOMIC METRICS SCALED BY POPULATION OF CLT-PRODUCING REGIONS WITH PER-CAPITA CLT PRODUCTION IN 2019 FOR EACH. [4] (UPDATED)

shift production capacity. All are summarized by regions [4]. All metrics except population density are expressed per capita. To facilitate an assessment of the potential of an individual country or region, one may view the metrics relative to that reference country or region. In the example presented in **Figure 9**, the relative metrics considered are listed along the vertical axis, while the regions being compared are listed along the horizontal axis. The values of individual metrics are reflected by the area (rather than diameter) of the bubbles for a given metric and region. In this example, the reference country of interest is the United States. Accordingly, the unit areas of the bubbles in the first column are the reference unit for other columns.

When metrics are compared visually in **Figure 8**, it is easy to see that, save for South Africa and South America, there are no dramatic differences among the regions in terms of GDP or softwood production per capita. One somewhat differentiating metric is population density, which is substantially higher for countries in the Central European region, including Austria, Czechia, Germany, Italy, and Switzerland. But even with that distinction, this relatively small region outweighs all others in terms of number of installed CLT manufacturing lines (followed by the rest of CLT-producing Europe and the Asia-Pacific region), and it has no equal in terms of the total annual CLT output volume or in per-shift production capacity. These gaps may be interpreted as an indirect indicator of the potential for regions that seem to be otherwise similar to the Alpine Region in other gross metrics scaled per capita.

With due respect to the gross simplifications of this approach, it is possible to cautiously conclude that in order to match the level of saturation seen in Alpine Europe, the US market should be able to support as many as 56 CLT production lines of various sizes and 9-fold increase of the production output volume from the level seen at the threshold of 2020 (209 thousand m^3/year). These numbers may be scaled down to 40 production lines and 2.5x increase in production volumes if other European-CLT producing countries outside the most advanced Central European region are considered as a model.

Overall, at the threshold of 2020s, the CLT industry continued its exponential growth across the globe. However, that upbeat picture could not possibly have predicted the pandemic triggering tectonic shifts in global economies.

0.10 FUTURE DEVELOPMENT IN THE AFTERMATH OF THE GLOBAL PANDEMIC[8]

The big question today is how the pandemic impacts the CLT industry as we speak, and what are the perspectives of CLT players regarding the post-pandemic new normal.

The industry has a substantial degree of intrinsic flexibility and is oriented towards custom-made products serving premium construction projects. Myriad questions arise from our current context:

What will be a winning strategy in the post-pandemic economy?

Will the industry's internal diversity provide sufficient resilience to weather the changes?

Will the high level of automation be an advantage in the post-pandemic new normal?

Will all elements of the complex supply chain of the industry be equally resilient?

How will the post-pandemic world affect the export prospects of CLT companies that typically export to overseas markets?

Will public enchantment/enthusiasm last?

Finally, with respect to governments, will utilization of low-value local species remain a priority? Will the industry be perceived as a dispensable luxury or a part of a solution for the new normal?

The anecdotal evidence based on brief, unstructured conversations with industry leaders in the US suggests that the CLT industry in the Pacific Northwest is navigating the pandemic relatively well. This sentiment is corroborated by the latest news from Central Europe [17].

0.11 SUMMARY AND CONCLUSIONS

Overall, at the threshold of 2020s, the CLT industry continued its exponential growth across the globe. The number of new, high-capacity lines in regions outside Alpine Europe have grown substantially, and production coming out of that region has increased. After 25 years of development, the industry still feels as young and exciting as ever. However, that upbeat picture is clouded by the pandemic that is triggering tectonic shifts in global economies and leaving us with more questions and unknowns than answers.

8 Based on [18]

ACKNOWLEDGMENTS

This project was funded by USDA ARS program. Additional support: Softwood Export Council, Linnaeus University, Estonian Forest and Wood Industries Association. The authors also acknowledge support of Dr. Chris Knowles (OSU), Ms. Tomoko Igarashi and Mr. Yuichi Hayashi (American Softwoods, Japan), Ms. Jasmin Rainer and Mr. Günther Jauk (Holzkurier).

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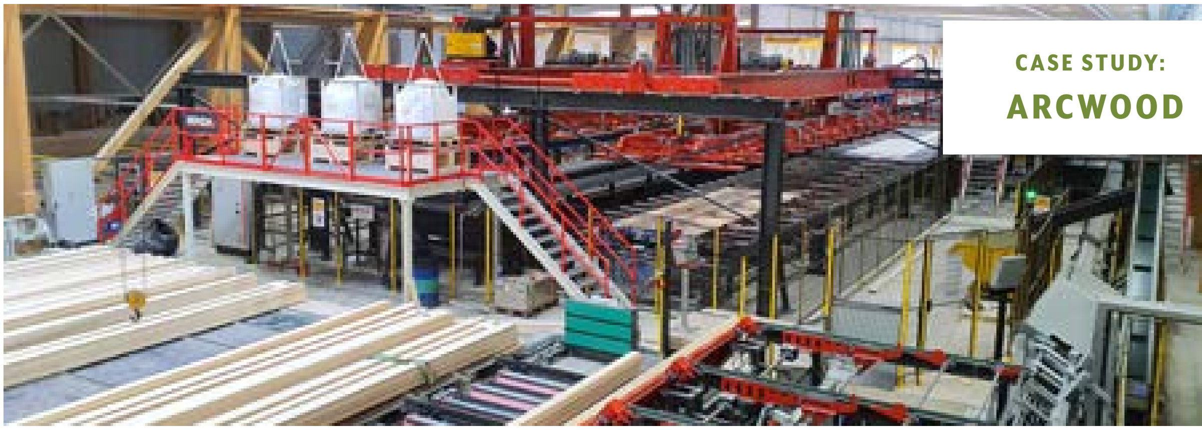


CLT PRODUCTION IN THE EXPANDED ARCWOOD PRODUCTION HALL

CUSTOM DESIGNS DELIVERED THROUGH FLEXIBLE, EFFICIENT AUTOMATION

Arcwood by Peetri Puit delivers special custom designs to their customers. Since 2002, the Estonia-based company has been steadily and organically growing with its continued focus on efficiency and flexibility in construction and architecture.

With the mass timber industry on the rise in early 2019, Arcwood looked into adding an alternative production line for CLT to replace their vacuum pressing technology. They wanted an offline alternative because their lamellas would continue to be produced on an existing finger-jointing line and brought to the CLT line as a block stack.

MINDA proposed a flexible concept for CLT production that would offer higher capacity output and a high level of automation. A low-attendance CLT production line was built within a facility area of 2100 m^2, and it annually produces approximately 40,000 m^3 of CLT during two shifts.

A LOOK INTO ARCWOOD'S CLT PRODUCTION LINE

Arcwood's new CLT production line includes a MINDA TimberPress X 336 for production of CLT elements in larger sizes. The CLT elements are pressed from loose, finger-jointed lamellas. First, the lamellas are unstacked and cut for length or cross layers. These cut-to-length lamellas are batched into layers and transferred automatically to the lay-up area via an automated conveyor system. The vacuum laying gantry alternately places the length and cross layers on the laying table. The automated glue portal applies PUR glue to the entire surface between each layer.

Thus, packages of cross-layered lamellas are created that consist of three to ten layers. The packages are pressed in the hydraulic TimberPress X 336, where length and cross compression is applied. CLT elements are produced in widths from 2050mm to 3600 mm, by lengths from 3000mm to 15,200 mm, at thicknesses from 60mm to 350 mm. The outer length layers can also be pressed in a brick compound.

At the end of the pressing process, the CLT elements are assessed for quality from both sides by an element turner and can be sanded and repaired if necessary. The entire line, designed for batch size one, is controlled by the higher-level MINDA production control system, which is linked to the customer's work preparation system.

CHAPTER 1: INTRODUCTION

THE MASS TIMBER EFFECT

- Between 2020 and 2034, the number of mass timber buildings constructed globally will double every two years. The result is that the North American building construction sector will reach carbon neutrality.

Historically, wood's use as a construction material, while extensive, was largely limited to low-rise and light-frame buildings. Typical light-frame construction features 2-by-4s and 2-by-6s as wall supports, wood joists as floor supports, and rafters as a roof assembly. The application of this construction style is primarily limited to homes, smaller apartment buildings, and low-rise, non-residential structures.

Now, though, the use of wood in construction is starting to shift with the game-changing introduction of mass timber in North America. According to Perkins and Will, an architecture and design firm that was an early proponent of mass timber:

"The growing field of mass timber is a fundamental disruption of conventional concrete-and-steel approaches to building design and construction. Instead of limiting wood to low-rise, light-frame applications, we can now reimagine wood as an advanced structural system that produces communities with greater speed, efficiency, and resilience."[1]

This report provides readers with a broad and yet deep understanding of the North American mass timber industry in 2020. This chapter explains why the report was assembled, defines mass timber, describes how it is 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, held annually in Portland, Oregon, beginning in 2016. As evidenced by dramatic year-over-year growth in attendance, the conference has strengthened the mass timber community by providing a forum for the exchange of ideas and information, and for the development of relationships along the supply chain.

Mass timber has captured widespread attention in recent years. Architects, engineers, developers, builders, the forest industry, and community leaders are excited about mass timber's revolutionary potential in building construction. And rightly so.

It's a technology that uses renewable resources, reduces building construction and development costs, increases versatility in building sites, is safe, and yields highly usable structures. It seems every day a new mass timber article or report is released—be it a story on a new mass timber high-rise, the announcement of a new manufacturer, or news about a favorable change in building codes. 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 aspect of the industry. By contrast, this report is intended as a single, comprehensive, in-depth source of North American mass timber information, circa 2020.

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

1 Mass Timber: A Primer and Top 5. Perkins + Will Blog Article. November 17, 2017. Sindhu Mahadevan.

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

FIGURE 1.2: CLT PANEL
Photo Source: APA

1.2 WHAT IS MASS TIMBER?

Mass timber is not just one technology or product. Solid wood (i.e., timbers and lumber) has been used as a structural material for millennia. More recently, however, a different class of wood products has emerged. These engineered wood products (EWPs) are a group of construction materials that combine wood's inherent strength with modern engineering.

1.2.1 ENGINEERED WOOD PRODUCTS

EWPs are manufactured by using adhesives to bind strands, particles, fibers, veneers, or boards of wood to form a composite product. The basic theory underlying all EWPs is that the process of disassembling wood into small 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. In EWPs, the disassembly and reassembly process randomizes the location of defects and yields products with predictable strength characteristics. Examples of EWPs include structural building materials such as plywood, oriented strand board (OSB), laminated veneer lumber (LVL), and wooden I-joists.

1.2.2 MASS TIMBER PRODUCTS

Mass timber panels are a distinct class of EWPs. The following sections provide a description of the different types of mass timber products developed to date.

FIGURE 1.3: NLT PANEL
Photo Source: StructureCraft

Cross Laminated Timber (CLT)

CLT is a panelized structural engineered wood product 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 three or more layers of lumber, each layer oriented perpendicular to the adjacent layer. The layers are then pressed together with a special adhesive. The lumber is typically pre-selected so major defects (knots, checks, etc.) are removed prior to lay-up. CLT panels used for building construction are commonly 8 feet to 12 feet in width, 20 feet to 60 feet in length, and in 3.5 inches to 9 inches in thickness. Panel length is limited only by press size and highway trucking regulations.

Because the lumber is layered with 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-controlled (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 tailored to one building. Openings for doors and windows, as well as openings or channels for electrical, plumbing, and HVAC, are commonly pre-planned and cut by the manufacturer using CNC routers. The prefabricated panels minimize the labor needed at the construction site and dramatically speed construction.

After manufacturing, CLT panels are transported to the construction site, typically by truck. Crews hoist the massive panels into place using cranes, with straps or cables attached to preinstalled "pick points" on the panels, which are removed once the panel is in place.

In some cases, CLT panels are prefabricated into entire modular units (rooms, building sections) that can be transported by truck and installed using cranes, further reducing jobsite construction requirements.

Nail Laminated Timber (NLT)

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. However, in an NLT panel, the wood grain orientation does not alternate. Instead, numerous pieces of lumber are stacked face to face. Rather than using adhesive to bond the layers (as in CLT and glulam), nails hold the pieces of lumber together. Because it does not require the specialized presses used in CLT manufacturing, NLT can be assembled at a temporary or makeshift workshop

FIGURE: 1.4 DLT PANEL
Photo Source: StructureCraft

close to the construction site, or the panels can be assembled at the building site.

In most cases, NLT panels are used in horizontal applications (i.e., floors and roof decks) but not in vertical applications such as walls. As a result, fewer precision-machined openings, such as those required for doors and windows, are needed. One drawback is that the metal nails used in NLT can dull or damage woodworking tools such as saws, drills, and routers if the NLT panels are machined. NLT panels can be produced in any thickness common to softwood dimension lumber (e.g., 2-by-4 to 2-by-12). The width and length of the panels are only limited by the dimensions required for the application. NLT is recognized as code-compliant for buildings with varying heights, areas, and occupancies.

Dowel Laminated Timber (DLT)

Dowel Laminated Timber (DLT) is similar to NLT, but wooden dowels hold the boards together instead of nails. In a process called friction fitting, hardwood dowels are dried to a very low moisture content and placed into 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. The result is a tight-fitting connection that holds the boards together. The panel sizes are similar to CLT and NLT (8 feet to 12 feet wide and up to 60 feet long). The thickness depends on the width of the softwood boards being used. DLT is most commonly used in floor and roof applications, but StructureCraft, the lone North American manufacturer of DLT, says its panels also can be used in vertical applications.

DLT is the only all-wood mass timber product. With no metal fasteners, DLT panels can be processed with CNC machinery without 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

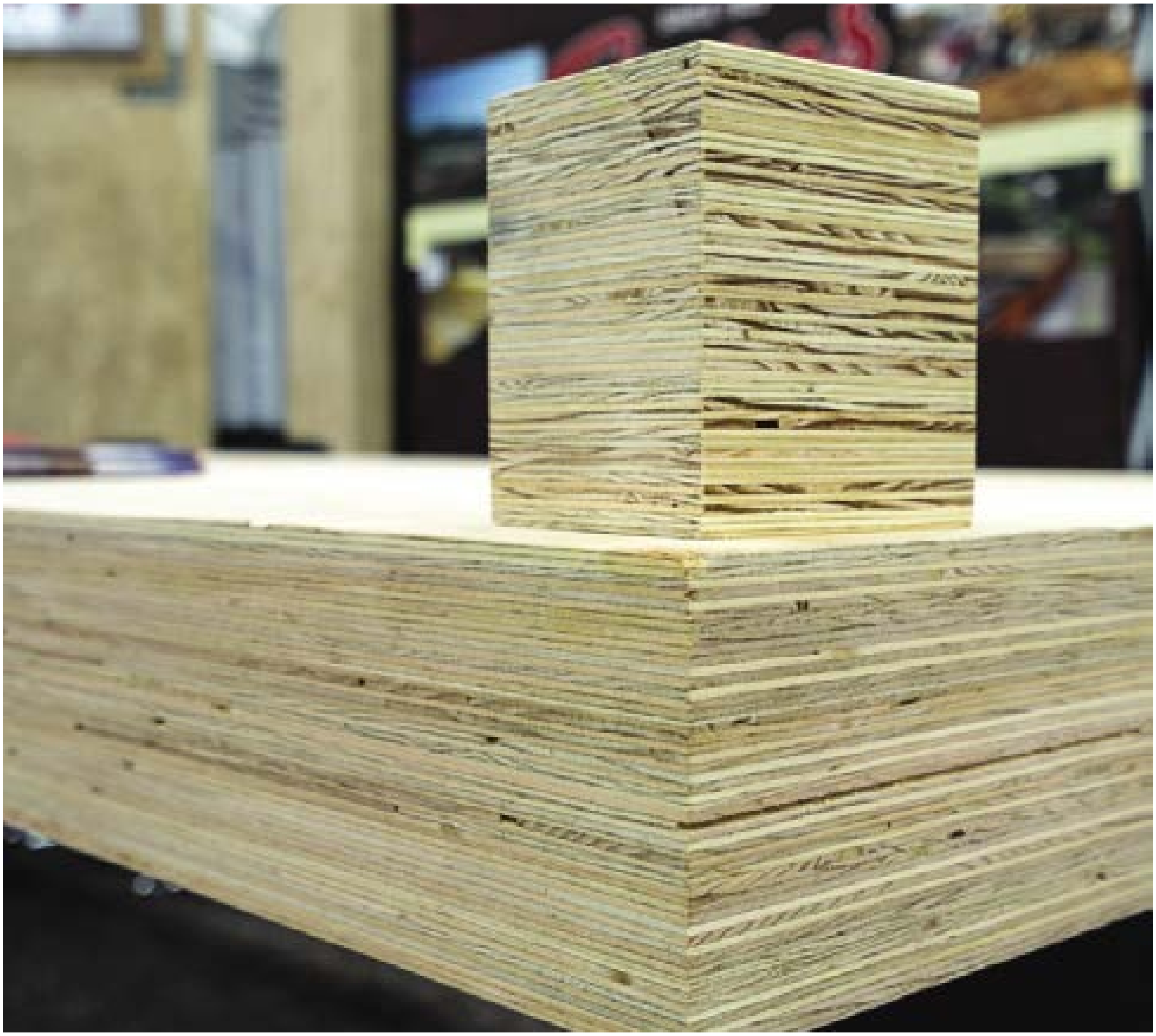


FIGURE 1.5: MASS PLYWOOD PANEL
Photo Source: Oregon Department of Forestry

all-wood design also allows building designers to select a material with no chemical adhesives.

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

Mass Plywood Panel

A Mass Plywood Panel (MPP) is another innovative panelized mass timber product, currently produced at a single plant located in Oregon (Freres Lumber). MPPs are veneer-based (rather than lumber-based) and are constructed by gluing together many layers of thin veneer in various combinations of grain orientation. The uses of MPPs are very sim-

FIGURE 1.6: GLULAM TIMBERS
Photo Source: APA

ilar to those of other mass timber panels, though the manufacturer boasts that using veneer-based panels can lead to reduced panel thickness and/or longer unsupported spans than are possible with lumber-based panels.

Glue Laminated Timber (Glulam)

Glue laminated timber (glulam) is an engineered wood composite made from multiple layers of lumber, bonded with adhesive to form a large-dimension structural element. Glulam is typically used as either a beam in a horizontal application or as a column in a vertical application.

Most glulam is made from standard dimension lumber (e.g., 2-by-4 to 2-by-12). Thus, the typical widths range from about 2.5 inches to 10.75 inches. The potential thicknesses and lengths of glulam, however, are much larger. Glulam depth ranges between 6 inches and 72 inches, and lengths can surpass 100 feet.

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

Glulam is a very well-established product that has been in use in both residential and non-residential construction for many years. In mass timber structures, glulam is commonly used as a support for panels (CLT, NLT, heavy timber decking, etc.) and in post and beam structures.

Post and Beam

Post and beam 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 non-residential and multifamily residential buildings (office buildings, schools, warehouses). In these larger buildings, structural loads are typically higher than for single-family residences, so larger-dimension posts and beams and/or engineered wood composites such as glulam may be used. In many cases, post and beam frames make up the structural element of a building frame, while nonstructural walls are commonly constructed with light wood framing.

FIGURE 1.7: POST AND BEAM

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

FIGURE 1.8: HEAVY TIBER DECKING

Photo Source: Southern Wood Specialties

Heavy Timber Decking or Jointed Timbers

Heavy timber decking is used in horizontal applications (floor and roof) 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-6 or 4-by-6) joined edgewise with tongue and groove profiles on each piece, locking them together. The pieces may be solid sawn, or glue-laminated. 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.

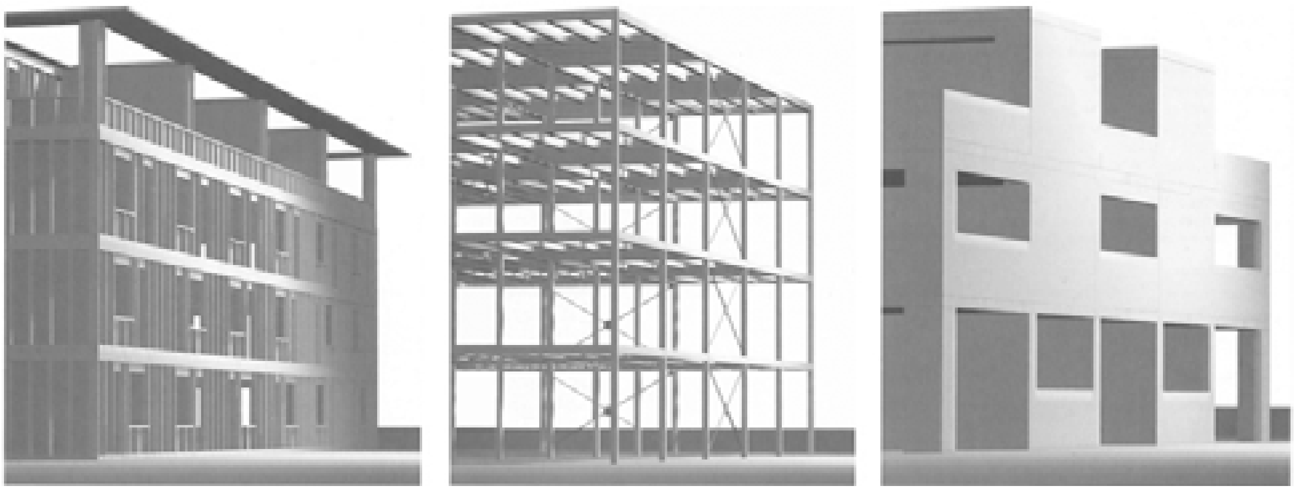


FIGURE 1.9: WOOD-BASE BUILDING CONSTRUCTION SYSTEMS
Image Source: Fast and Epp

1.3 HOW IS MASS TIMBER USED?

Figure 1.9 offers an illustration of how mass timber construction differs from more traditional wood construction.

Light wood-frame construction (building on 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 panels sheath 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 rather than 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 is new to North America and 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 (cross laminated timber), NLT (nail laminated timber), DLT (dowel laminated timber), and MPP (mass plywood panel). 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 fundamental idea in this report is that a mass timber supply chain is rapidly developing in North America, and that examining the components of that supply chain offers a way to organize and think about this rapidly changing and developing industry.

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**). As the figure illustrates, mass timber begins in a forest and ends with people living or working in a new building. In this report, we assess the state of each link in the supply chain. 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 the industry's 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.

1.5.1 LOG MEASUREMENT

Standing timber and log volume is reported on a cubic foot basis. Cubic feet can be converted

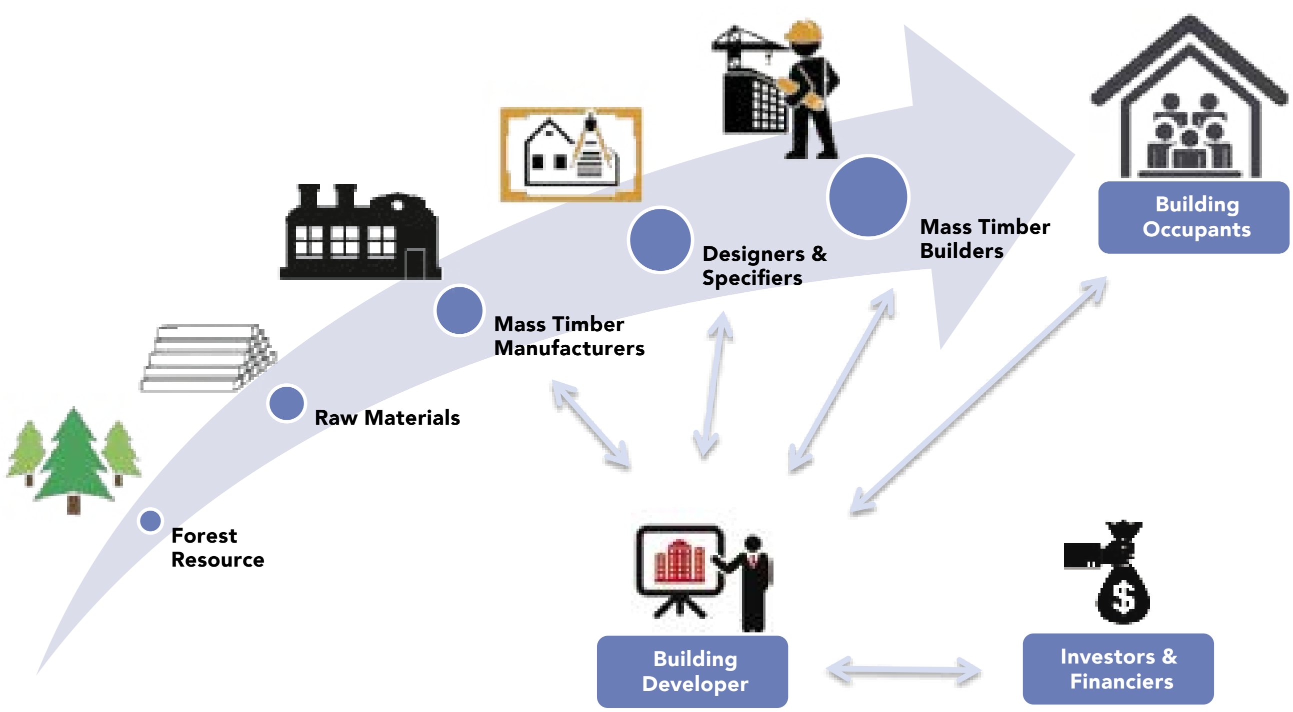


FIGURE 1.10 MASS TIMBER SUPPLY CHAIN

Nominal Size				Actual (Dry, Surfaced) Size				Conversion Factor (CF/BF)	Conversion Factor (BF/CF)
Thickness (IN)	Width (IN)	Length (FT)	Volume (BF)	Thickness (IN)	Width (IN)	Length (FT)	Volume (CF)		
2.00	4.00	20.00	13.33	1.50	3.50	20.00	0.73	0.055	18.3
2.00	6.00	20.00	20.00	1.50	5.50	20.00	1.15	0.057	17.5
2.00	8.00	20.00	26.67	1.50	7.25	20.00	1.51	0.057	17.7
2.00	10.00	20.00	33.33	1.50	9.25	20.00	1.93	0.058	17.3
2.00	12.00	20.00	40.00	1.50	11.25	20.00	2.34	0.059	17.1

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

to cubic meters using the standard conversion of 35.315 cubic feet per cubic meter. In contrast to the cubic volume log measurements used in this report, a variety of measurement units are used when logs are sold, especially in the United States. In fact, different measurement systems are used regionally, including a variety of log scales and weight-based measurements. Analysis of these marketplace measurement systems is beyond the scope of this report.

1.5.2 LUMBER MEASUREMENT

In mass timber, two 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. Dimension lumber is bought and sold in board feet.[2] Theoretically, there are 12 board feet per cubic foot. However, the sales volume of dimension lumber is expressed as a nominal size, which is larger than the actual finished size. This difference in dimension lumber's nominal and actual sizes means that a cubic foot of wood in a mass timber panel contains more than the theoretical 12 board feet.

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 two columns on the right side of the table.

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

2 A board foot is equivalent to 1 inch by 12 inches by 12 inches.

1.5.3 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 the local conventions for measuring logs. A full description of these various lumber yield measurements is beyond the scope of this report. But, for the purposes of understanding how lumber volumes relate to log demand and harvest, it is most useful to consider cubic yields.

Cubic lumber yields at sawmills vary depending on a variety of 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 byproduct (chips, sawdust, 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 U.S. 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 very 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.

1.5.4 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 ÷ 35.315).

When considering the amount of lumber used in mass timber or glulam products, it is important to consider the nominal vs. the cubic size of the lumber feedstock (**Table 1.1**), as well as any volume lost during the manufacturing process. In CLT, DLT, and glulam, the lumber is surfaced during the manufacturing process, with about 1/16 of an inch removed from all four 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 are used per cubic foot of finished product.

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

1.5.5 MASS TIMBER TO LOGS EXAMPLE

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. For a hypothetical building project that uses 100,000 cubic feet of CLT and glulam, **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 a number of assumptions (lumber yield, size of lumber used, CLT and glulam wood utilization), 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 utilized in the final mass timber product is not wasted. Depending on the region where the lumber and mass timber are manufactured, the byproducts can be utilized in a variety of ways. Chips are typically used for making paper. Sawdust or planer shavings make composite panels (particleboard or medium-density fiberboard). Byproducts can also be manufactured into wood pellets for heating or power generation, or they may be combusted in a boiler to generate power and/or provide thermal energy for lumber drying or other uses.

CHAPTER 2: THE FOREST RESOURCE

IMPACTS OF THE MASS TIMBER EFFECT

- Forestland area in the US and Canada has been stable for more than 100 years. A contributing factor to that trend is that making products from trees, like mass timber, creates an incentive for landowners to maintain their land as forest.
- Both US and Canadian forests have the capacity to sustainably supply more timber as the market for mass timber buildings grows. We expect this to contribute to maintaining and possibly increasing the area of North American forests in the future.
- US and Canadian forests can simultaneously provide wood products via harvesting and other ecological functions, such as clean air, clean water, carbon storage, recreation, and wildlife habitat.

This chapter focuses on forests—the beginning of the mass timber supply chain. Included in the first section of the chapter is an analysis of the area, ownership, and types of forests in North America. In the second section of the chapter, the focus shifts to how those forests are managed, including their ability to sequester and store carbon relative to their ability to sustainably provide raw materials used for mass timber construction and many other industrial, packaging, and building materials applications.

2.1 CHARACTERIZING THE NORTH AMERICAN FOREST RESOURCE

Figure 2.1 illustrates the portions of North America containing greater than 15 percent tree cover. As shown by the differing color shadings that represent different forest types, forests are generally comprised of coniferous (softwood) trees in the coastal and mountainous areas of the west; mixed hardwood and coniferous trees in the Eastern US and Canada, and upper Midwestern US; and largely coniferous trees in the US Southeast. Note also there are vast areas of boreal forest in the far north of Canada and Alaska, but given the distance of those forests from major population centers and their generally smaller tree sizes, trees in those regions have little commercial value.

As further discussed in Chapter 3, it is convenient to think of forested regions as they relate to the types of softwood lumber they most commonly produce. There are five main lumber producing regions in North America: the US West, US South, US Other, Eastern Canada, and Western Canada. Forests in the US West are generally dominated by Douglas fir, Western hemlock, and various pine species. In both Eastern and Western Canada, the forests are heavily composed of various mixtures of spruce, pine, and fir (SPF). In the US South, four types of pine, including loblolly, slash, shortleaf, and longleaf, are the leading species of note for mass timber. When sold as lumber, all are lumped into a common group called Southern Yellow Pine (SYP). The US Other region includes the Upper Midwest and Northeast. Forests in those regions are generally more heavily stocked with hardwood trees and, therefore, are of somewhat less significance from a mass timber industry perspective. This is because, to date, mass timber panels made from hardwood have yet to be commercialized.

FIGURE 2.1: EXTENT OF FORESTS IN NORTH AMERICA

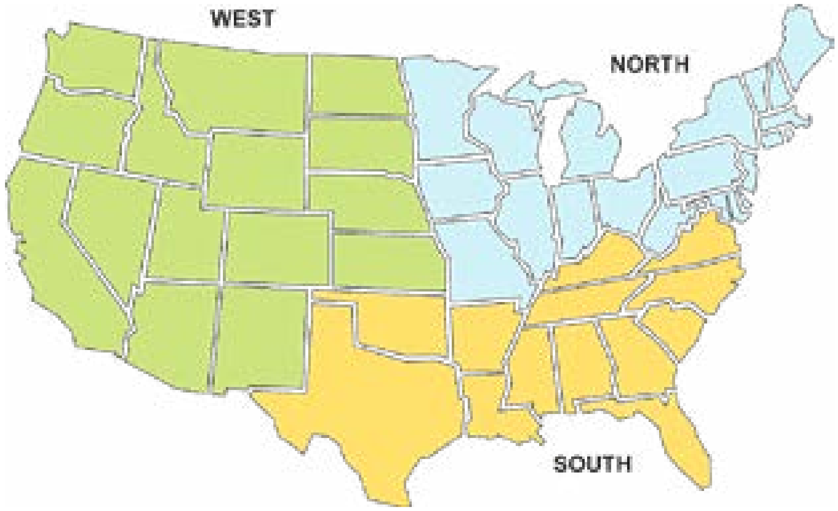


FIGURE 2.2: MAP OF US FOREST REGIONS

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)

2.1.1 US FORESTS

Extent of US Forests: The total land area in the United States 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 data in the table is from *Forest Resources of the United States, 2017.*[1] It is an update to the 2012 version of the same publication that was used as a reference for prior versions of the Mass Timber Industry report. Notable is that the total forest area increased from 766 million acres to 822 million acres in the most recent assessment. It is also important to note that the area of forested land in the US has been stable (or increasing per the most recent analysis) since the early 1900s, despite the US population tripling during the same time. It is encouraging to consider that despite the massive growth in population and the associated increase in demand for wood fiber, the area of forest in the US has remained stable for more than 100 years.

Within the broad category of forested land, there are several subcategories. They include Timberland, or forests that are more fully stocked with trees

1 Forest Resources of the United States, 2017. Sonja Oswalt, W. Brad Smith, Patrick D. Miles and Scott Pugh. 2019. Accessed at: https://www.fs.fed.us/research/publications/gtr/gtr_wo97.pdf

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 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)

and capable of producing at least 20 cubic feet of new wood fiber growth per acre per year. There is also Reserved forestland, or forests where utilization (harvesting) of trees is prohibited. It consists mainly of wilderness areas and national parks. In addition, there is also a category called 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** illustrates the location of the regions listed in the table.

Ownership of US Forests: Regarding ownership of the Timberland portion (i.e., the most productive forest acres) in the US, **Table 2.2** shows a categorization by owner type (e.g., two types of public owners and two types of private owners). As the data in the table shows, significantly 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, with a general rule of thumb being that public and noncorporate private lands are managed for a broader set of objectives than a focus on maximizing timber production. In contrast, corporate timberlands are generally managed to maximize timber production.

Finally, **Table 2.3** shows a history of the area of timberland classified by tree size class, which includes sawtimber, pole timber, seedling/sapling, and nonstocked. Note that: sawtimber includes trees big enough to be sawed into lumber; pole

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)

trees are smaller trees that are too small for utilization as sawlogs; seedling/sapling are very young stands of trees; and nonstocked is bare land (typically just after harvest that has yet to be replanted). As the data shows, the number of acres of sawtimber (trees that could be utilized to make lumber for mass timber) has increased by nearly 100 million acres over the last 65 years. This is an encouraging finding as it relates to the capacity of US forests to supply raw material for the mass timber industry.

US Standing Timber Inventory: The US Forest Service is a federal agency charged with managing nearly 190 million acres of national forests and grasslands. Additionally, their Forest Inventory and Analysis (FIA) program was established nearly 100 years ago for monitoring the condition of all the nation's forests. A key feature of the FIA program was establishing more than 325,000 permanently located growth plots across the forests of the United States. Each plot is revisited at a regularly repeated interval, and data is collected about the trees within the plots' boundaries. Through this system, the FIA program is able to track changes in the status of the nation's forests. For example, the inventory of standing trees by species, diameter, age, cubic volume, etc. are all key metrics tracked by the FIA program.

Table 2.4 shows the most recently available estimate of standing timber volume in the US on timberland acres. As shown, there is an estimated 1.1 trillion cubic feet of standing timber in the US. The standing volume is relatively evenly split between hardwoods and softwoods.

More specific to the mass timber industry is **Table 2.5**, which shows the history of softwood standing timber inventory by region. Note that over the last roughly 65 years, the total volume of standing timber in the US has increased by nearly

FIGURE 2.3: CANADIAN FOREST REGIONS

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

30 percent in total and by more than 230 percent in the South. Both are positive findings about the capacity of US forests as it relates to anticipated increased demand from the mass timber industry.

2.1.2 CANADIAN FORESTS

The Extent of Canada's Forests: The total land area in Canada is about 2.467 billion acres. Of that total, about 857 million acres are forested. Both statistics are like the United States, with both countries having roughly equal total land areas and total forested areas. The area of forest has been stable in Canada for decades. **Figure 2.3** illustrates that there are several distinct types of forest in Canada, including a vast boreal forest that stretches the length of the country from east to west. It is composed mainly of spruces, firs, and, to a lesser extent, pines. Around the Great Lakes, Canadian forests are primarily hardwoods, including maple

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	1,684,796
1995	1,682,783
2000	1,671,058
2005	1,623,808
2010	1,607,034
2015	1,594,356
2016	1,591,567
2017	1,585,493
2018	1,575,640

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

and birch. The montane forests of Western Canada are populated with Douglas fir, hemlock, and pines. And finally, the coastal forests in Western Canada are heavy with cedar, hemlock, and firs.

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

Canada's Standing Timber Inventory: According to *The State of Canada's Forests 2020 Annual Report,*[2] the standing timber inventory in Canada as of 2018 was 1.575 trillion cubic feet, approximately one-third more standing timber volume than the United States. **Table 2.7** shows a history of Canada's standing timber volume. Note that standing volume has declined since 1990. The causes of this are many, but two keys are extensive insect outbreaks and wildfires—with 2017 and 2018 being two years of the worst fires on record in Canada.

2 The State of Canada's Forests 2020. Accessed at: https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/16496

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)

Table 2.8 provides a more detailed estimate of standing timber volume, with categorizations by forest type and stand age class. As the data shows, more than 70 percent of Canada's forests are coniferous (i.e., softwoods). Note the volumes are consistent with the 2000 standing inventory estimate in the preceding table, and the proportions by species type are likely still accurate.

2.2 FOREST SUSTAINABILITY

People across the globe are universally interested in access to clean air and water, a safe and stable government, and economic opportunity. When all are present, they can pursue a meaningful life. Forests are key to providing access to clean air and water. Thus, assuring forest sustainability is critical to all global citizens. Sustainability is defined as meeting current needs via the consumption of natural resources without jeopardizing the ability of future generations to meet their needs as those needs relate to the same natural resources.

2.2.1 GROWTH TO DRAIN

Given that definition of sustainability, one measure foresters use to monitor it is the concept of Growth to Drain. It is a ratio of the amount of wood fiber a given area can grow annually (net of natural mortality from insects, disease, fire, etc.) to the amount of wood fiber harvested annually. A ratio greater than 1 is an indicator that forests in the area are being managed sustainably. In other words, a ratio greater than 1 indicates that the area is adding more wood fiber each year through net growth than is being removed by harvesting. Although there are many other considerations related to sustainability, Growth to Drain is frequently used as a key consideration in forest management and timber harvest planning. The following sections provide analysis and discussion about Growth to Drain for US and Canadian forests.

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

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

US Timberlands Growth to Drain: As long as the ratio of Growth to Drain is greater than 1, forests can supply fiber in perpetuity. **Table 2.9** provides information about historical Growth to Drain ratios in the United States. At the top of the table is data for all softwoods in the US; in the middle is information about hardwoods; and, at the bottom, softwoods and hardwoods are combined. As the data indicates, in all cases, the ratio is greater than 1.

This is a positive finding for the mass timber industry because it indicates that US forests are not being overharvested. However, the data shows a troubling trend. Natural mortality, which is trees dying from factors such as wildfire, drought, insects, disease, etc. has increased by 250 percent from 1976 to 2016. There is considerable debate about whether the cause is climate change or lack of management, especially in publicly owned forests in the US West. In any case, pressure on Growth to Drain

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

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

ratios would ease considerably if more trees were utilized through harvesting rather than lost to natural mortality.

Note also that Growth to Drain ratios can vary dramatically by region and species. For example, specific to the US South, the Growth to Drain for softwoods is significantly higher than softwoods for the entire US. **Table 2.10** illustrates the data supporting that statement. It shows that for both naturally regenerated and plantation stands of Southern Yellow Pine (i.e., the overwhelming majority of softwoods in the US South), the Growth to Drain ratio is well over 1. This means that each year 80 percent more wood is being added to the standing volume than is being utilized or that dies from natural mortality. As is further discussed in Chapter 3, the combination of a high percentage of privately owned lands and a large amount of excess growth are leading to extensive investment in new sawmilling capacity across the region.

Canadian Growth to Drain: **Table 2.11** provides a nearly 30-year history of Growth to Drain for Canadian forests. Note that total wood supply is the Annual Allowable Cut (AAC), a calculated value that projects the amount of timber that can be harvested sustainably based on the capacity of the forests to grow new fiber and their natural mortality. As the data shows, in all cases, the actual harvest levels have been lower than the AAC by an average factor of 1.4 for all species, 1.3 for softwoods, and 2.2 for hardwoods. This is a positive finding for the mass timber industry, as it indicates that Canadian forests are not being overharvested and could have the capacity to supply more fiber if warranted by increasing market demand.

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

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

2.2.2 ENVIRONMENTAL FOREST MANAGEMENT CERTIFICATION

Many forest landowners manage for multiple objectives and consider sustainability in their forest management planning and decision-making. Various environmental forest management certification programs offer landowners a formal process for assuring their forest management plans are consistent with sustainability objectives related to fiber production, wildlife habitat, clean water, recreation values, and a wide range of plants, animals, insects, and fungi that make up the web of life in a forest ecosystem.

Concern for sustainability and the protection of myriad forest values began fully emerging in the United States and Canada during the 1960s, '70s, and '80s with the passage of the laws such as the National Environmental Policy Act (NEPA), Endangered Species Act, Clean Water and Clean Air Acts, National Forest Management Act (NFMA), and others. All of those laws help insure a baseline of sustainability and accountability in forest management, especially on public lands. However, in the 1990s, concern began to arise about the sources of wood from private lands and wood imported from countries where illegal logging is prevalent or forest management practices are lax.

Those concerns, spurred by buyers of wood products who wanted to be assured that their products were sourced from well-managed forests, led to the development of environmental forest management certifications. Precipitating events were the World Summit in Rio De Janeiro and the Montreal Process meetings in the early 1990s. Through those meetings, forest health and management criteria and indicators were developed, 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. In other words, environment forest management certification. Importantly, wood is the only building material that has third-party certification programs in place to demonstrate compliance with sustainability principles.

In the several decades that have passed since the advent of environmental forest management certification, only about 11 percent of the world's forests have been certified as complying with one of several environmental forest management certification programs, according to the Global Forest Atlas from the Yale School of Forestry and the Environmental Studies. Additionally, despite accounting for only 11 percent of the certified acreage, those same certified forests provide an estimated 29 percent of global timber production. Also more than 92 percent of all certified forestland is found in the Northern Hemisphere, with the US and Canada accounting for more than half the 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, which is 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 20 percent of all North American forests, have been certified under various third-party forest certification schemes. There

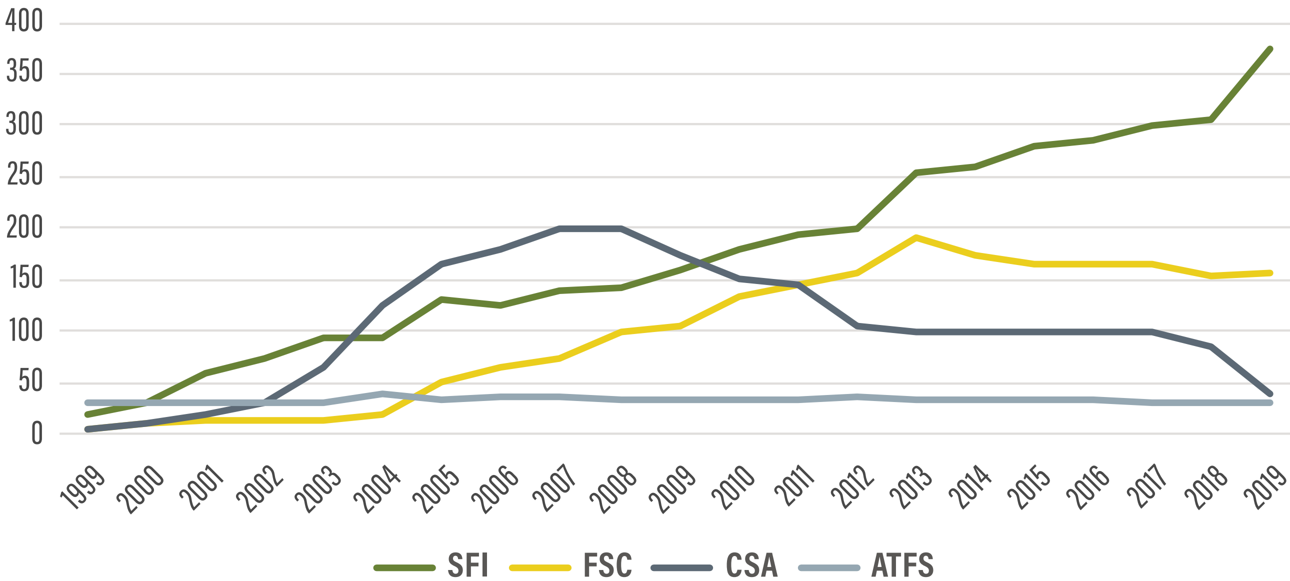


FIGURE 2.4: HISTORY OF ACRES CERTIFIED IN NORTH AMERICA BY FOREST CERTIFICATION PROGRAMS

are four main certification programs currently operating in North America including:

- American Tree Farm System: ATFS is managed by the American Forest Foundation and is designed to serve family forest ownerships that are relatively small. ATFS is also endorsed by PEFC (Programme for Endorsement of Forest Certification), which is a global umbrella organization that endorses a variety of forest certification systems that are national in scope. Through AFTS's association with PEFC, landowners certified by ATFS have global certification status. See additional information here: https://www.treefarmsystem.org/

- Forest Stewardship Council: FSC was initiated in 1993 and is a global forest certification program. As of 2019 (the most recent annual report) nearly 500 million acres of forest have been certified globally. In North America, FSC certificate holders include a variety of publicly owned forests, native forest enterprises, family forest trusts, and industrial timberlands. Roughly 160 million acres are FSC-certified in North America. See additional information here: https://www.fsc.org

- Sustainable Forestry Initiative: SFI was initiated in 1994 and primarily serves large, industrial forest landowners. It is endorsed by PEFC. As of 2019, about 375 million acres of North American forestland have been certified to the SFI standard. See additional information here: https://www.forests.org/

- Canadian Standards Association: CSA is the Canadian standards system that was established in 1996. Like SFI and ATFS, CSA is also PEFC endorsed. See additional information here: https://www.csasfmforests.ca/

Figure 2.4 shows the history of the acres certified in North America under each program. Note that data in the figure was interpolated by the author team from a figure included in the 2020 SFI Annual Progress Report.[3]

Certification of Public Lands in the United States: Most federal land in the United States, including national parks, national forests, Bureau of Land Management lands, and wildlife refuges are not certified to any of the standards of any of the programs described in the preceding section. Rather, federal laws guide management planning and activity. Notably, 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 utilization of other resources. The revenue from management activities is often used to support school systems and other rural, local government needs. Unlike federal lands, a number of states and municipal governments have certified management of their forests by one of the forest management certification programs described in the preceding section. For those landowners who have not pursued third-party certification, each state and municipality has laws and/or Best Management Practices (BMPs) that govern or guide forest management within the jurisdiction. The nature and extent of these laws varies considerably across the United States. 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 is overwhelmingly compliant 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 the details vary from province to province, the basic concept is that a privately owned company signs a long-term agreement with the Canadian government. The agreement encompasses a designated forest acreage, and it dictates certain forest management guidelines (i.e., applicable forestry laws, regulations, and policies) that the private company must comply with in exchange for the right to harvest timber. In addition to those standards, about 420 million acres of forest in Canada have been certified by third parties, including FSC, SFI, and CSA. Canada also has 59 million acres reserved from harvest in the form of parks and other protective designations. The reserved areas represent about 6 percent of Canada's forests.

Future of Forest Certification: A report[4] recently released by Dovetail Partners Inc., a non-profit that seeks to provide authoritative information about the impacts and trade-offs of environmental decisions, provides an analysis of what the future might look like for forest certification. A key takeaway from the report is that competition among forest certification programs may hinder

3 Accessed at: https://www.forests.org/progressreports/
4 Forest Certification Update 2021: The Pace of Change. Dovetail Partners, January 2021. Accessed at: https://dovetailinc.org/upload/tmp/1611160123.pdf

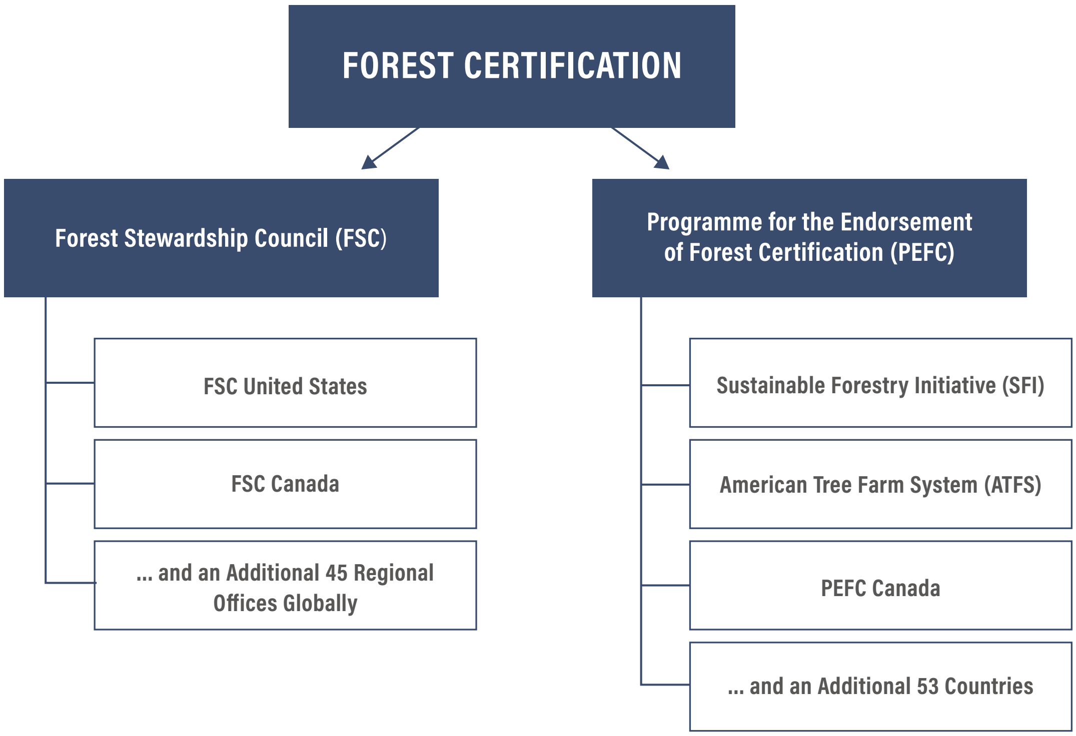


FIGURE 2.5: RELATIONSHIPS AMONG FOREST CERTIFICATION PROGRAMS

the ability of forest certification to continue having a meaningful impact on forest management. **Figure 2.5**, adapted from the Dovetail Partners report, illustrates the divergence among forest certification programs by showing that the FSC program stands alone while the PEFC program acts as an umbrella organization for numerous global forest certification schemes.

Key drivers cited as threats to forest certification programs are the steady growth within supply chains in the development of private and public sector alternative approaches (to forest certification), technological innovation, and government policies. Potential solutions for ratcheting down competition among forest certification programs recommended in the report include supply chain influencers adopting either a neutral position about utilizing material sourced from the different programs or using a ranked choice approach to sourcing certified fiber that would define an order of preference. According to Dovetail Partners, ranked choice is an alternative to an "all or nothing" approach that is apparently a common current practice among some sectors of forest products end users.

2.3 FOREST DIVERSITY

Species richness, a measure of the number of unique species in a given area, is frequently used as another measure of forest sustainability. In the United States, there are many different ecological zones, which translates into numerous species of trees. During US Forest Service FIA timber cruises in 2017, timber cruisers identified nearly 1,000 unique species of trees growing in US forests. Most abundant were red maple, loblolly pine, balsam fir, sweetgum, and Douglas fir. However, when considered on the basis of biomass rather than tree count, Douglas fir comprises the largest portion, accounting for about 1 percent of all the above ground biomass in US forests.

Virtually all US forests are native species, and the vast majority are naturally regenerated, with planted forests accounting for just 10 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. Examples include longleaf pine and shortleaf pine restoration efforts in the Eastern United States. 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. For further information about trends associated with forest types across the country, see the FIA Forest Facts publication available from the US Department of Agriculture. In Canada, the vast majority of forests are comprised of native species. A little over half of the harvested acreages are replanted, while half rely on natural regeneration. Canada boasts a number of different forest types.

2.4 FOREST HEALTH

What is a healthy forest? The answer is nebulous, but the primary disturbance agents affecting forest health are clear: insects, disease, and wildfire. How one views the impacts of those disturbance agents on forests differs depending on a landowner's management goals. If the forest is reserved (wilderness or a national park) and the purpose is to manage for natural processes, the definition of healthy is very different than that for land managed by a publicly traded company where timberlands must provide a return on investment for shareholders. A noncorporate family forestland manager with multiple, diverse goals will provide yet another definition. The answers reflect different objectives. Not every forest meets every objective on every acre. What is healthy also varies by forest ecosystem, requiring different management practices.

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

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

FIGURE 2.6: EXAMPLE OF A HIGH-INTENSITY FOREST FIRE

2.5 FOREST FIRE RESILIENCE

Forest fires and the smoke they generate once again filled the news in 2020. Wildfire risks are driven by two 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 North America. High-intensity wildfires are evermore common, with proportionately severe consequences, see **Figure 2.6**.

Many land managers, scientists, wildfire managers, and increasingly, the public, are calling for action to mitigate these risks. Two common treatments to reduce wildfire risk are thinning, or the removal of forest fuels including some trees and underbrush; and controlled burning, or 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 tolerance for cutting or burning trees across the landscape is low. Some treatment areas are in municipal watersheds with reservoirs that serve domestic and agricultural water users.

The process of thinning and/or prescribed burning of these overgrown forests is costly. That's because the cost of removing smaller trees is almost always greater than their commercial value.

FIGURE 2.7: THE EFFECT OF FOREST MANAGEMENT ON FIRE BEHAVIOR

Source: USDA Forest Service How Fuel Treatments Saved Homes from the Wallow Fire, Location: Wallow Fire, Accessed at: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5318765.pdf

However, when thinning and burning costs are weighed against the immense cost of firefighting and the associated losses 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 saved property, lives, and even communities. For example, **Figure 2.7** shows how forest management affected the Wallow Fire in Arizona. High on the ridge (upper portion of photo), the fire killed the trees as it burned with high intensity through the tree crowns. Lower on the ridge (middle portion of photo), the forest had been thinned prior to the fire, and when the flames reached that area, the fire dropped from the tree crowns and became a much lower intensity ground fire that allowed the trees to survive and firefighters to prevent the loss of several homes and structures (foreground of the photo).

Thinning can be accomplished with mechanical harvesting equipment or by crews sawing trees and piling them for burning, or with planned low-to moderate-intensity burns completed under prescribed conditions. Often, the two tools (thinning and burning) are used in conjunction with

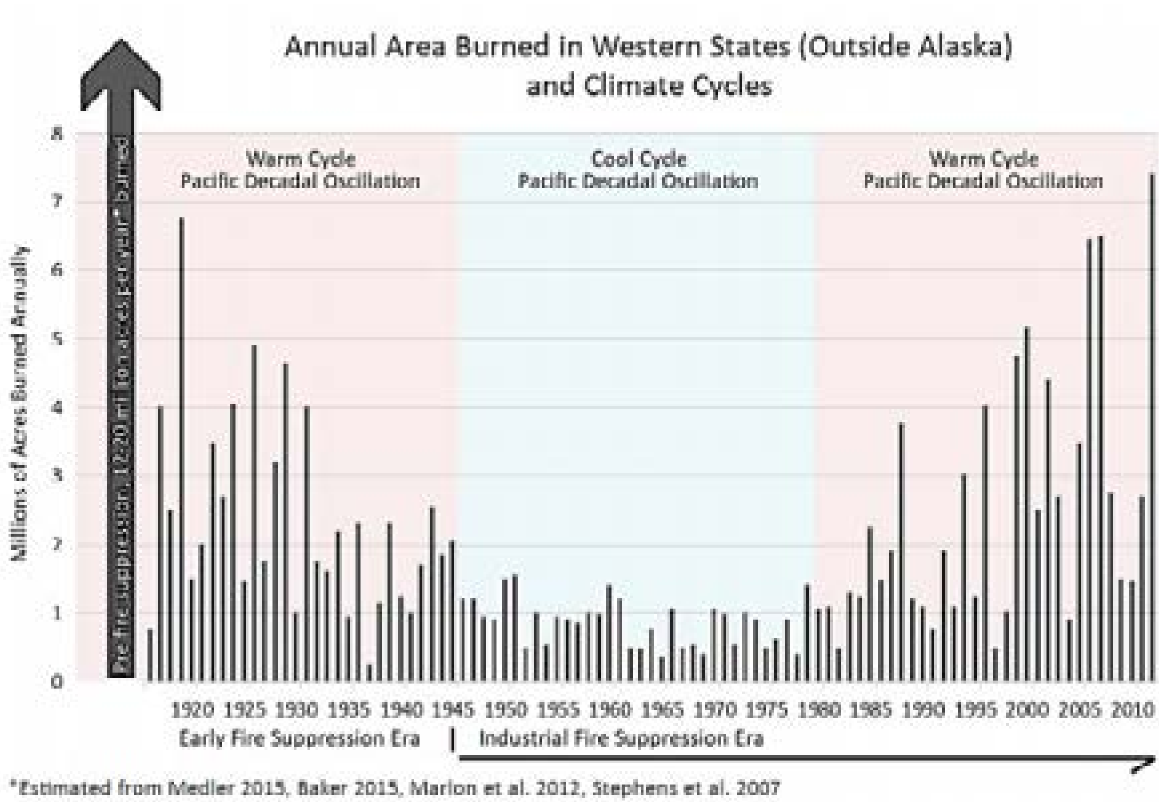


FIGURE 2.8: HISTORY OF ANNUAL BURNED AREA IN WESTERN STATES

Everything You Wanted To Know About Wildland Fires in Forests But Were Afraid to Ask, DellaSalla, Ph.D, Ingalsbee, Ph.D, Hanson, Ph.D, 2018

one another with greatest efficacy. Some trees in need of removal can be used for forest products, including mass timber. When such markets exist, it's considerably more affordable to manage forests for the desired outcomes.

For as long as humans have wielded fire and tools for cutting, forests have been managed in every region of the globe; prehistorically, there is evidence that human intervention increased and improved the health and diversity of forests, while providing a sustainable source of wood for building, weaving, and toolmaking. In modern times, well-intentioned efforts to "preserve" natural areas have led to overcrowded trees and a number of disastrous outcomes, including pine beetle outbreaks and megafires. Industrial fire suppression techniques began in earnest in the 1940s, along with a very successful Smokey Bear Fire Prevention campaign, engaging a public view strongly favoring the active prevention of forest fires. This has led to an overall deficit in wildfires in North American forests compared to preindustrial cycles, see **Figure 2.8**.

Forest fires—even large, high-intensity fires—are essential for biodiversity and a healthy forest ecosystem. Forests are additionally strained by the longer and more intense heat and drought seasons of recent decades. Climate change, in combination with colonial fire-suppression imperatives and some types of industrial forestry practices, has created a situation where forests are primed to, potentially, quickly release a significant amount of the carbon they currently sequester.

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

2.6 FOREST CARBON

Forests are key to the Earth's natural carbon capture and storage system. As part of the photosynthesis process, trees take in carbon dioxide (along with sunlight and water) to create simple carbohydrates, or sugars, that can be used to either nourish their existing cells or create new cells (growth). When used for growth, carbon is stored by creating woody material. When the sugars are consumed for nourishment, the tree releases carbon dioxide as a byproduct back into the atmosphere. In the United States alone, forests store more than 14 billion metric tons of carbon, not counting Alaska and Hawaii (see **Table 2.12**).

If unaltered by human activity, the complete life cycle of a tree is carbon neutral. However, this cycle can take hundreds of years to complete, depending on local conditions and the species involved. Some are relatively short-lived (only 80 to 120 years), such as quaking aspen and lodgepole pine. Others can live many centuries, such as ponderosa pine, Douglas fir, Western larch, and others. A forest is often a mix of different species of varying lifespans and adaptations. Some ecosystems have frequent natural disturbance cycles, only decades apart, and others have cycles lasting centuries. Disturbances come in a variety of forms: fire, insect epidemics, drought, hurricanes, ice storms, windstorms, and more. And many of these interact with each other, creating synergies among them. For example, a windstorm can blow down hundreds or thousands of acres of trees to then provide a food base for bark beetles or other insects to breed and expand their populations to then attack live trees. These events can then set the stage for high loads of fuel in the forest that can feed a severe wildfire.

The natural, or unmanaged, tree and forest cycles can be thought of as having three phases: carbon capture, carbon storage, and carbon release. The cycle for an individual tree and the overall forest may or may not be synchronous depending on the disturbance regime. In the first phase of the cycle, a tree grows and uses carbon dioxide absorbed from the atmosphere as its 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 current systems, and so is not as efficient at capturing and storing carbon. In the third phase, the tree releases more carbon than it captures as it declines in vigor and parts of the tree may begin to decay. It then dies of old age, disease, insect attack, or fire, eventually releasing most of its remaining carbon back into the atmosphere. A portion will remain in the soil, if undisturbed. In the natural forest, while some trees decline or die, others will regenerate, grow, and replace them, and in the process absorb and sequester more carbon. In a forest with a long disturbance cycle, the dead trees might retain

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 2.12: TONS OF CARBON IN FORESTS BY STATE BY OWNERSHIP TYPE (METRIC TONS IN MILLIONS)

FIGURE 2.9: FOREST PRODUCTS' CARBON STORAGE

quite a bit of carbon as they slowly decay, or they might release it relatively quickly if the species of wood is more susceptible to rot. If it is a forest with more frequent disturbances, like fire, then the carbon stored in dead wood, litter, and duff is much lower.

As part of actively managing forests, the carbon cycle can be extended. After trees are harvested, they can be manufactured into durable, long-lived products that can continue storing carbon while in service. The harvested forests regenerate with vigorous growth, starting a new cycle. Active forest management often decreases natural mortality and captures usable material before the carbon release cycle begins. Wood then enters the industrial cycle in the form of products that store carbon in building structures, furniture, packaging, and paper, see **Figure 2.9**.

The carbon sequestration impact of a wood product is contingent on how the forest it comes from is managed. Forest certifications like FSC and SFI help consumers source sustainable materials, but it is often unclear which practices are more effective at achieving various outcomes desired in the market. A lot depends on the kind of forest in question. Ongoing research will help inform the evolution of forest practices in an era of critical carbon sequestration, and show how building design teams can incorporate wood into their Life Cycle Analyses (LCA).

Consensus around how to shift practices to a balanced triple-bottom line in forestry is desirable at each point in the wood products supply chain, but the path forward is not yet clear. Fortunately, the exponential increase in interest in mass timber products has captured the public imagination in ways not seen since Smokey Bear, pushing a much-needed wave of multidisciplinary conversations around Carbon Stewardship in forests.

Because forests have such a critical role in absorbing atmospheric carbon, it is important to avoid converting forestlands to other uses. Although it may seem counterintuitive to many, one way to ensure that forestlands remain forested is to provide an economic return to the landowners. North America and Western Europe have some of the highest per capita wood use in the world, but they also have net positive forest growth. That's because the demand for and value of wood products creates an economic incentive to maintain forests as a land use. In developing countries, deforestation is often driven by the desire to produce something more valuable for the landowner, so the land is converted to other non-forest uses. Thus, increasing the demand for and value of wood and the forests that produce them reduces the risk of deforestation.

CREE BUILDINGS

About CREE

CREE is an international technology and consultancy firm, dedicated to sustainable and healthy buildings using prefabricated timber-based components. Their unique hybrid approach revolutionizes the construction industry.

BUILDING TYPES AND SWEET SPOT

- Heights of up to 30 stories possible
- Commercial, residential or mixed-use large volume buildings
- Projects starting at 3,000 m²

BENEFITS OF THE CREE SYSTEM

- Structure based on standardized, prefabriacted timber-hybrid system components
- Quality, schedule, and cost certainty
- Higher construction productivity and speed – 400-500 m² per day of floor space (air/weathertight)
- Repeatable design solution with highly adaptable floor space
- Healthy and attractive indoor environment through exposed wood elements
- Reduced operation and maintenance costs
- Up to 80% reduction in $CO2$ emission; "Core & Shell" are carbon-negative

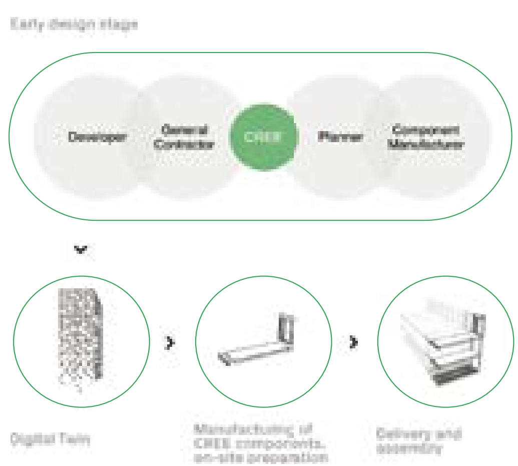
Find more details here:
creebuildings.com/system/

THE CREE PLATFORM

Our innovative digital platform exists to foster an eco-system for users to continuously develop and share knowledge and resources with each other. It is not only a space to interact with or mobilize peers and partners, but also to exchange and refine ideas that will have a visible impact on the construction industry and beyond. Here we ensure that our shared vision continues to expand, improve, and evolve. Find more information here:
creebuildings.com/platform/

THE CREE PROCESS

The early engagement of CREE in the design-and-build process, plus early involvement of all stake-holders, is key. Workflow simulations carried out in the digital twin, prefabricated modules and CREE's active participation as a knowledge provider for the manufacturer also lead to real efficiency in construction projects. Find more details here:
creebuildings.com/system/



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Our global partner network currently extends from Europe to Asia and North America. Find our locations here: creebuildings.com/contact/

CHAPTER 3: RAW MATERIALS

IMPACTS OF THE MASS TIMBER EFFECT

- It is estimated that each square foot of building constructed with mass timber consumes, on average, 0.9 cubic feet of mass timber raw material (panels and beams).
- Each cubic foot of finished mass timber (panels) is estimated to require 22.5 board feet (nominal tally) of dimensional lumber to produce.
- US and Canadian softwood lumber production in 2020 was about 60 billion board feet. There is ongoing significant investment in softwood lumber sawmilling capacity in the US South.
- Mass timber is 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 given sawmill's output capacity, the sawmiller's ability and willingness to do "extra" drying is an important factor in mass timber's raw material supply chain.

It's a fact: manufacturing mass timber requires raw material that, in the case of most mass timber products, is dimension lumber made from various softwood species. Those interested in mass timber will find it helpful to understand key features of these raw materials as they are used in mass timber applications. Accordingly, this chapter includes a technical analysis of the raw material specifications for the use of mass timber; a look at the production capacity among mass timber's raw material manufacturers (e.g., sawmills); and an estimation of the demand that mass timber's development could create for raw material suppliers.

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

3.1 RAW MATERIAL SPECIFICATIONS

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

3.1.1 CROSS LAMINATED TIMBER

Before launching into a technical discussion about how lumber can be used in mass timber, it's helpful to first understand the terminology. Every CLT panel has major and minor strength axes. The major axis is the direction with the greatest number of layers of wood grain having a parallel orientation. For example, **Figure 3.1** below shows

1 Structural Composite Lumber 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.

a 3-layer panel. In the two outer layers, the grain of the wood is *parallel*, and thus the longest axis of the panel is the major strength direction. Note: sometimes the parallel axis is also called the *longitudinal* axis. In the middle layer of the panel, the wood grain is oriented *perpendicular* to the adjacent layers. Because there is only one perpendicular (or *transverse*) layer, it is the panel's minor strength direction. The following technical sections reference these preceding italicized terms.

The Engineered Wood Association (APA) developed a standard that addresses the manufacturing, qualification, and quality assurance requirements of CLT panels. It's called *ANSI/APA PRG-320 – 2020: Standard for Performance-Rated Cross Laminated Timber*. The 2020 edition was approved by the American National Standards Institute (ANSI) on January 6, 2020. At the time of this writing, it was the most recent approved version. However, readers should check www.apawood.org to see if a more recent version is available.

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

Species: Lumber from any softwood species[2] or species combination (e.g., hem-fir, fir-larch, spruce-pine-fir, etc.) recognized by the American Lumber Standards Committee under PS 20 or the Canadian Lumber Standards Accreditation Board under CSA-0141 with a minimum published specific gravity of at least 0.35 is permitted. Importantly, any given layer (lamination) in a CLT panel shall 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 meeting the standards of ASTM D5456, it is permitted.

Lumber Grade: The distinction between major and minor strength axes is important as it relates to lumber grade because differing grades are required depending on whether the lumber is in a longitudinal or transverse layer. Lumber is graded in one of two 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, accordingly, 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 at least visual grade No. 3 or equivalent. Any proprietary lumber grades meeting or exceeding the mechanical properties of the approved CLT lumber grades can be used if they are qualified by an approved agency.

Thickness: The minimum thickness of any lumber layer in a CLT panel is ⅝ inch (16 mm) at the time of gluing. Maximum thickness is 2 inches (51 mm) 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 (0.20 mm) across the width of the layer, and plus or minus 0.012 inch (0.3 mm) across the length of the layer. Any bow or cup present in lum-

2 The higher a species' specific gravity, the more dense the wood, and generally the more dense the wood, the greater its strength properties. Douglas fir, larch, Western hemlock, Southern yellow pine, lodgepole pine, Norway pine, various spruce species, and various true firs are all 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	1.50	2.00	1x2	0.75	1.50	2.00
1x3	0.75	2.50	3.33	1x3	0.75	2.50	3.33
1x4	0.75	3.50	4.67	1x4	0.75	3.50	4.67
1x6	0.75	5.50	7.33	1x6	0.75	5.50	7.33
2x2	1.50	1.50	1.00	2x2	1.50	1.50	1.00
2x3	1.50	2.50	1.67	2x3	1.50	2.50	1.67
2x4	1.50	3.50	2.33	2x4	1.50	3.50	2.33
2x6	1.50	5.50	3.67	2x6	1.50	5.50	3.67
2x8	1.50	7.25	4.83	2x8	1.50	7.25	4.83
2x10	1.50	9.25	6.17	2x10	1.50	9.25	6.17
2x12	1.50	11.25	7.50	2x12	1.50	11.25	7.50

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

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

ber "should be small enough to be flattened out by pressure in bonding."

Width: For longitudinal layers, the net lamination width for each board shall not be less than 1.75 times the net lamination thickness. For transverse layers, the net width of a board shall not be less than 3.5 times the net thickness of the board. **Table 3.1** illustrates the thickness-to-width ratios for the longitudinal and transverse layers of common lumber sizes. Note that it is common practice for CLT manufacturers to plane about 1⁄16 inch off all four sides of a piece of lumber prior to panel lay-up. Thus, the width-to-thickness ratios of a board's final dimension may differ slightly from those shown in the table. The rows highlighted in red are lumber sizes that do not meet the standard for ratio of width to thickness. Notably 2-by-4 lumber, which is one of the most commonly produced sizes 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: For lumber used in CLT panels, the moisture must be 12 percent, plus or minus 3 percent, when the panel is manufactured. Because lumber shrinks or swells as it loses or gains moisture, the moisture content of lumber used in mass timber panels is a key focus area for mass timber manufacturers. It is also an important part of the lumber manufacturing process because the majority of lumber is sold after it has been kiln-dried. Importantly, the lumber grading rules require that lumber be dried to a minimum of 19 percent moisture content. Given these circumstances, during market conditions when demand for lumber is strong, sawmills may be reluctant to reduce kiln capacity by running batches of "mass timber lumber" for a longer-than-normal drying cycle. This issue is further discussed in Section 3.4 and from the perspective of the mass timber panel manufacturer in Chapter 4.

Surfacing: Any sawn lumber used in a CLT panel must be planed or sanded, at least on any surfaces to be bonded, and the planed (or sanded) surface must not have any imperfections that might adversely affect the bonding process (i.e. raised grain, torn grain, skip, burns, glazing, or dust). ANSI and the APA also include a note important to understanding the intricacies of bonding the layers within a CLT panel. It states that for some species, it may be necessary to plane the bonding surfaces within 48 hours of the actual bonding process. Planing or sanding of face-bonding surfaces of SCL used to make CLT panels is not required, unless needed to meet thickness tolerances.

3.1.2 NAIL LAMINATED TIMBER

The International Building Code recognizes NLT as a structural material and provides guidance for structural and fire safety resistance design. No product-specific ANSI standard has been developed, however, but design guides are available for both the U.S. and Canada, and they can be downloaded for free at *www.thinkwood.com*. NLT is commonly manufactured at the building site by simply nailing pieces of lumber together after they have been arranged so that the wide faces are touching the adjacent piece. Virtually any properly graded softwood dimension lumber can be used to make NLT. However, considerations such as cost, availability, species, structural performance (grade), and aesthetics all come into play when making material selections. Most NLT panels manufactured to date utilize No. 2 grade dimension lumber in 2-by-4, 2-by-6, and 2-by-8 sizes. The moisture content of lumber used in NLT panels must be below 19 percent before NLT fabrication.

3.1.3 DOWEL LAMINATED TIMBER

The structural design of each lamination in a DLT panel is covered by both the International Building Code and the National Building Code of Canada. The ICC-ES Evaluation Report ESR-4069, published in November 2020, provides guidance for 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. Additionally, StructureCraft, a North American mass timber manufacturer of DLT, has developed a design guide.

Species and Grades: DLT panels are made from Spruce, Pine, Fir (SPF), Douglas fir, and hem-fir species or species groupings. Panels made from other species are available on request. The structural grades used 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 used in manufacturing must be kiln-dried to 19 percent or less moisture content at the time of manufacture. Note that the hardwood wooden dowels used to join the DLT laminations are at a much lower moisture content at the time of manufacture. When the drier dowels are exposed to the wetter softwood laminations, they gain moisture, swell, and, thereby, form a tight connection between laminations.

GRADES	1. PREMIUM	2. SELECT	3. STANDARD	4. INDUSTRIAL
COMMON APPLICATION	Residential, Hotels, Feature Walls	Residential, Libraries, Schools, Museums, Offices	Offices	Non-visual, high ceilings
SPECIES	SPF, Dfir (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 ≤1/8" Length ≤2' No bark	Width ≤1/4" w/o bark, Length ≤5' w/ bark, Length ≤2' Max 1 every 5 boards	Width ≤3/8" w/o bark, Length ≤ 10' w/ bark, Length ≤ 7' Max 1 every 4 boards	Permitted
KNOTS	No open Knots Tight Knot Permitted	Open Smooth ≤3/4" Dia Open Jagged ≤1/2" Dia 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	Non-permitted	Width ≤1/16" Length ≤12"	Width ≤1/16" Length ≤ 24"	Permitted
CHARACTERISTICS DISTRIBUTION	Distributed	Distributed	Some distribution	No re-distribution required
PANEL SURFACE	Deviation on board-to-board elevation <= 1/8".		Deviation on board-to-board elevation <= 1/4".	Deviation permitted.
UNNATURAL BLEMISHES	Except for Type 4 (Industrial), the underside of the DLT panel shall be free of "unnatural" characteristics, eg. black marks, scuffs, damage, glue, etc. Such blemishes shall be sanded/required as needed.			
CHARACTER OF WOOD	All wood, as a natural material, will exhibit characteristics such as knots/holes, wane, grain, checks, coloration, etc. The intent of the above appearance grading is to provide a degree of predictability/ limitation to these characteristics. However, some variations in the visual appearance will be apparent			

TABLE 3.2: LUMBER CHARACTERISTICS ALLOWED WITHIN STRUCTURECRAFT DLT PANEL GRADES

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

Lumber Size: DLT panels are made in thicknesses ranging between 4 inches and 12.17 inches. Lumber widths are available from 2 inches to 6 inches (nominal).

Appearance: StructureCraft has developed four grades of DLT panels: Premium, Select, Standard, and Industrial.

Table 3.2 specifies the lumber characteristics allowed within each of StructureCraft's grades.

SPECIES GROUP	SPECIES INCLUDED IN GROUP
ALASKA CEDAR	Alaska cedar
DOUGLAS FIR-LARCH	Douglas fir, Western larch
EASTERN SPRUCE	Black spruce, red spruce, white spruce
HEM-FIR	California red fir, grand fir, noble fir, Pacific silver fir, Western hemlock, & white fir
PORT ORFORD CEDAR	Port Orford cedar
SOUTHERN YELLOW PINE	Loblolly pine, longleaf pine, shortleaf pine, slash pine
SPRUCE-PINE-FIR	Alpine fir, balsam fir, black spruce, Engelmann spruce, jack pine, lodgepole pine, Norway pine, Norway spruce, red spruce, Sitka spruce, white spruce
SOFTWOOD SPECIES	Alpine fir, balsam fir, black spruce, Douglas fir, Douglas fir south, Engelmann spruce, Idaho white pine, jack pine, lodgepole pine, mountain hemlock, Norway pine, Norway spruce, ponderosa pine, Sitka spruce, sugar pine, red spruce, Western larch, Western red cedar, white spruce

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

3.1.4 GLULAM

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

Key specifications include:

Species: The ANSI A190.1-2017 standard states that any softwood or hardwood species is approved for use in structural glued laminated 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: For dry-service conditions, wane up to ⅙ the width at each edge of interior laminations is permitted in certain grade combinations. When this is the case, the basic shear design value shall be reduced by ⅓. When wane is limited to one side of the 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 shall be either visually graded, mechanically graded, or proof graded, and shall be identified by grade before bonding. Visually graded lumber shall be graded according to standard grading rules approved by the Board of Review of the ALSC or written laminate grading rules. Mechanically graded lumber shall be graded according to standard grading rules approved by the Board of Review of the ALSC or special rules that conform with the A190.1 standard. Proof-graded lumber shall be qualified under the supervision of an accredited inspection agency. Such proof-graded lumber shall be subjected to quality control based on full-size tension tests, as set forth in ATIC 406. Proof grading shall be limited to individual pieces of lumber without end joints. A variety of more specific grading rules apply depending on the position of the piece in the glulam timber, species, whether the lumber is ripped prior to bonding, etc. See A190.1-2017 for details.

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

Thickness: Laminations shall not 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. The variation in thickness along the length of an individual piece of lumber or along the lamination shall not exceed plus or minus 0.012 inches.

3.1.5 POST AND BEAM

Traditionally, post and beam construction utilizes large timbers of nominal width and thickness, and of at least 6 inches. There is less guidance about the specification of lumber (timbers) for this category of mass timber than for other forms. Nevertheless, The Code of Standard Practice for Timber Frame Structures (2018) developed by the Timber Frame Guild (*www.tfguild.org*) provides some guidance. A few basic specifications are:

Grade: Grade shall be Select Structural, No. 1, or No. 2. All structural timbers shall be graded by a grader certified by an approved lumber grading agency or a qualified individual who has completed a timber grading training course. Timbers shall bear a grade stamp or certificate of grade from the lumber grader. 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 shall not be construed as defects.

Species: Acceptable species include Douglas fir, Eastern white pine, red oak, white oak, Southern pine, and Alaska yellow cedar.

Moisture: Timbers shall be dried to a maximum moisture content of 19 percent.

Size: Timbers 8 inches by 12 inches and smaller shall be Free of Heart Center (FOHC). Timbers larger than 8 inches by 12 inches shall be boxed heart. All timber sizes are nominal (actual) dimensions.

Surfacing: Timbers may be Surfaced Four Sides (S4S), rough sawn, or hewn.

3.1.6 HEAVY TIMBER DECKING

Specifications for heavy timber decking are less prescriptive than other mass timber products. Some guidance is provided by a document titled *Heavy Timber Construction* published by the American Wood Council. Key excerpts include:

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

Sizing: The decking used in heavy timber floor decks shall be of sawn or glued laminated plank, splined, or tongue-and-groove plank not less than 3 inches, nominal, in thickness, or of planks not less than 4 inches, nominal, in width set on edge. For roof applications, the timbers shall be sawn or glued laminated, splined, or tongue-and-groove plank not less than 2 inches, nominal, in thickness or of planks not less than 3 inches, nominal, in width set on edge.

3.1.7 VENEER

Freres Lumber Company in Oregon is the only manufacturer in the world making mass timber panels and mass timber beams and columns using wood veneer as the basic raw material. Their mass timber products are ANSI/APA PRG 320 certified and include mass plywood panels up to 11 feet 10 inches wide, 12 inches thick, and 48 feet long. Freres recently announce that it can manufacture beams and columns made from veneer, which ANSI/APA PRG 320 certified in dimensions up to 12 inches wide, 72 inches deep, and 48 feet long.[3]

The veneers used are first formed into Laminated Veneer Lumber (LVL) billets that are subsequently formed into mass plywood panels. Because the veneers are first formed into LVL billets, certification of mass plywood panels falls under the classification of SCL (SCL; it includes LVL and is covered under ASTM D5456.

More specifically, the manufacturing process involves using wood veneers to manufacture LVL billets. These billets are 1.6E, 1.55E, or 1.0E Douglas fir LVL recognized by APA in product report PR-L324 in accordance with custom lay-ups of ANSI/APA PRG 320 through product qualification and mathematical models using principles of engineering mechanics. The LVL billets can range in thicknesses between 1 inch and 24 inches and widths between 1.5 inches and 72 inches. Depending on the dimensions of the billets and MPP design needs, the billets are parallel laminated, bonded with qualified structural adhesives, and pressed to form a solid panel (i.e., MPP).

In summary, Freres uses veneer from Douglas fir to produce its mass plywood panels. Veneers used in LVL manufacturing are classified by species, moisture content, and veneer grade (G1, G2, G3) with the grade heavily dependent on strength as measured by Ultrasonic Propagation Time

3 The equipment Freres uses to make the columns and beams can handle widths up to 24 inches. Freres is currently 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.

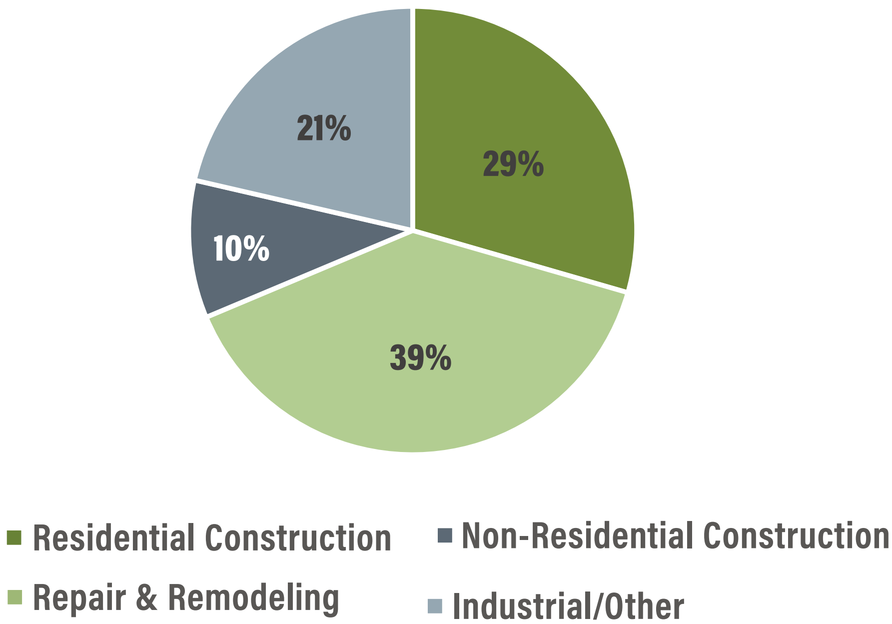


FIGURE 3.2: CONSUMPTION BY LUMBER MARKET END-USE SEGMENT (AVERAGE 2010 TO 2019)

(UPT) testing, which correlates the time it takes for sound to pass through wood veneers to key strength determinants, such as specific gravity and modulus of elasticity. Importantly for Freres, they are also a manufacturer of veneer and plywood. Thus, through other businesses owned by the company, they control the raw material supply for their mass timber manufacturing operations from standing timber through the entire mass timber manufacturing process.

3.2 NORTH AMERICAN LUMBER SUPPLY

As the number and size of mass timber construction projects continues to grow, the capacity of sawmills to supply lumber, the key raw material in mass timber products, is an issue of considerable interest. Thus, this section focuses on softwood lumber production and use in North America.

3.2.1 END-USES FOR SOFTWOOD LUMBER

Historically, softwood lumber has been used in four key end-use market segments including: Residential Construction, Repair and Remodeling, Non-Residential Construction, and Industrial/Other. **Figure 3.2** illustrates the average portion of softwood lumber consumed by each end-use market segment for the period from 2010 to 2019 in the United States. As the data show, for the last 10 years, on average, nearly 40 percent of all softwood lumber consumed was for repair and remodeling, followed by nearly 30 percent in residential construction of new homes. Thus, historical softwood lumber demand has been strongly linked to either

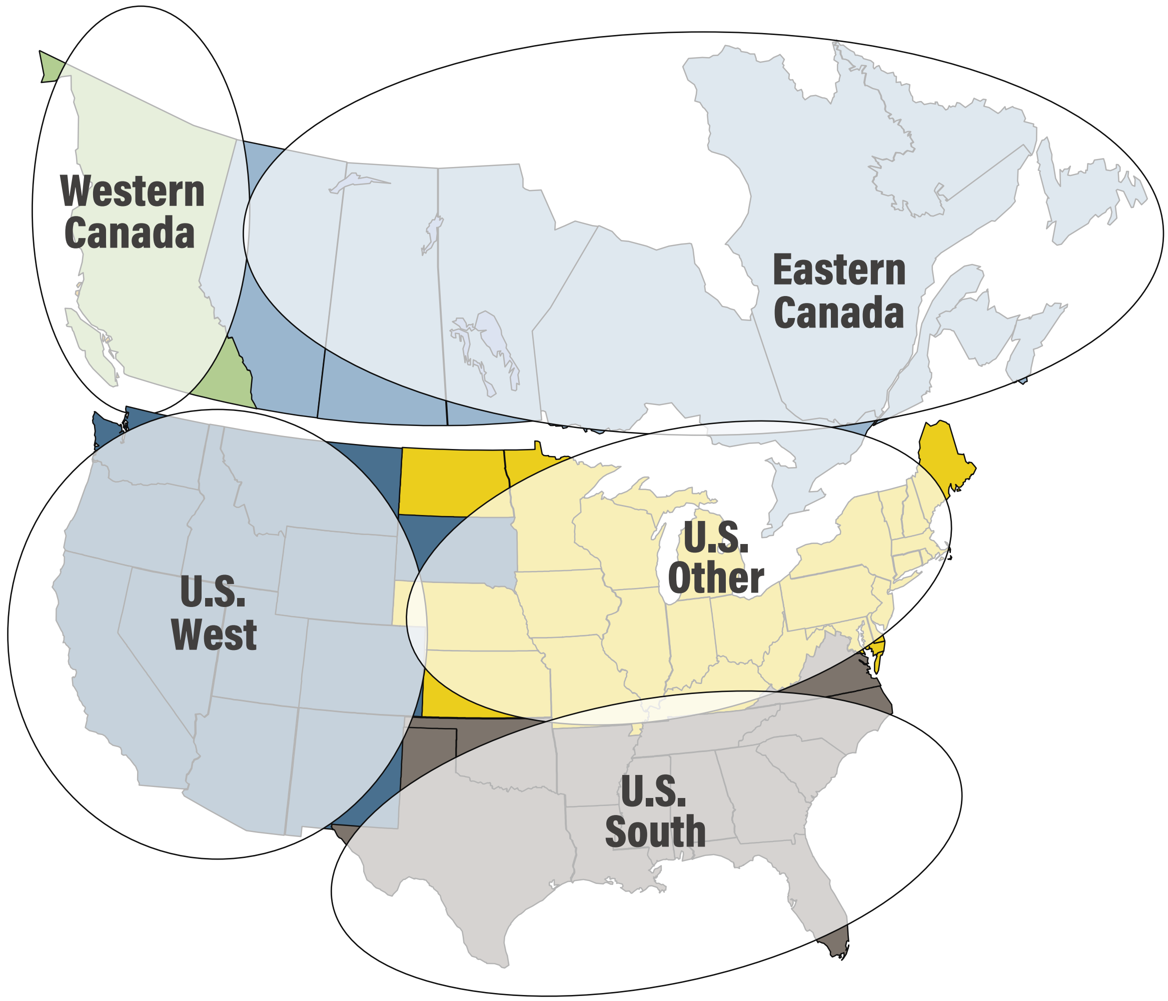


FIGURE 3.3: NORTH AMERICAN SOFTWOOD LUMBER PRODUCING REGIONS

new home construction, or repair and remodeling of existing homes. The Industrial/Other end-use segment is lumber typically used for applications such as packaging, pallets, furniture, etc. Generally, the lower grades of lumber are most utilized in this sector. The advent of mass timber and the new demand it places on softwood lumber is the focus of the remainder of this chapter.

3.2.2 WHERE SOFTWOOD LUMBER IS PRODUCED IN NORTH AMERICA

Softwood lumber in North America is produced in five geographical regions, including the US West, US South, US Other, Western Canada, and Eastern Canada. **Figure 3.3** illustrates these locations. Note that in the US South, 4 species of pine (loblolly, longleaf, shortleaf, and slash) are commonly manufactured into lumber and sold as a species grouping designated as Southern Yellow Pine. In Eastern Canada and Western Canada, the predominant lumber grouping is SPF, but the makeup of species within the SPF

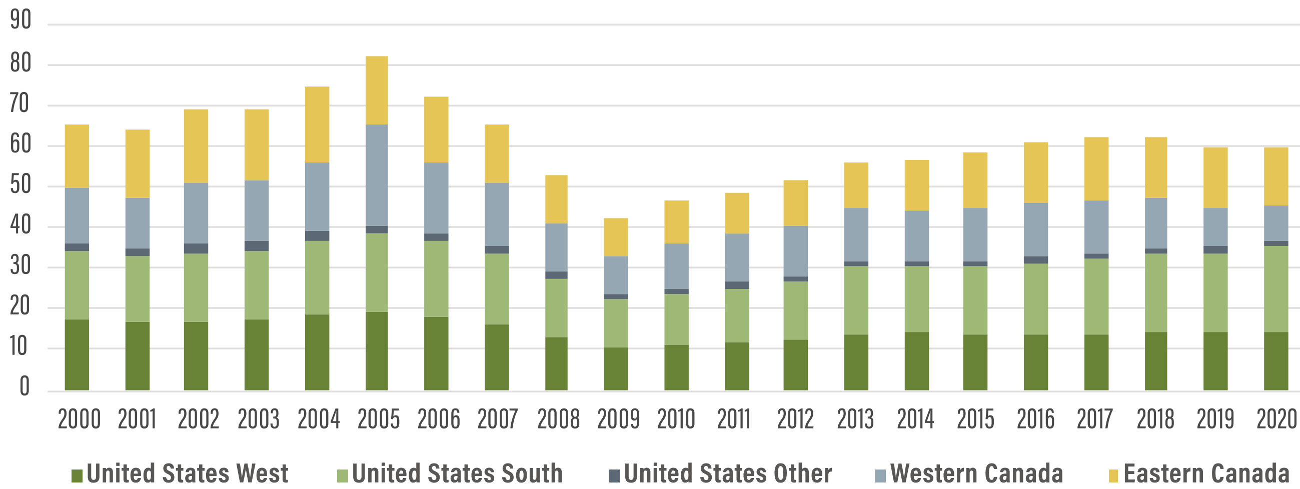


FIGURE 3.4: HISTORICAL UNITED STATES AND CANADIAN SOFTWOOD LUMBER PRODUCTION BY REGION (BOARD FEET IN BILLIONS)

lumber grouping differs throughout Canada. In the US West, the predominant lumber species or species groupings are Douglas fir, Douglas fir-larch, and hem-fir.

Figure 3.4 shows the volume of softwood lumber produced in each North American region for the period from 2000 to 2020 as reported by the WWPA (2020 is a forecast based on the first six months of the year). Note that there is some difference in lumber production and consumption (i.e., some lumber produced hasn't been sold when data is collected for the WWPA reports). To simplify the discussion, we treat production and consumption as being equal because the volume in inventory is typically a small portion of total annual production.

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. Also, the US West and US South were nearly equal in production at the time with about 19 billion board feet produced each.
- Lumber production across North America decreased dramatically during the Great Recession, with totals in 2009 dropping to only about 50 percent of the 2005 peak.
    - Since the low in 2009, North American lumber production has increased steadily through 2018. However, during the long climb several shifts in regional production occurred:

Western Canada: One of the most dramatic changes is that Western Canada went from producing 25 percent of North America's lumber in 2005, to producing only an estimated 14 percent in 2020. That change is mainly driven by reductions in the annual allowable cut 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 pine timber. The outbreak started in the 1990s, and during the 2000s, timber harvests were significantly increased to salvage the standing dead timber.

The salvage efforts are now complete, but current and future harvests have been significantly reduced to allow annual forest growth to rebuild to a level where the standing inventory of timber will once again allow for higher harvest levels. The rebuilding of standing inventory is a long process, meaning the reduced timber harvest rates in the interior region of British Columbia will remain in place for the foreseeable future. The sawmill industry in the region was built up during the salvage period, and the existing capacity is too large for the available log supply. As a result, many sawmills across the region have permanently closed.

US South: Perhaps equally dramatic are the changes occurring in the US South. Prior to the Great Recession, the US South and the US West produced roughly equal amounts of lumber each year. However, since the Great Recession, the US South has bounced back. In recent years, the US South produced 19 to 20 billion board feet of lumber per year—levels that exceed even the peak year of 2005.

Key drivers in the rise of US South lumber production are the short, 30-year timber harvest rotation that has been brought about by improved forest practices (e.g., genetic improvement of seedlings, extensive planting and thinning operations, etc.). The end result is higher volume yields per acre. Thus, during the significant years-long drop in lumber production during the Great Recession, a massive amount of sawtimber inventory built up "on the stump."

Additionally, about 85 percent of the timber in the region is owned by private landowners, meaning saw timber harvest levels are largely dictated by economic drivers rather than regulatory drivers. These conditions have spurred massive capital investment in new sawmilling capacity across the US South through a combination of upgrades to existing mills and greenfield (i.e., new mill at a new site) sawmill development. Approximately 4.5 billion board feet of capacity have or will come online in the near term. The Beck Group estimates that the capital investment associated with the increased sawmilling capacity across the US South is approximately $2.5 billion. It is worth noting that the 4.5 billion board feet of new/upgraded capacity and associated capital investment are a "first wave" of projects that are largely complete or ongoing. Despite the increased capacity, there are still regions in the US South with excess saw timber supply. Thus, companies are planning further investments in sawmilling capacity in the region.

US West: Lumber production in the US West has been essentially flat at 14 billion board feet annually since 2014. This is caused by several key drivers. First, for several years following the Great Recession, log exports from the US West Coast to China, Japan, and Korea increased greatly. Those increased exports translated into fewer logs available for domestic mills to process into lumber. In recent years, however, the level of log exports has declined significantly, especially in 2019 and 2020.

Second, log supplies are also constrained by who owns the timberland in the US West. Privately held timberland accounts for about 70 percent of the total harvest. Industrial timberland owners manage their timberlands intensively

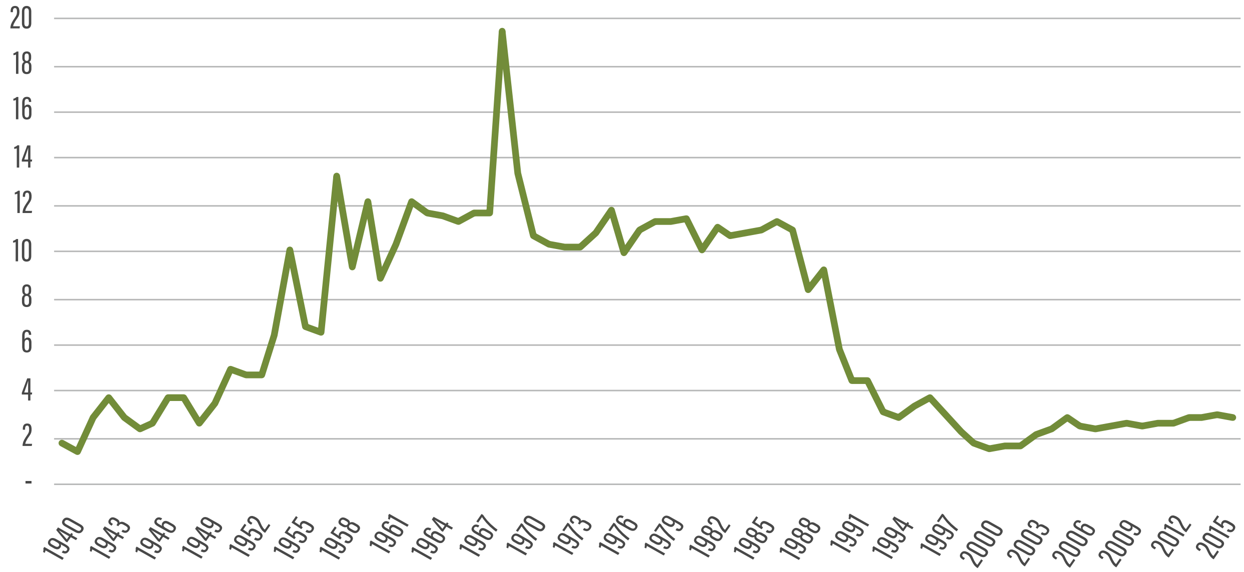


FIGURE 3.5: HISTORY OF US FOREST SERVICE TIMBER SALES FISCAL YEAR 1940 TO FISCAL YEAR 2017 (ANNUAL VOLUME BOARD FEET [LOG SCALE] IN BILLIONS)

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

and are generally harvesting near maximum allowable sustainable rates. Thus, harvests on industrial lands cannot increase to supply more logs to mills. Small private timberland owners account for a significant acreage and a considerable portion of the annual timber harvest across the US West. However, this segment of timberland owners is made up of many thousands of individuals and families. As a group, small private landowners typically do not act in sync because individuals within this group have a variety of management objectives, and timber production is not always a top priority. Thus, small privately held timberland could account for additional log supply, but the individual owners do not act collectively, constraining log supply from this source.

The balance of the timberland in the US West is under public ownership (e.g., the US Forest Service, the Bureau of Land Management, and miscellaneous states, counties and municipalities). In fact, about 70 percent of all timberland acres in the US West are publicly owned, a very high percentage relative to public ownership of timberland 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, in turn limiting lumber production.

For nearly 4 decades starting in the mid 1950s, the US Forest Service sold 10 to 12 billion board feet of logs each year. However, changes to federal land management policies spurred by changes to the Endangered Species Act resulted in the listing of the Northern Spotted Owl, various salmon species, and the Marbled Murrelet. All combined to result in a dramatic decline in the annual volume of timber sold by the US Forest Service since 1988 (**see Figure 3.5**). Data from the US Forest Inventory and Analysis (FIA) database suggests that despite the massive tree mortality from many wildfires across the US West in recent years (which have been heavy on public lands), federal lands are currently growing 3 times more wood fiber than is being removed via harvests and natural mortality. This suggests that timber harvests could be increased significantly on federal lands across the US West without endangering the sustainability of the timber resource. In the meantime, increased lumber production across the US West is largely held in check by limited log supply.

Eastern Canada: Like other North American regions, except for the US South, lumber production in Eastern Canada has been stagnant for the last 5 years, generally hovering between 14.5 and 15.0 billion board feet per year. Unlike Western Canada, where timber supply is constrained due to the lingering effects of the mountain pine beetle, standing timber is readily available in the region. However, parts of Eastern Canada are a very long distance from markets, and the small tree size in those parts increases manufacturing costs where there are economic constraints on sawmill production capacity. For example, relative to mills in other regions in North America, the annual production capacity of an average mill in Eastern Canada is small. Generally, larger mills enjoy economies of scale, allowing for lower manufacturing costs. Also, historically, Eastern Canada has had a high concentration of pulp and paper mills producing newsprint. Those pulp mills were largely supplied via residue from sawmills. As demand for newsprint has steadily dwindled, the economics of producing lumber from very small logs has become more difficult, constraining milling capacity in the region.

Finally, as alluded to in the preceding paragraph, tree size in Eastern Canada is small relative to other regions of North America. This means that lumber tends to be narrower and shorter. Also, to produce a reasonable annual lumber volume, the mills in the region must operate their lines at very high throughput rates (because of small average piece size). The mills likely have little ability to further increase throughput rates to increase mill production. However, in late 2020, Quebec announced plans to nearly double the amount of wood harvested each year in the province over a period of 60 years. Few details about the plans were available, but, over time, an increasing supply of timber could support development of additional sawmilling capacity.

Global: Forests in Central Europe have been suffering through several years of a widespread spruce bark beetle outbreak. The trees killed by the beetles are being salvaged, but it is creating a glut of logs and dampening lumber prices across the region. As a result, European mass timber manufacturers are enjoying low raw material costs relative to their North American peers, making European producers very cost competitive under current market conditions. As discussed in more detail in Chapter 4, global lumber market conditions during 2020 have meant that European manufacturers have supplied much of the US mass timber market.

REGION	% DIMENSION 2" THICKNESS	ESTIMATED 2020 PRODUCTION OF DIMENSION (BBF)	% SMALL TIMBERS 3"- 5" THICKNESS	ESTIMATED 2020 PRODUCTION OF SMALL TIMBERS (BBF)	% LARGE TIMBERS 6"+ THICKNESS	ESTIMATED 2020 PRODUCTION OF LARGE TIMBERS (BBF)	% OTHER	ESTIMATED 2020 PRODUCTION OF ALL OTHER SIZES	TOTAL 2020 PRODUCTION (BBF)
US West	55%	7.9	5%	0.7	5%	0.7	35%	5.0	14.3
US South	80%	16.7	10%	2.1	5%	1.0	5%	1.0	20.8
US Other	20%	0.3	n/a	n/a	n/a	n/a	80%	1.3	1.6
Western Canada	75%	6.4	n/a	n/a	n/a	n/a	25%	2.1	8.5
Eastern Canada	50%	7.2	n/a	n/a	n/a	n/a	50%	7.2	14.3
North America Total		**38.4**		**2.8**		**1.8**		**16.6**	**59.6**

TABLE 3.4: ESTIMATED NORTH AMERICAN SOFTWOOD LUMBER THICKNESS MIX IN 2020 (BOARD FEET IN BILLIONS)

3.2.3 2020 NORTH AMERICAN SOFTWOOD LUMBER PRODUCTION DETAILS

As described in Section 3.1, mass timber product standards specify the use of only certain lumber sizes and grades. Therefore, it is also important to consider current softwood lumber production in terms of grade and size mix. Accordingly, **Table 3.4** shows lumber production by thickness (e.g., dimension = 2 inches in thickness; small timbers = 3 inches to 5 inches in thickness; and large timbers equal greater than 5 inches in thickness). The values presented in the table use the estimated North American softwood lumber production volumes for 2020 based on the WWPA's reports through fall of 2020. The percent of production by size values are estimates from sawmill industry benchmarking data collected by The Beck Group. Of the estimated 59.6 billion board feet of lumber produced in North America in 2020, about 65 percent is estimated to be nominal 2-inch-thick dimension lumber (i.e., boards nominally 2 inches thick and 8 feet to 20 or more feet long). Only small portions are produced as thicker timbers, and about 25 percent is produced 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 only produced in 4-inch and-6 inch widths and is mainly produced in lengths 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 other products.

REGION	% ABOVE #2	ESTIMATED PRODUCTION ABOVE #2 (BBF)	% OF #2	ESTIMATED PRODUCTION OF #2 (BBF)	% OF #3	ESTIMATED PRODUCTION OF #3 (BBF)	% BELOW #3 AND OTHER	ESTIMATED PRODUCTION OF BELOW #3 & OTHER (BBF)	TOTAL PRODUCTION OF DIMENSION (BBF)
US West	35%	2.8	55%	4.3	5%	0.4	5%	0.4	7.9
US South	40%	6.7	40%	6.7	10%	1.7	10%	1.7	16.7
US Other	10%	0.0	55%	0.2	20%	0.1	15%	0.0	0.3
US Total		**9.5**		**11.2**		**2.1**		**2.1**	**24.9**

TABLE 3.5: ESTIMATED US SOFTWOOD DIMENSION LUMBER GRADE MIX IN 2020 (BOARD FEET IN BILLIONS)

Similarly, it is useful to understand the grade mix of the softwood lumber produced in North America. Accordingly, **Table 3.5** illustrates the estimated grade mix of US production. Using the WWPA's 2020 production estimates and The Beck Group's sawmill benchmarking data, it is estimated that about 85 percent (20.7 billion board feet) of the dimension lumber production in North America 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 for US softwood dimension lumber production in 2020. As the data in the table illustrates, about 30 percent of all dimension lumber is estimated to be 4 inches wide, followed by about 30 percent that is 6 inches wide. A significantly higher percentage of 2-by-4s are produced in the US West than in the US South. Lumber width is a significant consideration for mass timber manufacturers, as prices vary between widths, and productivity at a mass timber plant improves when wider pieces of lumber are used.

3.2.4 SOFTWOOD LUMBER PRICING

Purchasing raw material is the single largest cost associated with the manufacture of mass timber products, accounting for more than 50 percent of a plant's total operating cost. Therefore, lumber pricing is a key focus area for mass timber manufacturers. Over the last 10 years in the United States, demand for lumber in the residential construction and repair and remodeling market segments has ranged from a low of 20.8 billion board feet per year to a high of 34.5 billion board feet per year. The associated swings in supply (as it follows shifting demand) create considerable volatility in lumber prices, a phenomenon that is fairly unique among all global countries.

Price volatility was in full effect during 2020. For about the last 25 years, the price of dimension lumber in North America has averaged roughly

REGION	% 2X4	ESTIMATED 2X4 PRODUCTION (BBF)	% 2X6	ESTIMATED 2X6 PRODUCTION (BBF)	% 2X8	ESTIMATED 2X8 PRODUCTION (BBF)	% 2X10	ESTIMATED 2X10 PRODUCTION (BBF)	% 2X12	ESTIMATED 2X12 PRODUCTION (BBF)	TOTAL 2020 DIMENSION PRODUCTION (BBF)
US West	40%	3.2	30%	2.4	10%	0.8	10%	0.8	10%	0.8	7.9
US South	25%	4.2	30%	5.0	20%	3.3	15%	2.5	10%	1.7	16.7
US Other	40%	0.1	30%	0.1	10%	0.03	10%	0.03	10%	0.03	0.3
US Total		7.5		7.5		4.2		3.3		2.5	24.9

TABLE 3.6: ESTIMATED US SOFTWOOD DIMENSION WIDTH MIX IN 2020 (BOARD FEET IN BILLIONS)

$350 per 1,000 board feet (MBF). The low point occurred in 2009 in the depths of the Great Recession when dimension lumber was selling around $200 per MBF. The high point was in mid-2018 when prices were approaching $600 per MBF. However in 2020, driven by a COVID-induced increase in demand in the home repair and remodeling sector and constrained ability to produce lumber because of COVID-related labor shortages, prices skyrocketed to all time highs. In September 2020, dimension lumber prices in North American averaged more than $900 per MBF. Numerous widths, lengths, and species were selling at prices well over $1,000 per MBF.

3.2.5 ENVIRONMENTAL CERTIFICATION OF SOFTWOOD LUMBER

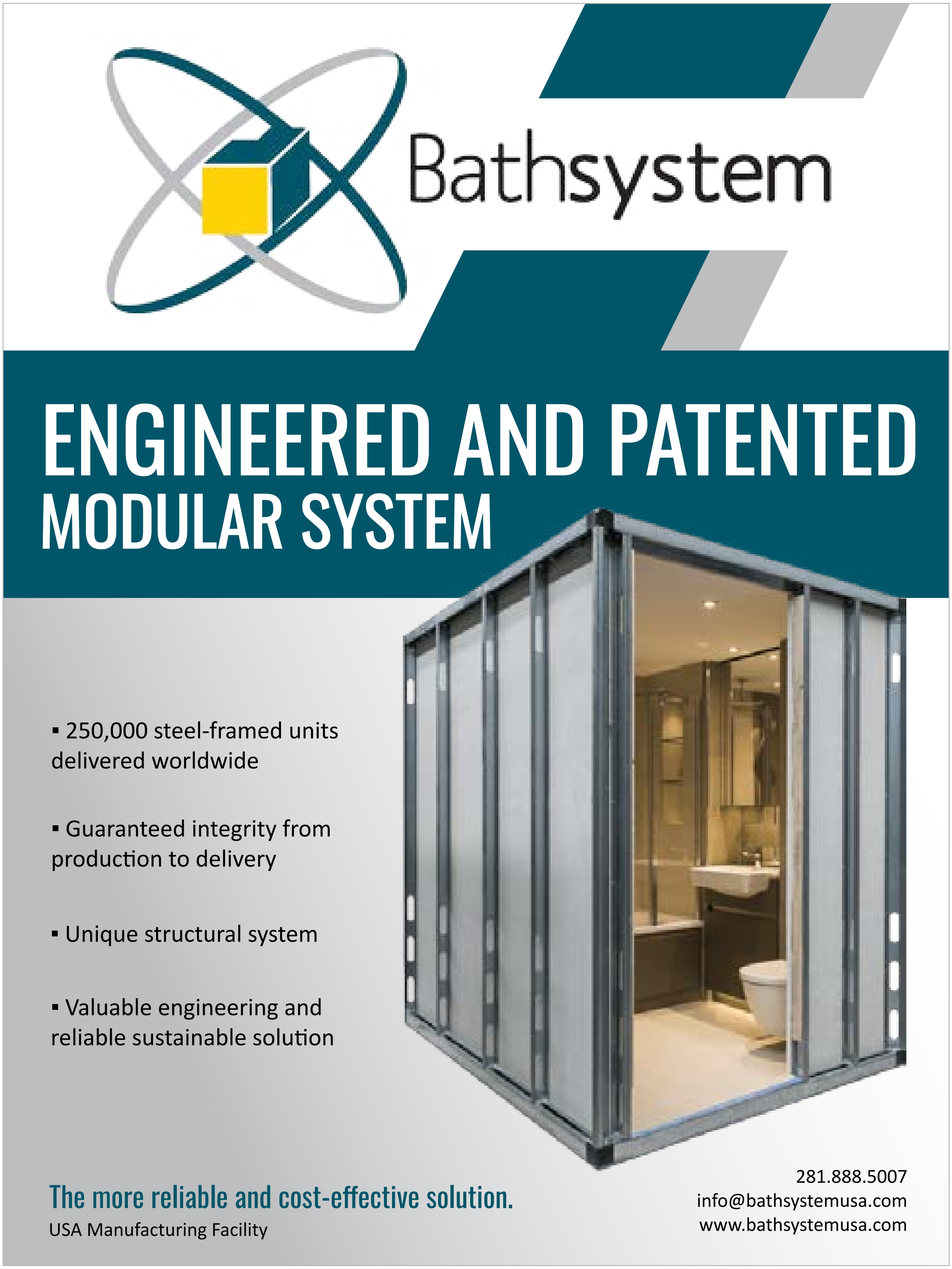
Chapter 2 of this report explains how forested land is certified when managed under certain protocols that have been judged to represent sustainable forest management. Such forest management certifications programs (e.g., Forest Stewardship Council [FSC], Sustainable Forestry Initiative [SFI], Programme for the Endorsement of Forest Certification [PEFC], and American Tree Farm System [ATFS]) also offer chain-of-custody certification to participants in the supply chain for wood products. Chain-of-custody is the process of certifying that as products move through the supply chain from the forest to end user, material originating from certified forests is identified or kept separated 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-use consumer's desire for assurance that products are sourced from forests certified as being well-managed. This is especially true for developers seeking to certify a building under Leadership in Energy and Environmental Design (LEED) and other similar programs. Additionally, large tech companies that have expressed interest in mass timber (e.g., Google, Facebook, etc.) are also keenly interested in using environmentally certified raw materials. It remains to be seen which environmental certification programs will be given preference by these large and influential mass timber users.

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

One of the main reasons that sales of environmentally certified products are not well tracked is that for most consumers this product attribute is relatively unimportant. Considerations such as price, quality, species, grade, etc. are much more important. Additionally, forest landowners and forest products manufacturers must expend considerable effort and money to acquire and maintain environmental certifications. Therefore, given limited market demand and the expense, many forest landowners and forest products manufacturers decide not to certify their products, even though they could be. Alternatively, some elect to certify their material only on a case-by-case basis as dictated by customer expectations. In yet another approach, a small number of producers choose to certify as much of their product as possible regardless of the level of demand from customers.

What this means for producers of mass timber products is that at the current time, the market demand for environmentally certified materials (aside from mass timber products) is relatively low. Therefore, finding environmentally certified material may be an obstacle, but likely it is not a total roadblock. From interviews conducted by The Beck Group with mass timber producers, their general feeling is that only a small portion of their demand is for certified mass timber products, and when those orders need to be filled, they can usually oblige. However, it may cost more to acquire certified lumber. As previously mentioned, a big wildcard on the environmental certification topic is whether one of the large tech companies will announce plans for a large mass timber project (or projects), and that they intend to give preference to using raw materials from a given environmental certification program (e.g., FSC certified materials). 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.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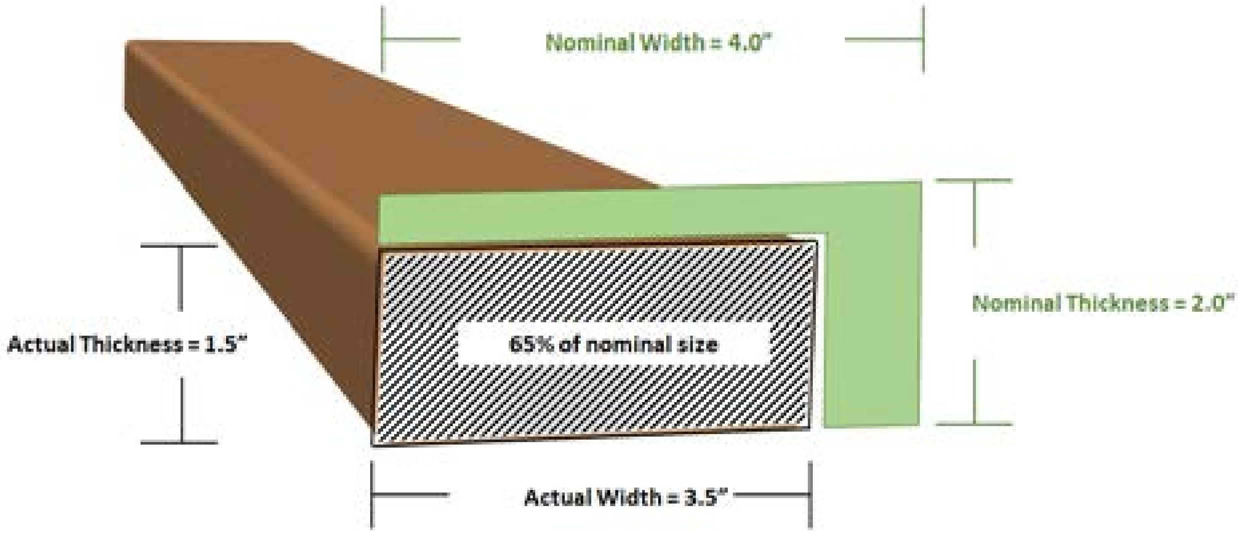


FIGURE 3.6: COMPARISON OF NOMINAL AND ACTUAL DIMENSIONS FOR BOARD FOOT LUMBER TALLY

Source: The Beck Group

3.3 THE MASS TIMBER INDUSTRY'S ESTIMATED DEMAND FOR RAW MATERIALS IN 2020

In this section, we provide an estimate of lumber demand arising from mass timber products. First, however, it is important for readers to understand a quirk of the North American lumber industry—the difference between actual and nominal lumber sizes.

3.3.1 NOMINAL VERSUS ACTUAL LUMBER SIZES

As described in Chapter 1, an estimated 22.5 board feet (nominal tally) are 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, one cubic foot of mass timber should be equal to 12 board feet. 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, which means 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 much of a nominal lumber tally is airspace, it means more than 12 board feet of lumber will be needed to produce a cubic foot of mass timber panel. Additionally, about 8 percent to 10 percent of a board's thickness is planed away before it is glued up as a mass timber panel. Planing activates the wood surface for the adhesive that bonds the wood. Also, during the finger jointing process, 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, etc.

	ACTUAL			NOMINAL				
Lumber Size (thick x width)	Actual Thickness (Inches)	Actual Width (Inches)	Cross Sectional Area (Inches^2)	Nominal Thickness (Inches)	Nominal Width (Inches)	Cross Sectional Area (Inches^2)	Actual Fiber % (Actual/ Nominal)	"Air Space" %
2″ x 4″	1.50	3.50	5.25	2.00	4.00	8.00	65.6%	34.4%
2″ x 6″	1.50	5.50	8.25	2.00	6.00	12.00	68.8%	31.3%
2″ x 8″	1.50	7.25	10.88	2.00	8.00	16.00	68.0%	32.0%
2″ x 10″	1.50	9.25	13.88	2.00	10.00	20.00	69.4%	30.6%
2″ x 12″	1.50	11.25	16.88	2.00	12.00	24.00	70.3%	29.7%

TABLE 3.6: COMPARISON OF THE PERCENTAGE OF ACTUAL FIBER TO AIRSPACE AMONG LUMBER SIZES FOR NOMINALLY TALLIED LUMBER

The percentage of airspace decreases as lumber width gets larger, as shown in **Table 3.6**. Nevertheless, a significant portion of the board foot tally for every piece of lumber is airspace.

3.3.2 ESTIMATED LUMBER CONSUMPTION FROM MASS TIMBER IN NORTH AMERICA

Given the preceding discussion about the board feet of lumber needed per cubic foot of mass timber panel, it is possible to calculate the total volume of lumber consumed annually in North America, if the production capacity of the plants is known. Data is not available to definitively state the actual output of North American mass timber in 2020. However, as described in Chapter 4, the maximum annual production capacity of North America's existing mass timber manufacturers (for both industrial matting and building panels) is estimated to be 1.67 million cubic meters, or about 58.8 million cubic feet. Thus, if all North American plants operated at maximum annual capacity and assuming, on average, 22.5 board feet of softwood lumber are needed per cubic foot of finished mass timber, then the total annual lumber consumption of the North American mass timber industry could be as high as about 1.322 billion board feet. To provide perspective, recall from **Figure 3.4** that in 2020, North America was estimated to have produce about 60 billion board feet of softwood lumber. Thus, lumber consumption by mass timber plants in 2020 could be as high as about 2.2 percent of North America's softwood lumber production. However, given the market factors at play in 2020, which both hindered mass timber project development and gave European manufacturers a cost advantage, North American mass timber manufacturers operated at rates significantly lower than their total practical capacity. The actual lumber consumption among North American manufacturers is estimated to be between 250 million and 300 million board feet. This topic is analyzed in further detail in Chapter 4.

3.4 SUPPLYING THE MASS TIMBER MARKET: SAWMILLER PERSPECTIVES

Conceptually, sawmillers are always interested in developing new markets for the lumber they produce. However, dimension lumber is a largely commoditized product in North America. As such, prices are volatile as various supply and demand factors ebb and flow. Regardless, manufacturers face the constant discipline of producing at a low cost. Thus, many sawmillers tend to operate their mills in a manner that emphasizes high productivity and minimizes distractions that slow production without adding significant value.

For the mass timber market, the area where the preceding sawmiller's mindset has had the largest impact is the issue of lumber drying. As previously, stated the moisture content specification for lumber used in mass timber is 12 percent to 15 percent moisture, but the grading rules for kiln-dried dimension lumber only require drying to 19 percent moisture. Thus, lumber destined for mass timber manufacturing must receive extra drying at the sawmill, or the mass timber manufacturer must have a means of further drying the lumber at their manufacturing facility.

From the perspective of the sawmiller, lumber drying is often the "bottleneck" in the whole manufacturing process. In other words, the output of the entire operation (i.e., sawmill and planer mill) are limited by the capacity of the dry kilns. Therefore, taking extra time to dry lumber to a lower moisture content is a decision that must be carefully considered. This is because it not only takes extra time in the kilns, but the yield of lumber of the appropriate sizes and grades must be considered. In other words, in any given batch sent through a kiln, not all the lumber will meet the grade and size specifications for use in mass timber. That lumber is known as downfall. Thus, some percentage of the lumber that receives the additional time and expense of extra drying cannot be sold to mass timber manufacturers.

The strategies for dealing with this issue are evolving. One approach is that sawmilling companies have entered contracts with mass timber manufacturers to provide lumber that meets the moisture content specifications. Such contracts likely include a significant above-market premium on the lumber price to account for the extra drying time and downfall. Data isn't available on the extent of the premium, but The Beck Group estimates it is likely in the range of $50 to $100 per MBF. Another consideration is that during lumber market cycles where prices are high (like the market during much of the latter part of 2020), numerous sawmilling companies are unwilling to slow down their process, regardless of any premium they might earn for extra drying.

Another emerging strategy is that mass timber manufacturers are purchasing "ordinary" kiln-dried lumber, which may have further air-dried during shipment and storage in inventory to an acceptable range for mass timber manufacturing. Such an approach requires that the mass timber manufacturer has an inline moisture meter in their manufacturing process, allowing the sorting of individual boards that can be used from those that have too much moisture. The "wet" boards are then set aside. They can be diverted to an on-site controlled drying process or an off-site custom drying service, or be set aside for more air-drying, which is an uncontrolled process.

Each has advantages and disadvantages as described below:

On-site, controlled kiln-drying: Some mass timber manufacturers have invested in their own kilns so the moisture content issue can be addressed in a controlled manner and with their own equipment. The advantages of this approach are that it allows for the best control over product quality. The disadvantages are that expenses are increased. They include the up-front capital expense of kilns; the ongoing operating costs of the kilns (both labor and energy); and potential yield loss from any material that degrades (e.g., case hardening, bowing, cupping, warping, etc.) during the kiln-drying process to the point where it can no longer be used for mass timber manufacturing. An experienced kiln operator is needed. Note, however, that some mass timber manufacturers have reported experimentation with dehumidification kilns. These kilns operate at much lower temperatures, meaning a lower likelihood of degrades. The drawback is that drying takes longer at the lower temperatures. The early results indicate that because relatively little moisture needs to be removed (since the lumber was already kiln-dried to 19 percent moisture) the slow drying issue associated with dehumidification kilns is mitigated.

Off-site, custom kiln-drying: Some mass timber manufacturers have utilized the services of off-site, custom kiln-drying. The advantages of this are, like on-site, it allows for the drying of lumber under controlled conditions. The disadvantages are that not only are there costs for handling the wet lumber, but there are also costs for transporting it to and from the custom kiln-drying site, and for the kiln-drying service. Additionally, the extent that custom kiln-drying services are available differs by region.

Uncontrolled air-drying: Lumber will lose (or gain) moisture depending on the ambient air conditions. Thus, lumber simply left to further air dry may lose enough moisture to reach conditions allowable for use in mass timber panels. There is no energy cost for this process, but it is an uncontrolled process that depends on weather conditions. Thus, it may work only during certain times of the year and in certain regions where the ambient conditions generally allow for drying. Also, for best results, the lumber should be placed on stickers (i.e., spacers between layers of lumber that allow air flow and, in turn, drying). The labor, time, and expense associated with the handling increase the expense.

Yet another approach is that some mass timber manufacturers are part of vertically integrated companies that have sawmilling, kiln-drying, and mass timber manufacturing capacity. This offers several advantages from a mass timber manufacturer perspective, in that the material is controlled—often from the tree in the forest (when timber is either owned or purchased standing)—through the manufacture of a mass timber panel. Assuming kiln-drying capacity is not a bottleneck at such operations, the issue of moisture content is less problematic. However, during the lumber market conditions experienced in 2020, vertically integrated operations are better able to “hold the line” on raw material costs in the production of mass timber panels, but they must recognize that doing so comes at the opportunity cost of selling lumber in an extraordinarily hot market at prices never seen in the softwood lumber industry.

3.5 CARBON CONSIDERATIONS

The September 2017 issue of the Forest Products Journal included an article[4] that analyzed the carbon impact associated with the production of softwood dimension lumber in the Pacific Northwest and Southeastern United States. Key conclusions from the study were that the global warming impact indicator is 129 pounds of CO_2 equivalent was released for each cubic meter of lumber produced in the Pacific Northwest, and 179 pounds of CO_2 equivalent was released for each cubic meter of lumber produced in the US South. An additional key finding was that in the Pacific Northwest, nearly 1,900 pounds of CO_2 equivalent is stored per cubic meter of lumber produced, and nearly 2,100 pounds of CO_2 equivalent is stored per cubic meter of lumber in the US South. Thus, there is a net carbon benefit of nearly one ton of CO_2 equivalent associated with wood use during 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 CO_2 equivalent during their useful life and that require considerable energy and associated carbon emissions be expended in their manufacture. Note also from the study that for lumber production, well over 90 percent of the global warming impact arises from the process of manufacturing the lumber (e.g., sawing, planing, kiln-drying, packaging, etc.). Only a very small percentage of the impact arises from the energy expended in log processing and transport (i.e., forest operations).

4 Life-Cycle Assessment for the Cradle-to-Gate Production of Softwood Lumber in the Pacific Northwest and Southeast Regions. Michael Milota and Maureen E. Puettmann. Forest Products Journal. Vol. 67, No. 5/6.

CHAPTER 4: MASS TIMBER PANEL MANUFACTURING

IMPACTS OF THE MASS TIMBER EFFECT

- The estimated practical annual capacity of the North American mass timber industry is 1.085 million cubic meters, nearly a 20 percent increase over the estimated capacity in the prior year.
- COVID-related slowdowns in building projects and a COVID-related run-up in North American lumber prices created difficult market conditions for North American mass timber manufacturers in 2020. The estimated production of North American mass timber panels used in building construction in 2020 was only 0.355 million cubic meters.
- Mass timber manufacturers continue to refine their services and means of bringing product to market, including adding staff with timber engineering/design expertise, establishing partnerships, developing of design guides, and creating supporting businesses that better link the mass timber manufacturing and building construction communities.

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

4.1 MASS TIMBER PANEL TYPES

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

4.1.1 BUILDING PANELS

Two common building panel grades have been developed by panel manufacturers, based on appearance rather than strength. The first is architectural grade, for use when a panel surface will be exposed to building occupants. The second is industrial grade, for when a panel surface will either be covered or does not need to meet an appearance requirement. Either grade can be PRG 320[1] certified, if needed. Each manufacturer offers an array of finishes; in most cases, the finish can be customized.

Architectural grade panels are designed to ensure the lumber is of the proper grade and species for visual exposure, and may include special sanding, epoxy finishes, staining, or coating. Finishing of architectural grade panels may include filling holes, gaps, or knotholes. Additionally, lumber grain orientation may be varied, and other visual defects will typically not be included on the panel's face layer. The face layer may also include an added appearance grade layer of lumber (hardwood or softwood) laminated onto the panel. Each manufacturer offers a unique set of architectural grade finishes.

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

Industrial grade panels are likely to have the same strength characteristics as comparable architectural grade panels but may not meet the same aesthetic standards because the surface of the panel is usually covered following installation. Visual defects in industrial grade panels may include unfilled voids on the edge of laminations, loose knotholes on face layers, or the inclusion of wane (lumber pieces that are not fully square-edged on all four corners) on the face layer. Industrial grade panels are typically less expensive than architectural grade panels, as both the cost of materials and the labor and machining required are lower.

Additionally, the panel application plays a significant role in the grade type. For example, a floor may have architectural grade on the ceiling side but industrial grade on the floor side because a floor covering will be installed. Similarly, many exterior walls will be covered with a siding, and, therefore, only one face of the panel may be architectural grade. Mass timber panels used in roofs and elevator shafts are typically industrial grade.

4.1.2 MATTING

Matting panels are not intended for use in buildings, but rather in environmental protection applications and other industrial uses. Typically, these mats are placed on the ground to form temporary roads and prevent environmental degradation caused by the heavy machinery used in mining, drilling, pipelines, utility right-of-way maintenance, and remote construction. Traditionally, mats are made of lower-value hardwood timbers that are nailed or bolted together. CLT mats are becoming more common. CLT mats can offer superior value because of their lighter weight and substantially longer useful life span. Also, CLT mats usually include built-in hardware, making them easy to lift and place using a forklift, excavator, or crane, reducing the set-up time compared to traditional industrial mats. Matting panels and their uses are described in more detail in **Section 4.6**.

4.2 MASS TIMBER PANEL MANUFACTURING PROCESS DESCRIPTIONS

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

4.2.1 CROSS-LAMINATED TIMBER

CLT is produced in an industrial-scale, dedicated manufacturing facility. Although CLT is an innovative product, the major steps in its manufacturing process utilize well-established technologies borrowed from other segments of the wood products industry. The basic manufacturing process includes:

1. **Raw Material Receiving:** Lumber is received into inventory at the mass timber manufacturing facility.
2. **Raw Material Preparation:** Lumber inventory is sorted by grade, width, species, etc. in preparation for the manufacturing process. Also, lumber is checked for moisture content to assure that variation between pieces is not too great. Pieces that are too wet are separated for additional drying. For the lumber pieces fed into the manufacturing process, defects (e.g., knots, wane, etc.) are removed using a crosscut/chop saw.
3. **Finger-Jointing:** The remaining pieces of lumber (now defect free) are glued together end-to-end

FIGURE 4.1: ILLUSTRATION OF FINGER-JOINTED LUMBER
Source: The Beck Group

using a machine that cuts finger joints into the lumber ends and an adhesive that's applied to the joint to securely bond the pieces together. See **Figure 4.1**.

4. **Cutting to Length:** The finger-jointing process creates a "continuous" piece of lumber that can be cut to any length as called for by the dimensions of the mass timber panel (e.g., 4-foot to 12-foot lengths for the panel's minor strength axis and 30-foot to 60-foot lengths for the its major strength axis).

5. **Surfacing:** Also known as planing, the surfacing process removes a small amount of material (e.g., typically about $^1/_{16}$ inch) around all 4 sides of the lumber piece. This assures that all pieces have the same dimensions and that the lumber's surface is activated to assure good absorption and bonding of the adhesive used to glue the panel layers together.

6. **Panel Lay-up:** The finger-jointed and cut-to-length lumber pieces are assembled into a panel one layer at a time. For example, in a 3-layer panel, all the long pieces comprising the first major strength axis layer are assembled. Next, a glue spreader travels over the pieces applying a layer of glue to the wide surfaces of the board (note that for some panels, glue is applied to all four sides of the lumber). Then the short pieces are assembled into the layer making up the panel's minor strength axis. Another layer of glue is applied. And finally, the long pieces making up the second major axis layer are assembled.

7. **Pressing:** This occurs after the lumber has been formed into a panel and all the adhesive has been applied. The panel is pressed while the adhesive cures. Note that there are several variations on the adhesive and pressing technology, affecting the press time and the amount of energy consumed at the plant. Some processes utilize glue that does not require heat to cure, but the press times are longer. Other processes use glue that needs heat to activate, but the pressing time is reduced. For heated presses, radio frequency waves penetrate the panel to cure the glue.

8. **Final manufacturing:** The edges of mass timber panels coming out of the press are typically irregular in shape and overrun by adhesive that has bled out between the layers. Additionally, the "raw" panels are produced slightly oversized. All of this means that the panel is cut to final dimensions in a secondary process. Typically, the final manufacturing is accomplished with a CNC machine (i.e., a robotic machine that uses a variety of saws, drills, and other cutting heads to uniformly trim the edges and to cut out openings for windows and channels for utilities, such as, electricity and water). Additionally, most CLT plants use a sander to surface the face of the panel.

9. **Packaging and Shipment:** The final steps in the process involve placing "pick points" into the panels. A pick point is metal hardware placed into a panel that allows construction site cranes to pick it up and place it in a building. Panels are also assembled into a sequence for shipping so that when they arrive at the construction site, they can be moved directly into place rather than unloaded and stored.

The specific pieces of equipment needed to complete the preceding tasks include:

- **Moisture Meter:** Tests the moisture content of each piece of lumber, ensuring that any lumber not meeting the target range (12 percent +/- 3 percent) is rejected.
- **Optical Grade Scanning:** Photo eyes to identify any lumber with unacceptable defects (rot, splits, wane).
- **Defect Trim Saw:** Cuts out short lineal 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 to the final size of the CLT panel (4 feet to 12 feet for the cross layers, and 30 feet to 60 feet for the adjoining layers). Aside from the size of the press, the highway/truck restrictions on delivering panels from the manufacturer to the building site are the only limits on the length of a CLT panel.
- **Planer or Molder Line:** Removes a thin layer of wood from the surface of the lumber to "activate" it for reaction with the glue and to ensure all pieces are of uniform thickness. This step must be completed less than 48 hours before applying the glue.
- **Panel Lay-up:** Arranges pieces of lumber into layers in accordance with the CLT panel design. Glue is applied to each layer at this step.
- **Pressing:** Hydraulic or Vacuum:
    - **Hydraulic press:** Uses hydraulic pressure on face and sides to hold a panel in place as glue cures. Press time varies based on glue formulation and panel lay-up time.
    - **Vacuum press:** Uses a clamshell and plastic sleeve to encapsulate a panel and then sucks out the air to tighten gaps between boards.
- **CNC Machine:** Uses computer-controlled saws and router heads to precisely trim the edges of each panel and cut openings needed for doors, windows, utility channels, etc.
- **Sanding Machine:** Puts a smooth finish on the surface of the panel.

4.2.2 DOWEL LAMINATED TIMBER PANEL MANUFACTURING

DLT is produced in a dedicated manufacturing facility. As with CLT, incoming lumber is checked for grade and product consistency, with defective sections removed. The lumber is then finger jointed, cut to desired lengths, and molded/planed to the desired thickness. The cut-to-length boards are assembled into a panel, holes are drilled along the edges of the panel, and dowels are pressed into the holes. The entire panel is surfaced to ensure the dowels are not protruding. The final steps are panel finishing on a CNC machine (trimming, cutting openings, channels), packaging, and shipment. Unlike CLT, all lumber in a DLT panel is oriented in the same direction (i.e., the wide face of the board is placed so that it touches the wide face of an adjoining board). The orientation of the lumber pieces in DLT means that the panels do not have the same shear strength properties as those derived from cross lamination.

4.2.3 NAIL LAMINATED TIMBER PANEL MANUFACTURING

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

When making NLT on an industrial scale, jigs made from pony walls, back and end stops, and fences are employed to maintain panel dimensions and straightness. Each board is nailed together using a pneumatic-powered nailer. This 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 critical for each panel, as nails will negatively impact cutting tools, such as saws and drills.

4.2.4 MASS PLYWOOD PANEL MANUFACTURING

MPP is a veneer-based engineered wood product and is a recent addition to the list of mass timber products. The first step in the manufacturing process is to produce appropriately sized and graded veneer of an appropriate species. Freres Lumber Co., the only current MPP manufacturer, also produces its own veneer. The MPP is created in a two-stage process. First, billets of 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 billet vary, depending on desired strength. In the second stage, the SCL billets are assembled into a larger and thicker mass plywood panel, with dimensions and strength engineered to meet the requirements of a given project.

Regardless of the size of the mass plywood panel, however, scarf joints are used to join the SCL billets, and the joints are staggered through the mass plywood panel so that they do not create weak points. As an example, a 6-inch-thick mass plywood panel is comprised of six 1-inch billets, each made of 9 plies of veneer. Thus, the total panel thickness is made of 54 veneer plies. Throughout this process, both the entire MPP panel and each 1-inch SCL billet are engineered to specific strengths. Adhesive is used to bond all veneer plies within the SCL billets and to bond each SCL billet to an adjacent billet.

STREAMLINING THE MASS TIMBER MARKET, FROM CONCEPT TO CONSTRUCTION

Timberlab was born out of a commercial general contracting business by builders of commercial buildings and timber systems. Although not a manufacturer that actually presses wood into building blocks used, Timberlab is a group of construction practitioners educated in timber and all other building systems. Timberlab is the link between the manufacturing and building communities.

Timberlab understands that the speed of construction is derived from information gathering, great modeling, and attention to detail. Their practitioners provide clients with full-service partners supplying complete mass timber solutions. Timberlab also coordinates the mass timber system with the other building components, like exterior skin systems, mechanical, electrical, plumbing, and fire sprinkler systems, and other structural systems.

DESIGN & FABRICATION SERVICES

The critical part of a mass timber project often is not the pressing of the wood or the fabrication of the wood product, and it is usually not the installation of the product on-site. Rather, the critical part is the procurement of information. Information is the single hardest thing to get on a construction project, and, because the procurement is accelerated, it is even tougher on a mass timber project.

DESIGN VS. MANUFACTURING

The design process is a circular, iterative process. Design takes time; it takes revision, creation, and re–creation. Design is a process of trying, failing, trying, and succeeding, over and over, in steps toward the final form. Manufacturing is linear. It is streamlined, it deals with absolutes, and it has tangible outcomes. Manufacturing is on a schedule and doesn't like revision. Timberlab is a partner in the design process, and it helps translate the design process into tangible information used to make real building components.

ENGINEERING DESIGN & SUPPLY

Timberlab's engineering department can provide a variety of services on a project, from erection engineering (bracing/shoring/rigging); to delegated design of specialty systems, like stair systems and interior finish systems; to full timber engineering of a building's structural system.

TIMBERLAB'S SERVICES

Gravity Frame and Diaphragm Systems

- Complete timber structural system (glulam, CLT, and/or MPP)
- Detailing and single-piece shop drawings
- Hardware, fastening, and diaphragm strapping
- Fabrication service
- Optional: timber engineering or engineering design-assist

Gravity Frame System

Glulam Frame

- Detailing and single-piece shop drawings
- Pre-installation of hardware onto glulam
- Optional: timber engineering or engineering design-assist

Interior Architectural Mass Timber

- Design-build timber stair systems
- Design-build interior CLT systems
- Full supply and fabrication services

Fabrication Only

- Provide fabrication-only services in Portland on a CNC line

COMPANY	LOCATION	STATUS	ESTIMATED MAXIMUM ANNUAL PRODUCTION CAPACITY (M3/YEAR)
D.R. Johnson	Riddle, OR, United States	Operating	
Element5 #1	Ripon, QC, Canada	Operating	
Element5 #2	St. Thomas, ON, Canada	Operating	
Freres	Lyons, OR, United States	Operating	
Kalesnikoff	South Slocan, BC, Canada	Operating	
Katerra	Spokane, WA, United States	Operating	
Nordic Structures	Chibougamau, QC, Canada	Operating	
Smartlam North America	Dothan, AL, United States	Operating	
Smartlam North America	Columbia Falls, MT, United States	Operating	
Sterling Lumber	Lufkin, TX, United States	Operating	
Sterling Lumber	Phoenix, IL, United States	Operating	
Structurecraft	Abbotsford, BC, Canada	Operating	
Structurlam	Okanagan Falls, BC, Canada	Operating	
Texas CLT	Magnolia, AR, United States	Operating	
Vaagen Timbers	Colville, WA, United States	Operating	
Total			**1,665,000**

TABLE 4.1: CURRENTLY OPERATING NORTH AMERICAN MTP PLANTS

4.3 NORTH AMERICAN MASS TIMBER PLANTS

This section provides an assessment of mass timber manufacturing capacity. Manufacturer information was collected through a combination of personal communication with manufacturers, publicly available research, compiled information from industry experts, and company profiles from websites and other published information sources. Please note that the status of manufacturing operations is constantly changing, with shifting operating schedules, several plants recently reaching completion, and others under construction. The data and information that follows was current as of December 2020.

4.3.1 CURRENTLY OPERATING NORTH AMERICAN MTP PLANTS AND THEIR MANUFACTURING CAPACITY

In recent years, the North American mass timber manufacturing industry has grown significantly. At the time of this writing (late 2020), there were 12 companies operating 15 facilities in North America. As illustrated in **Table 4.1**, the total estimated maximum North American mass timber panel production capacity is estimated to be 1.665 million cubic meters per year (58.8 million cubic feet). Applying a 65 percent practical production factor rule-of-thumb to the maximum capacity results in an estimated practical annual production capacity of 1.085 million cubic meters per year (38.2 million cubic feet). See Manufacturing Capacity Discussion section for additional details. Additionally, VDMA, the German Woodworking Machinery Association, estimates that in 2020, actual North American mass timber production for panels used in buildings totaled 0.355 million cubic meters (12.5 million cubic feet). Thus, actual production in 2020 is estimated at only about 20 percent of maximum output and about one-third of practical capacity.

Note that capacity for utility matting production is more than half of the total North American installed capacity. Thus, the mass timber panel manufacturers making building panels likely operated at rates greater than suggested by simply looking at the industry as a whole. Finally, solid estimates of manufacturing capacity and operating rates are difficult to obtain at the present time. This is because such estimates rely on assumptions about differences in practical and maximum capacity and one-off estimates of plant operating rates. As the industry evolves and matures in North America, it is likely to form an association or other organization to systematically gather and report information about the industry's operating statistics. In the opinion of the report authors, transparency about such information is needed because it helps assure project developers, financial institutions, and private equity investors that mass timber manufacturing is stable and economically viable.

Manufacturing Capacity Discussion: Maximum annual production capacity as reported here is based on the theoretical capacity of a mass timber manufacturer's equipment when it is fully optimized. Practical annual production capacity refers to output after accounting for inherent plant operation inefficiencies. For example, given the made-to-order nature of most MTPs, it is difficult for the manufacturers to completely fill the available press space during every press cycle. In other words, while the press may accommodate making panels that are 12 feet wide, the order file may call for all panels for a significant production run to be 10 feet wide. In such a scenario, only 83 percent of the press's capacity (10 divided by 12) is utilized because the full volume of the press is not occupied. Even less press capacity would be utilized if the length of the panels in the example were shorter than the full length of the press. Based on discussions with several mass timber manufacturers, maximum production capacity should be adjusted to practical capacity using a factor of 65 percent to account for not fully occupying the press, unplanned downtime, etc.

4.3.2 MASS TIMBER PLANTS UNDER CONSTRUCTION

At the time of this writing (late 2020), there was only one mass timber plant under construction in North America, the Structurlam facility in Conway, Arkansas. The plant is an expansion for Structurlam beyond its existing Western Canada operations and is the company's first plant in the United States. The total investment in the facility is a reported $90 million. Walmart announced that a significant portion of the plant's initial output will be dedicated to constructing Walmart's new corporate headquarters. Using lumber from trees grown in Arkansas was an initial factor in Walmart's search for a supplier. That interest eventually led to the relationship with Structurlam. The Conway plant will produce a combination of panels for use in buildings and industrial matting.

4.3.3 PLANNED NORTH AMERICAN MASS TIMBER PLANTS

There is one publicly announced mass timber plant in development as of late 2020. Stoltze Timber Systems Inc. announced that they are planning a phased approach to developing a mass timber business in the United States. The company is a partnership between F.H. Stoltze Land & Lumber Co., Wooden Haus Supply, and Seno Group. In the initial development stage, the company will import finished European mass timber panels for North American building projects and other markets. In the next phase, equipment will be installed in Columbia Falls, Montana, for value-added processing of panels imported from Europe. Then a mass timber panel manufacturing plant will be developed that will utilize lumber from small-diameter trees. The lumber will be produced at the existing F.H. Stoltze Land & Lumber Company sawmill in Columbia Falls. The final phase, which would occur only after development of a manufacturing facility, is an entire wood campus that would further incorporate wood fiber into mass timber building materials.

Additionally, while there has been no public announcement at the time of this writing, industry observers believe that Binderholz, an Austria-based mass timber panel manufacturer, will develop mass timber manufacturing capacity in the United States. This belief is based on Binderholz's acquisition in 2020 of two sawmills in the US South from Klausner Lumber Co. Both sawmills were designed to produce 350 million board feet of SYP dimension lumber per year, but neither operation ever achieved full production. Thus, if mass timber manufacturing capacity is to be developed at one or both sawmill sites, it is likely further capital investment will be required in both sawmill upgrades and mass timber manufacturing equipment. If Binderholz does follow through on upgrades to the sawmills and development of mass timber manufacturing capacity, that means they will utilize a vertical integration model that is not common among the existing North American mass timber panel manufacturers.

4.3.4 NORTH AMERICAN MASS TIMBER PLANTS CANCELED OR OF UNCERTAIN STATUS

The pace of growth in mass timber manufacturing capacity has slowed in 2020. This is likely due to a combination of factors, many of which can be tied to the COVID epidemic. First, COVID initially created a "pause" in many projects as developers evaluated its impacts. Also, COVID forced major portions of our economy to learn to work virtually. Many businesses have found that employees can be just as effective and productive working remotely and virtually, if not more so. This in turn, has created uncertainty in the demand for office and retail space, ultimately pausing numerous building projects until the full impacts of COVID on building space can be ascertained. Second, as described in Chapter 3, COVID induced a run-up in North American lumber prices, creating high raw material costs for North American mass timber manufacturers who are competing with European mass timber manufacturers for market share in supplying panels to building projects. Thus, from COVID-related or other reasons, not all publicly announced plans for developing mass timber plants have resulted in a fully developed facility. Sidewalk Labs,

OPERATING	UNDER CONSTRUCTION	PLANNED	CANCELLED/ UNCERTAIN	TOTAL
15	1	3	4	23

TABLE 4.2: SUMMARY OF NORTH AMERICAN MTP PLANTS AS OF LATE 2020

for example, announced a halt to their plans for developing a mass timber facility in Eastern Canada. Additionally, several other plants thought at one time to be in the advanced planning stages now appear to be halted or of uncertain status, including prospective plants in Maine, Ontario, and British Columbia.

4.3.5 SUMMARY OF NORTH AMERICAN MASS TIMBER PLANTS

Table 4.2 summarizes the status of North American MTP plants as of late 2020. Note that two Binderholz plants have been included in the proposed section despite no public announcement.

Additionally, **Figure 4.3** illustrates the location of North American mass timber plants. Some plants cluster in the Western region of the United States and Canada where there is a mix of available species, including Douglas fir, Western larch, hemlock, spruce, and various true firs. The rest of the plants are distributed geographically in Eastern Canada, where the available species are spruce, pine, and fir; and the US South, where the available species is SYP (a mix of longleaf, loblolly, slash, and shortleaf pines). Even though panels can be shipped long distances, as evidenced by the import of panels from Europe, it is interesting that a mass timber manufacturing facility has not yet been developed in California. There is a large timber resource in the state, a significant sawmilling industry, and it is one the largest building construction markets in North America.

4.4 MASS TIMBER MANUFACTURERS: COMPANY AND FACILITY DETAILS

The level of experience and strategic orientation of companies entering the mass timber market is diverse. For example, some firms are vertically integrated on the supply side, with sawmills and/or glulam manufacturing plants located near panel manufacturing operations. Others are vertically integrated on the building and development end of the supply chain. Still others are stand-alone businesses. **Table 4.3** attempts to capture some of this diversity among current mass timber manufacturers by illustrating the various products they offer, the status of their design guides, their brand names, etc.

4.5 NORTH AMERICAN MASS TIMBER MANUFACTURER SERVICES

Mass timber is distinct from most other wood building materials because its manufacturers tend to work closely with architects and engineers during building design regarding product specifications (size, thickness, strength, appearance, etc.). Still, an important, but perhaps frequently overlooked, section of the mass timber supply chain is the additional support services that mass timber manufacturers can provide

COMPANY	WEBSITE	PANEL BRAND NAME	DESIGN GUIDE	PRODUCTS	SPECIES	PANEL TYPES	PANEL THICKNESS	MAX WIDTH	MAX LENGTH	ENVIRONMENTAL CERTIFICATION
D.R. Johnson	drjwoodinnovations.com	n/a	Yes	CLT, GLT, Lumber, Timbers, EWP	DF-L	A, I	4.125", 6.875", & 9.625"	10.00	41.5	FSC, GreenGuard glue specification
Element5	elementfive.co	Macro CLT & Nano CLT	No	CLT, GLT, NLT	SPF	A, I	up to 15"	11.48	52.5	FSC
Freres	frereslumber.com	Mass Ply Panels (MPP)	Yes	MPP, Timbers, Plywood, Veneer	DF	A, I, M	*up to 24"	11.83	48.0	American Tree Farm System
Kalesnikoff	www.kalesnikoff.com	n/a	Yes	CLT, GLT, Timbers, Lumber	SPF, DF-L, Hemlock	A, I, M	2.00" to 15.15"	11.48	60.0	Publicly available forest stewardship plan
Katerra	katerra.com	n/a	Yes	CLT	SPF, or DF-L	A, I	3.4" up to 12.4"	11.75	60.3	FSC, SFI, PEFC
Nordic Structures	nordic.ca	X-Lam	Yes	CLT, GLT, I-Joist, Lumber	SPF (90% black spruce)	A, I	3.5" up to 10.5"	8.85	64.0	FSC
Smartlam North America	smartlam.com	n/a	Yes	CLT, Glulam	DF-L, SPF, Hemlock, SYP	A, I, M	4.13", 5.50", 6.88", 9.63", and 12.38"	**9.80, 11.25	**52.00, 51.75	FSC, SFI
Sterling Solutions	sterlingsolutions.com	Terralam	No	CLT, Lumber	SYP	M	3, 5, or 7 ply	8.00	18.0	No
Structurecraft	structurecraft.com	DowelLam	Yes	DLT	SPF, DF, Hemlock, Sitka Spruce, Western Red Cedar, Yellow Cedar	A, I	4", 6", 7.75", 9.75", 11.75"	14.00	60.5	FSC, PEFC, SFI
Structurlam	structurlam.com	CrossLam	Yes	CLT, GLT	SPF, DF-L***	A, I, M	3.00" to 12.38"	10.00****	40.0****	FSC, GreenGuard glue specification
Texas CLT	texasclt.com	n/a		GLT	SYP	A, I, M	Unknown	8.66	42.0	Unknown
Vaagen Timbers	vaagentimbers.com	n/a	Yes	CLT, GLT, FJ Lumber, Lumber	SPF, DF-L	A, I	4.13" to 9.63"	4.00	60.0	FSC

TABLE 4.3: SUMMARY OF NORTH AMERICAN MASS TIMBER MANUFACTURERS' PRODUCT INFORMATION

**Currently only certified up to 12" thickness*
***At Columbia Falls, MT, and Dothan, AL, respectively*
****The Conway plant currently under construction will use SYP*
*****The Conway plant currently under construction can produce panels of 12' maximum width and 60' maximum length.*

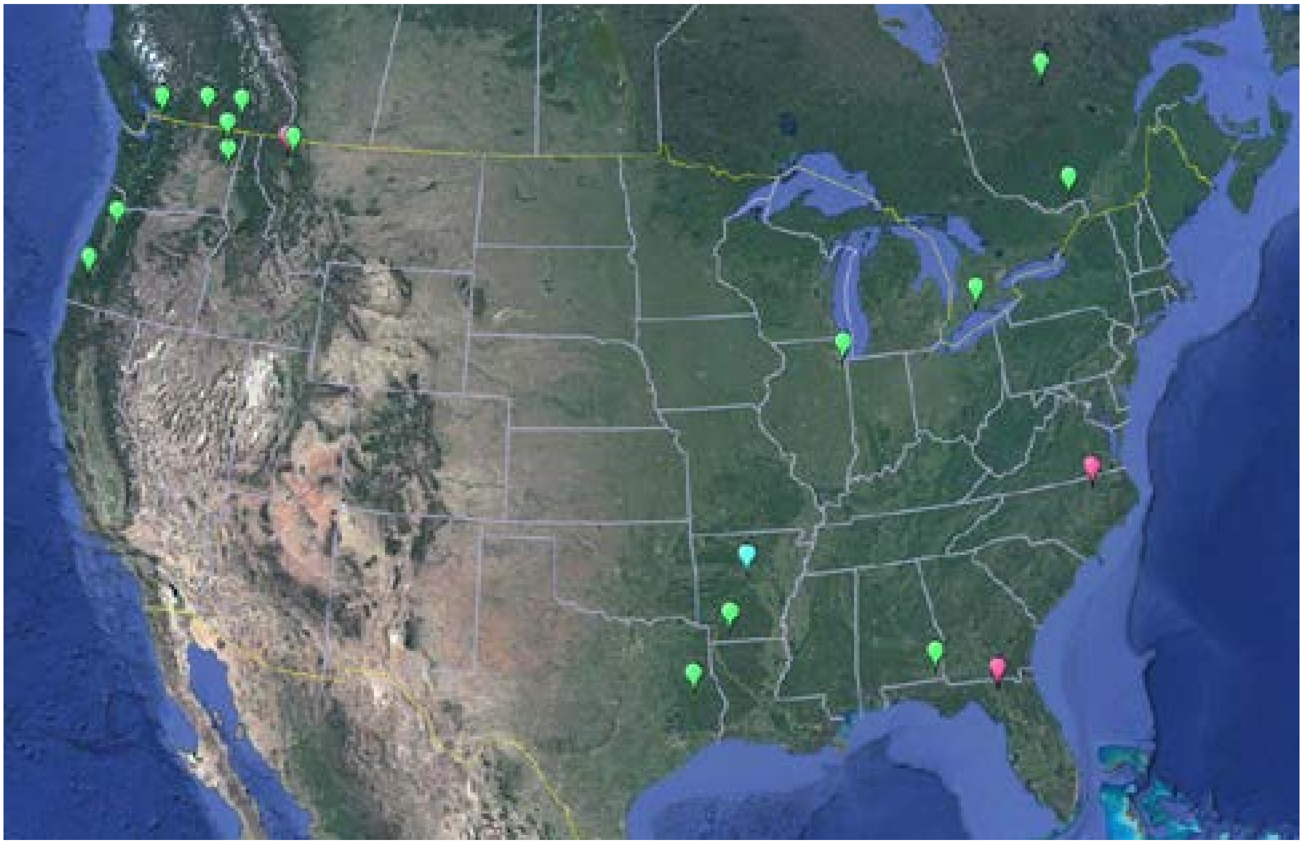


FIGURE 4.3: LOCATION OF OPERATING (GREEN), UNDER CONSTRUCTION (BLUE), AND PLANNED (PINK) MASS TIMBER PLANTS

Source: The Beck Group

their customers. The following bullet list briefly describes a number of these services. Note, however, that this is a rapidly evolving portion of the mass timber supply chain as companies are starting to emerge that provide those support services. An example of this concept is featured in Section 4.5.5 with a case study of Swinerton's new business, Timberlab Inc.

It remains to be seen whether the model adopted by the pioneering North American mass timber manufacturers (i.e., providing a one-stop, turnkey solution for their clients) or the more recent move to specialization (i.e., specialists that act as "middlemen" between the manufacturers, architects/designers, construction firms, and developers) becomes dominant. Perhaps there will always be a mix of both business models in the industry. Regardless of who provides the services, the following list includes a variety of "details" that are required to move building projects from concept to reality.

4.5.1 ARCHITECTURAL DESIGN AND PROJECT SUPPORT

Design Assist: Mass timber manufacturers assist architects with their design and how to best incorporate mass timber into the building.

Engineering Services: Many mass timber manufacturers employ engineers who help building designers with the engineering review of structural, mechanical, electrical, seismic, acoustic, fire, and other aspects of a building specific to the properties of mass timber products.

Modeling Work: Most mass timber manufacturers assist in an array of construction documentation. Most recently, the use of Computer Aided Design (CAD) services (e.g., BIM, SolidWorks, CATIA, cadwork, AutoCAD, etc.) has been important for panelizing projects and identifying building assemblies. Using these tools, mass timber manufacturers can simply transport engineering documentation into CAD programs and develop robust 3-D models of the project using mass timber as part of the building's structure.

4.5.2 MANUFACTURING AND MATERIAL SUPPLY

Panel Manufacturing: This is the manufacture of various panels at a production facility. This includes finger-jointing lumber into lamellas, molding/planing or surfacing the lumber, and pressing panels to desired thickness, width, and length.

Panel Milling and Finishing: This is the additional manufacturing or CNC milling of panels to shop-specific drawings. This also includes any architectural- or industrial-grade sanding, coating, and visual finishes. Many of the manufacturers list these two types of finishes (architectural and industrial) and can accommodate special requests for exposed elements. Some independently owned companies (i.e., unrelated to mass timber manufacturers) have also started up, offering secondary manufacturing (CNC milling, finishing) of panels, glulam, and timbers.

Supplying Connectors/Hardware/Fasteners: If mass timber manufacturers do not produce connectors and other hardware, they may source them from various manufacturers. They also might source products like hardware and fasteners that are required in mass timber buildings. As a service, most mass timber manufacturing firms will source needed components.

4.5.3 CONSTRUCTION AND INSTALLATION SUPPORT

Logistics planning: Several mass timber manufacturing companies help with the logistics of construction. These services include offering just-in-time delivery of construction panels and helping plan the panel installation sequence.

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

4.5.4 OTHER MISCELLANEOUS SERVICES

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

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

Renovation Services and/or Interior Design Options: In some cases, building development calls for a complete package including kitchen, baths, final appliances, and various finishing design elements. Some mass timber manufacturers offer a complete building package.

Environmental Protection Services: This is focused on industrial matting and consultation, using CLT to protect specific areas from soil compaction and impacts from heavy machinery.

Other: Most companies offer shipping as a part of the package, as well as identifying any project's special requirements.

4.6 INDUSTRIAL MASS TIMBER PRODUCTS

Although mass timber use in buildings gets a lot of attention, it is useful to remember that this product category makes up the bulk of North America's mass timber manufacturing capacity. This section, therefore, describes industrial mass timber products via two case studies about how mass timber manufacturers view this market and their products. Each case study includes several illustrations of applications, including industrial/utility matting, bridge decking, shoring, sound barriers, and retaining walls.

FIGURE 4.4: MASS TIMBER SHORING

Source: Texas CLT

CASE STUDY:
TEXAS CLT

FIGURE 4.5: SHORING USING I-BEAMS AND A MTP

Source: Texas CLT

TEXAS CLT CASE STUDY

Texas CLT operates a mass timber manufacturing plant in Magnolia, Arkansas, that has three custom-made, built-in-the-USA presses. The company recently obtained certification to manufacture panels according to APA PRG 320-2019 for commercial construction use. They have, however, been operating since 2018, and their focus before certification was industrial markets. Texas CLT representative Brant Cobb says, "We are creating a blank canvas (mass timber panels) for others to develop into products." Their experience has been that promoting CLT panels to a variety of potential end users results in those users identifying new and innovative uses and product categories. Should that hold true, expect further industrial MTP applications to develop in the future. In the meantime, each of the current industrial mass timber product types is described in more detail in the following subsections, along with several examples of Texas CLT's "blank canvas" guiding principle.

Shoring: Shoring (lagging) is the material used to temporarily support a structure or trench when it is in danger of collapse during repair or alterations. There are many types of shoring, but in the case of shoring made from mass timber, a common application up to this point has been in trenching. Texas CLT says that shoring made from mass timber is only a fraction of the cost of shoring made from metal (see **Figure 4.4**). Additionally, because the shoring is made from wood, it is much lighter than shoring made from metal or other common materials. As a result, much lighter, less-expensive-to-operate equipment can be used to set the shoring in place and remove it after the work is complete. A mini-excavator was used to set the shoring used in the **Figure 4.4**.

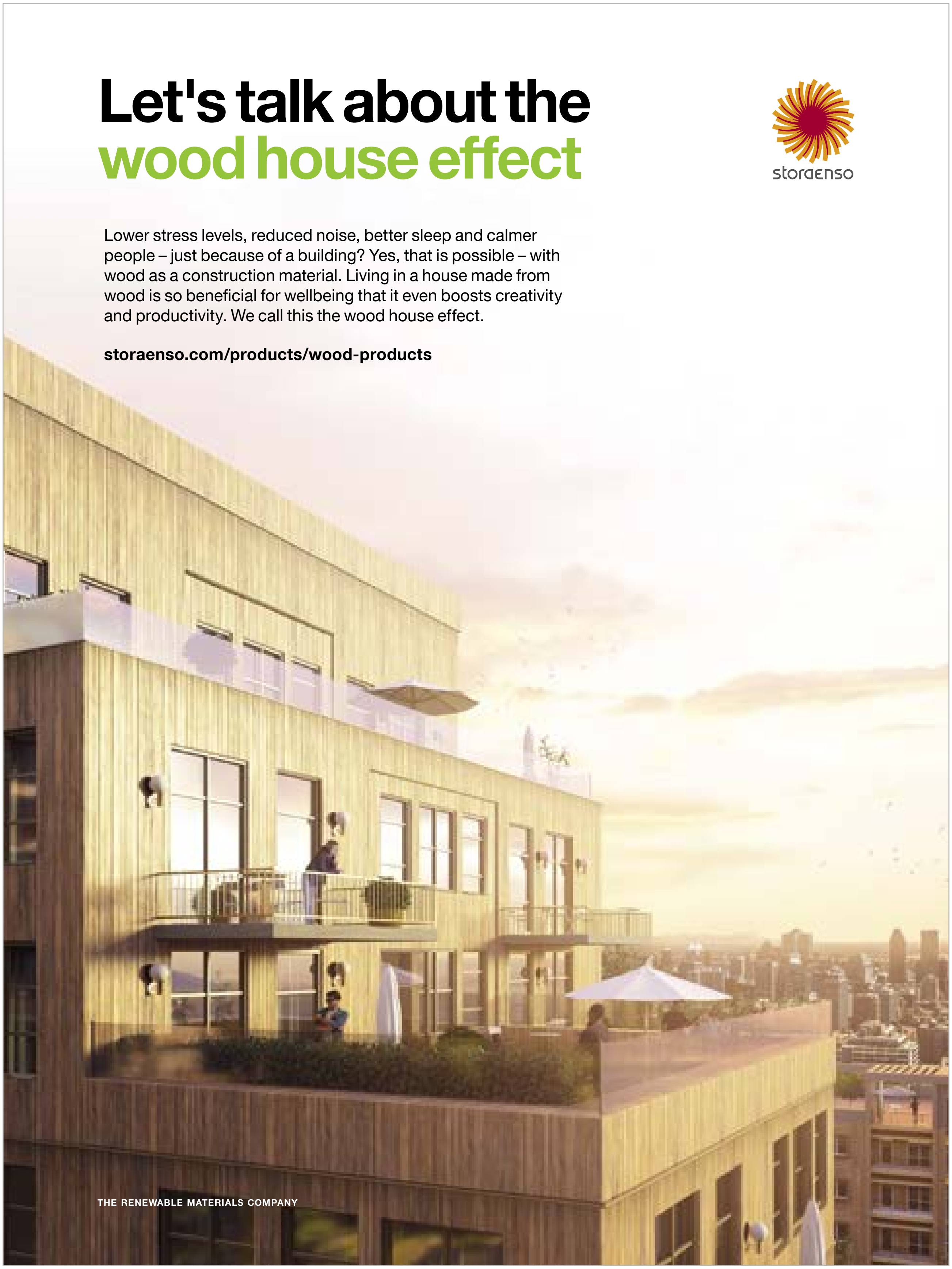
FIGURE 4.6: PRESERVATIVE-TREATED MASS TIMBER IN USE AS BRIDGE DECKING
Source: Texas CLT

Some shoring applications involve driving two steel I-beams into the ground as shown in **Figure 4.5**. In this case, the beams are 20 feet long by 6 inches and have been driven into the ground 14 feet apart. The CLT panel being slid into place between the beams is 4.25 inches thick by 8 feet wide and 14 feet long. The tractor shown lifting the panel into place is powered by only a 46-horsepower motor, again illustrating that relatively modest equipment is needed for using MTP in these applications. Note also that when the need for the barrier is finished, the panel can be lifted from between the I-Beams and laid on the ground for use as an access mat. The added versatility from this "dual purpose" use has been a strong selling point in the marketplace.

Preservative-Treated Applications: Mass timber panels used in sound barriers, retaining walls, and bridge decks are more permanent applications. This means that they need to be treated with preservative chemicals to inhibit the growth of fungus and mold. If those decay mechanisms are left unchecked, over time, they decay wood and reduce its structural integrity.

There are a variety of ways for treating wood with preservatives, but one of the most common and effective is placing the wood in a large metal vessel, sealing the vessel, and then creating a vacuum. The vessel is then flooded with a mix of water and preservative chemicals/oils and pressurized to levels well beyond normal atmospheric pressure. This forces the preservatives deep into the cell structure of the wood, where they remain after the pressure is relieved and the wood is removed from the vessel. Most treatment vessels are about 6 feet in diameter and come in lengths up to 120 feet long. Brant said, "Texas CLT treats CLT panels according to AWPA Standards and EPA UC4A."

Given the existing preservative treatment process and equipment, full size (e.g., 8-foot to 10-foot width panels) simply do not fit into pressure treatment vessels. However, Texas CLT has gotten around this issue by making the panels to be used in sound barriers and retaining walls only 4 feet in width and various lengths up to 20 feet. This sizing allows the panels to fit into the pressure-treating vessel. End users have reportedly been pleased with the products because, similar to building construction, the time needed for construction is greatly reduced because, in most applications, a few large panels can replace many individual large timbers. **Figure 4.6** illustrates mass timber used as bridge decking after it has been treated with preservative chemicals.


Let's talk about the
wood house effect
storaenso
Lower stress levels, reduced noise, better sleep and calmer people – just because of a building? Yes, that is possible – with wood as a construction material. Living in a house made from wood is so beneficial for wellbeing that it even boosts creativity and productivity. We call this the wood house effect.
storaenso.com/products/wood-products
THE RENEWABLE MATERIALS COMPANY

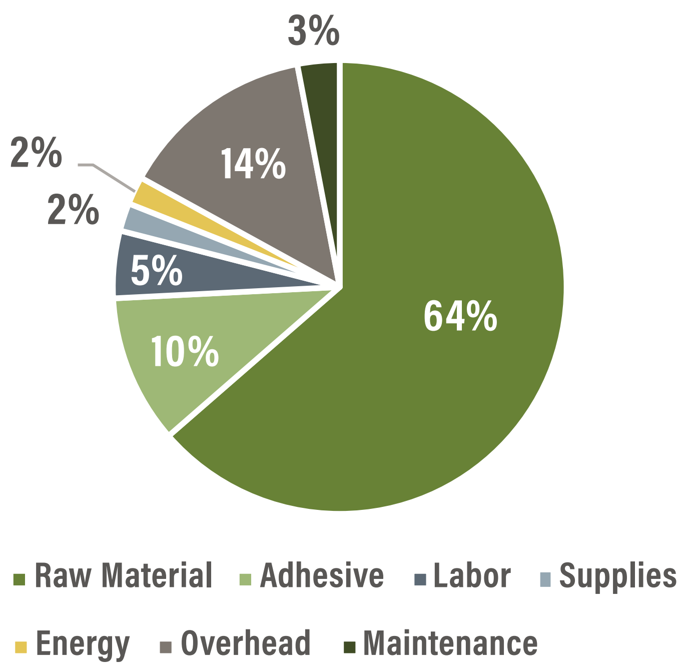


FIGURE 4.2: MASS TIMBER MANUFACTURING COST STRUCTURE

4.6.1 INDUSTRIAL MASS TIMBER MANUFACTURING CHALLENGES

Several mass timber manufacturers reported an unexpected workplace issue that arises when employees in a mass timber manufacturing facility produce both building panels and industrial panels. The issue is the perceived difference in the level of acceptable product quality between the two product types. In other words, when employees know the panels that are being produced will be used in industrial applications (e.g., being driven on by heavy equipment, shoring, etc.), there is an inherent relaxation in the expectation of the quality needed in the finished product. The same employees might then be asked to produce very high quality panels that are to be used in a high-profile building project. The problem arises when the lower-quality-inducing habits formed when producing industrial mats carry over to the production of the building grade panels.

Some manufacturers reported working diligently to improve company culture so that all panels are produced to the same level of quality regardless of the product type and end use. Others reported they intentionally decided to only produce building grade panels. The latter approach avoids the issue of perceived product quality differences among employees.

4.7 MASS TIMBER MANUFACTURING COST STRUCTURE

During "normal" lumber market conditions, the cost of raw material (i.e., lumber) is estimated to comprise about 64 percent of the total plant operating costs, as shown in **Figure 4.2**. Note that normal market conditions are a net lumber cost of about $350/MBF, which is approximately the long-term average price for dimension lumber in

North America. Also, note that the cost estimates are based on a financial model of a plant producing about 50,000 cubic meters per year and operating on a 2-shift basis.

As previously described, lumber prices in North America skyrocketed during 2020 to levels as much as 3 times higher than the long-term average price. In a scenario where lumber cost is double the long-term average (i.e., about $700/MBF), the cost of raw material increases to about nearly 80 percent of the total operating cost. Additionally, under a scenario where the cost of lumber doubles to $700/MBF, the total cost embedded per unit volume of finished mass timber panel is estimated to increase by a factor of 1.6. Recall that these estimates are based on financial models of mass timber manufacturing plants and are not actual operating costs as reported by existing mass timber manufacturers.

4.8 LIMITATIONS IN MANUFACTURING GROWTH IN NORTH AMERICA

Despite what is believed to be a temporary slowdown caused by COVID, both demand for and production capacity of mass timber panels are growing rapidly in North America. Nevertheless, continued expansion faces some potential limitations, primarily on the supply side. They are:

Understanding of building market and design phase: Although some companies in North America have provided a suite of business services focused on the architectural building uses of mass timber, some mass timber companies have limited knowledge of the construction industry. It will be important for those firms to either expand in-house expertise or hire outside design and engineering support to complete projects.

Delays from equipment suppliers: CLT manufacturing equipment is in high demand, and suppliers (Minda, Ledinek, USNR, and Kellesoe) have recently quoted up to 15-month lead times to deliver equipment.

Manufacturing learning curve: Several mass timber manufacturers have experienced quality control challenges in manufacturing CLT. Unless lessons learned are shared within the industry, new entrants are likely to repeat those mistakes, negatively affecting broader mass timber market growth.

Product standardization: Most manufacturers work hand in hand with the architect and developer to produce a mass timber building. This may help save construction time and improve the project's success, but it also comes with extra costs for mass timber manufacturers, including additional, highly trained staff, planning and logistical challenges, and longer design phases, extending production deadlines.

Trucking and shipping: As with most industries, trucking and shipping is a challenge for the supply chain. Many projects will require just-in-time logistics (a construction cost-saver). Disruptions in shipping can delay project deadlines and building targets. One transportation challenge cited by manufacturers, for example, is that when panels are to be shipped long distances, it is much more cost-effective to ship by rail. However, this is challenging because of panel size considerations and because the railroads are hesitant to insure the freight. After "bump testing" precut panels, especially those with sharp angles or cutouts that create weak points, at least one of the major railroads thinks the chance that the panels could be irreparably damaged by bumping and jostling during transit is too high.

4.9 OPPORTUNITIES FOR MANUFACTURING IN NORTH AMERICA

Local, state, and national building code changes: As described in Chapter 5, building code changes that allow wood's use in taller buildings continues to expand potential markets for mass timber. While the taller structures represent a relatively small percentage of the total construction market, publicity surrounding tall wood buildings raises awareness of possible mass timber use in a wide variety of buildings, spurring greater demand.

Improvements in efficiency: Since its development, the manufacture of CLT has improved by great leaps. Now, firms interested in entering the market can do so with major investments in state-of-the-art equipment—much of it from experienced vendors in Europe—that may allow new entrants to operate more cost-effectively than early MTP adopters.

Product standardization: A limitation in the growth of panel manufacturing, product standardization may be one of the industry's biggest opportunities. With standardized panel sizes, architects and designers could evaluate bids from multiple suppliers on an apples-to-apples basis, confident in the product standards of each manufacturer. This would save significant time and effort, and would allow the manufacturing sector to focus on production to shop-drawing specifications.

Continued support from government, NGOs, and other agencies: Various organizations that have directly supported expansion of mass timber construction in North America have provided a boost in growth and spurred investment in manufacturing operations. These organizations include FPInnovations, WoodWorks, and Think Wood, among others. Additionally, the International Mass Timber Conference has played a vital role as a venue for sharing information about this rapidly evolving industry.

Various local, state, and federal agencies have been instrumental in supporting the growth of mass timber manufacturing. Recent developments include:

- The passage of the National Defense Authorization Act (NDAA) means that the secretaries of defense and agriculture are directed to review the potential to incorporate innovative wood products, including mass timber, in constructing or renovating facilities owned or managed by the Department of Defense, and to issue a report to Congress.

- In 2002, the USDA created the BioPreferred Program as part of the Farm Bill with the goal of increasing the purchase and use of bio-based products. The program was reauthorized in the 2018 Farm Bill. Two major aspects of the program are mandatory purchasing requirements for federal agencies and their contractors, and a voluntary labeling program that allows certified producers to label their products with the USDA BioPreferred label, signaling the environmental attributes of the product. Given the renewal of the program, mass timber manufacturers have sought and achieved certification via the BioPreferred program for their mass timber products.

- The US Forest Service has expanded the scope of its long running Wood Innovation Grant program to include funding projects "showcasing quantifiable environmental and economic benefits of using wood as a sustainable building material in an actual commercial building and the projected benefits achieved if replicated across the United States based on commercial construction market trends." This development is widely viewed as a benefit to mass timber building projects.

- Additionally, various university and USDA Forest Products Laboratory research, all with funding support from the US Forest Service, have supported key changes in the 2021 ICC's national building code. These changes have opened pathways to the construction of taller buildings in the US.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STERLING CASE STUDY

Sterling is a leading manufacturer of industrial mass timber products. They have mass timber manufacturing facilities in Texas and Illinois. The following questions and answers are presented as a case study offering their perspective about various aspects of the industrial mass timber business.

Question: *What Industrial CLT products does Sterling offer?*

Sterling: We offer the following products:

- Access matting: all types
- Temporary bridge decking

Question: *What is the value proposition to consumers of these products relative to competing/substitute products?*

Sterling: To start, CLT is only one portion of Sterling's total offering. We generate access solutions with consultation and collaboration, and we offer turnkey execution of those solutions as well. TerraLam CLT is at the core of the solution and allows us to bring additional value to our clients. TerraLam CLT mats were created to address the major concerns of the industries we serve: economics, sustainability, and safety.

- **Reduced Cost:** High strength-to-weight ratio means moving more mats at a time, faster installation, and faster removal with close to half the freight costs.
- **Sustainability:** It's manufactured with farmed SYP versus hardwood; a solid surface lowers risk of invasive species transfer; and 50 percent fewer trucks on the highways reduces greenhouse gas emissions.
- **Safety:** No gaps eliminate slips, trips, and falls.

Question: *What is the overall size of the market for these products?*

Sterling: Developing an industrial matting forecast is very difficult. We think about it in terms of percentage of CLT vs other products with CLT representing approximately 10 percent of the total product currently in play (CLT, plastics, bolted hardwood). Additionally, we believe the market is growing every day with increased awareness of the benefits of matting and, specifically, the benefits of CLT matting solutions.

Question: *What is the sales value ($/unit volume) of these products relative to CLT used in building construction?*

Sterling: We look forward to answering that in more detail, but we have not taken our first order for structural CLT, yet. However, we can share that industrial CLT products are typically sold as commodities and, as such, earn single digit margins.

Question: *What are the key drivers in demand for these products?*

Sterling: Our solutions are in demand by the energy infrastructure owners and contractors of our nation. To support the delivery of power and heat to homes across America, we use our solutions to provide on-ground construction support and temporary bridges for equipment to gain access to otherwise challenging environments, and to do it safely and efficiently, and while protecting the environment they are working in.

Question: *What species of lumber do you use?*

Sterling: Sterling uses only SYP grade 2 or better for our panels. The species choice is relevant to the strength of the panel. SYP has tremendous strength properties.

Question: *What is the operating status of your two plants?*

Sterling: Both plants will have some excess capacity available in 2021. With the size and speed of our plants, they are designed to support our customers with a just-in-time inventory approach.

Question: *Anything else?*

Sterling: The rigors of a softwood panel held together with adhesive and fully exposed to the elements day in, day out under the pressure of aggressive equipment is far more stressful to the panel than structural applications and should not be taken for granted. Lives are also at stake in this application, and all manufacturers should become third-party certified to ensure they are making proper CLT panels. Some think the industrial market can take "anything" on their path to structural certification. For us, it is just the opposite. We could have been certified for structural quite easily compared to the process of manufacturing a panel for our industrial applications.

CHAPTER 5: DESIGNERS & SPECIFIERS

IMPACTS OF THE MASS TIMBER EFFECT

- Carbon neutrality by 2030 is an important goal, but the building industry can and should go further, and by 2040 can store more carbon than it emits if mass timber market saturation is achieved.
- Choosing sustainably harvested wood as a primary structural material significantly contributes to turning a building into a carbon store.
- Of the main structural material choices for buildings, wood is the most widely available bio-based option.
- Quantifying the embodied carbon of wood products is complex, and the effort is currently in a nascent and rapidly developing research phase.
- Currently, a Life Cycle Analysis for wood products assumes that the impact of forestry on emissions, sequestration, and stores of forest carbon in North America is neutral, because, overall, the growth of timber across the continent exceeds removals.
- Forestry practices matter greatly in accurately calculating the carbon storage potential of wood, but we do not yet have widely accepted methods to accurately measure or regulate different approaches to forest management on forest carbon pools.
- There are multiple ways of measuring a building's embodied carbon through a LCA. Designers may choose to exclude wood decomposition and presume material reuse in their carbon profiles to better understand short-term (2030) impacts.

What is the construction industry's appetite for innovation? The U.S. 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 resultant effect on building codes, it is likely that these industry leaders will pull the entire building construction industry in that direction.

Mass timber is promising as an environmental solution, but it is also a disruptive technology with respect to building construction. The implications of increased off-site fabrication and new, highly collaborative construction approaches are already allowing project teams to glimpse a future with increasingly higher levels of control over materials procurement and craftsmanship. As such, many designers will find that the information in **Chapter 6** is equally relevant to them as teams become more integrated, optimizing the design, schedule, and costs together in real time.

This chapter also covers how to approach designing and coordinating a mass timber project from the design team perspective, from systems choices to best detailing practices to building code paths.

5.1 CARBON CONSIDERATIONS

Many designers and building owners are drawn to choosing mass timber for its environmental credentials. A rapidly developing area of research seeks to answer their questions about how to quantify and maximize the benefits of this choice. Given Architecture 2030's recommended time frame of 10 years[1] to reach net zero emissions in the building industry, getting it right is critical. This section 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, especially at scale as the market sector grows, also ultimately impacts land use and forestry practices.

5.1.1 ENVIRONMENTAL IMPACT OF BUILDING MATERIALS

Analyzing and comparing the environmental impacts of building materials is complicated but critical to achieving the industry's carbon goals. Embodied carbon and biogenic carbon, as defined below, are two important concepts to understand before beginning such an analysis. To track progress, designers can use industry-developed tools that assist with environmentally conscious decision-making processes that include LCAs, and Environmental Product Declarations (EPD). A number of certification programs are designed to help building projects measure, meet, and promote their goals.

Embodied Carbon

Most processes involved in the extraction, manufacture, transport, and installation of building products rely on fossil fuels. The total amount of carbon emitted by a given product during this process is the embodied carbon of that product. Wood products have much lower embodied fossil energy content than concrete or steel because they require significantly less energy to produce (see **Figure 5.23**). We frequently compare wood with these two other materials specifically because the structural system of a building comprises up to 80 percent of the entire embodied carbon of a building. Wood is an effective replacement of 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."[2] The critical benefits of reduced embodied carbon are immediately achieved when a building is constructed. Bio-based products also stand apart from other materials in that they actually store carbon as well, potentially offsetting carbon impacts from other materials.

Biogenic carbon

"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."[3] One cubic meter of wood stores approximately one ton of carbon dioxide.

Wood, as a building material, provides long-term biogenic carbon storage. As illustrated in **Figure**

1 Architect Magazine, The Carbon Issue, January 2020, guest edited by Architecture 2030
2 Architecture2030. https://architecture2030.org/new-buildings-embodied/
3 https://www.sciencedirect.com/topics/engineering/biogenic-carbon

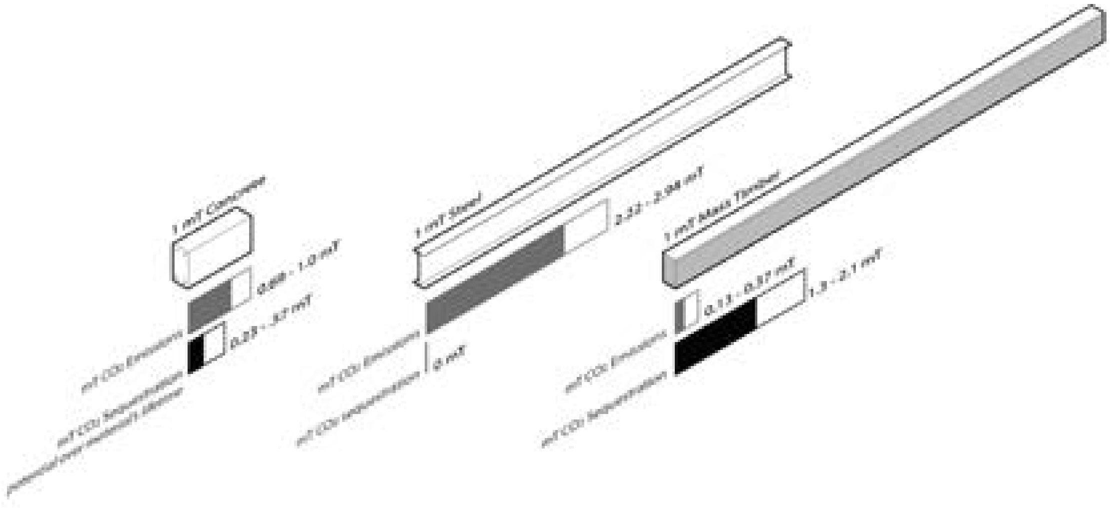


FIGURE 5.1: EMBODIED AND BIOGENIC CARBON IN COMMON STRUCTURAL MATERIALS

Illustration by the Timber City Research Initiative, Gray Organschi Architecture, timbercity.org.

5.1, carbon storage in long-lived wood products can extend the carbon cycle. Constructing buildings with wood products increases the length of time that carbon is kept in storage, as it avoids release into the atmosphere through forest decay or fire.

Biogenic carbon eventually returns to the atmosphere through decomposition or incineration, which may be acknowledged through a complete LCA that illuminates very long-term impacts. However, while end-of-life considerations are critically important to a circular economy (see Chapter 8), most buildings built today will remain standing long after global carbon reduction time lines have passed. 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 may be an unlikely occurrence, based on a likelihood for structural wood to be either reused or encapsulated in a landfill, rather than incinerated or mulched. Additionally, climate crisis goals should be taken into consideration.

Absorbing as much atmospheric carbon as possible in the next 30 years is a global priority to avoid irreversible climate change. The World Green Building Council (WorldGBC) stresses the importance of reducing "upfront" or embodied carbon in their 2019 report, "Bringing Embodied Carbon Upfront."[4] The report states: "To achieve our vision, we must take urgent action to tackle

4 https://www.worldgbc.org/sites/default/files/WorldGBC_Bringing_Embodied_Carbon_Upfront.pdf

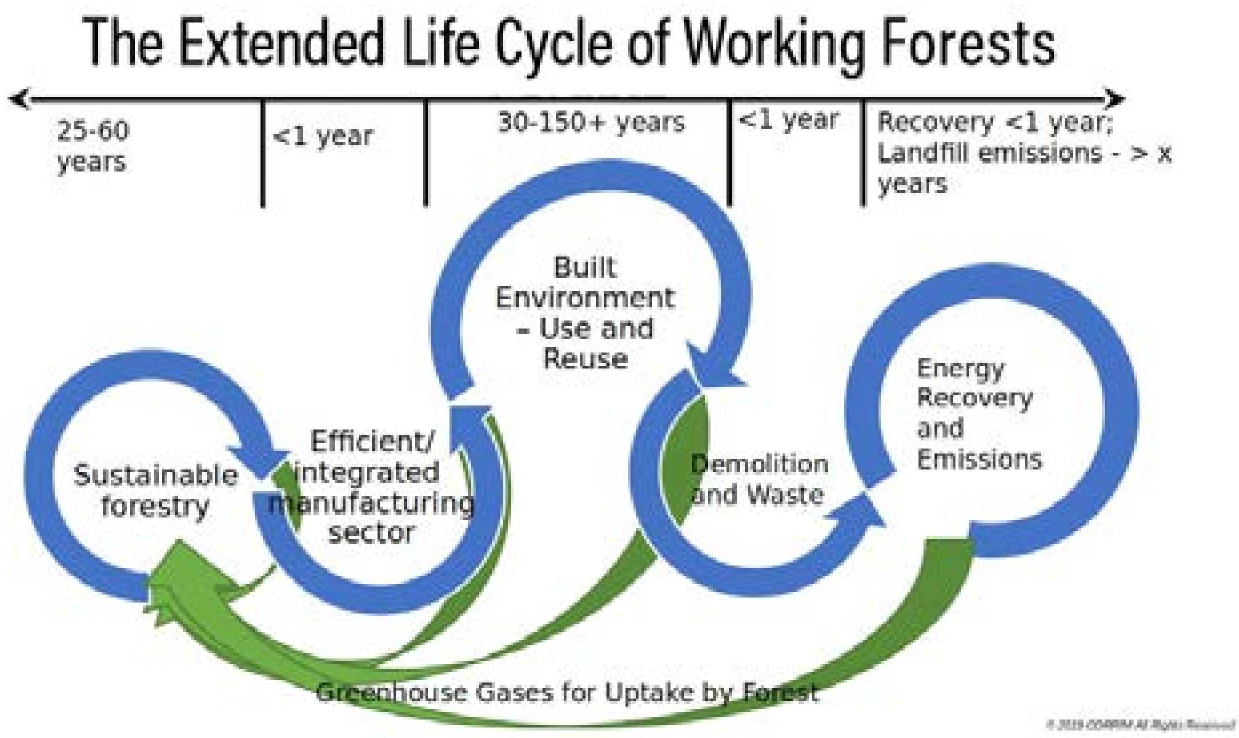


FIGURE 5.2: EXTENDED LIFE CYCLES OF WORKING FORESTS

Reprinted with permission, Elaine Oneil, Consortium for Research on Renewable Industrial Materials (CORRIM). www.corrim.org.

upfront carbon while designing with whole life carbon in mind." It can be argued that embodied carbon stored today is more critical than accounting for unknowns in deconstruction approaches, fire, or decay past that critical time line. Considering the urgent 10-year time line we face globally to eliminate emissions in the industry, project teams may choose to emphasize the short-term effect of using wood products.

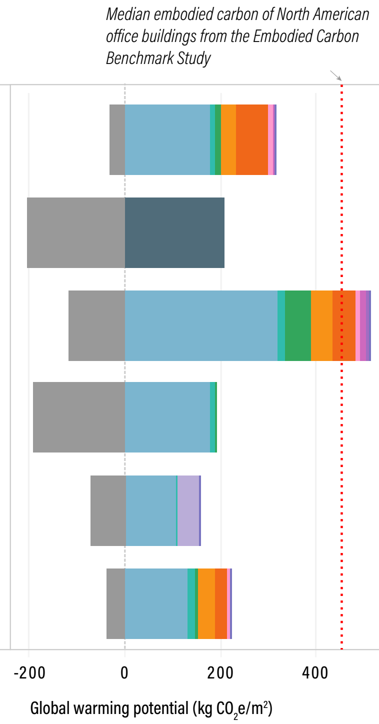
Buildings as Carbon Banks

On a global scale, the building industry stands out as having the potential to turn from being the largest contributor of global 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.

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 will likely develop[5] for mass timber, which would prolong use and further delay decomposition. In fact, decomposition is an unlikely outcome. A worst-case scenario

5 https://corrim.org/carbon-economy-workshop/

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 5.3: 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, (2) and 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.

Photo Credit: Carbon Leadership Forum.

1 *Bowick, M. (2018). Brock Commons Tallwood House, University of British Columbia: An environmental building declaration according to EN 15978 standard. Athena Sustainable Materials Institute. http://www.athenasmi.org/wp-content/uploads/2018/08/Tallwood_House_Environmental_Declaration_20180608.pdf*

2 *Huang, M., Chen, C.X., Pierobon, F., Ganguly, I., & Simonen, K. (2019). Life Cycle Assessment of Katerra's Cross-Laminated Timber (CLT) and Catalyst Building: Final Report. Carbon Leadership Forum. https://carbonleadershipforum.org/download/5173/*

3 *Bowick, M. (2017). Design Building, University of Massachusetts, Amherst: An Environmental Building Declaration According to EN 15978 Standard. Athena Sustainable Materials Institute. http://www.athenasmi.org/wp-content/uploads/2017/04/UMass_Environmental_Declaration_31_January_2017.pdf*

4 *Liang, S., Gu, S., Bergman, R., & Kelley, S. (2020). Comparative Life-Cycle Assessment of a Mass Timber Building and Concrete Alternative. USDA Forest Products Lab. 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 *Bowick, M. (2015). Design Building, University of Massachusetts, Amherst: An Environmental Building Declaration According to EN 15978 Standard. Athena Sustainable Materials Institute. http://www.athenasmi.org/wp-content/uploads/2015/06/WIDC_Environmental_Declaration_final.pdf*

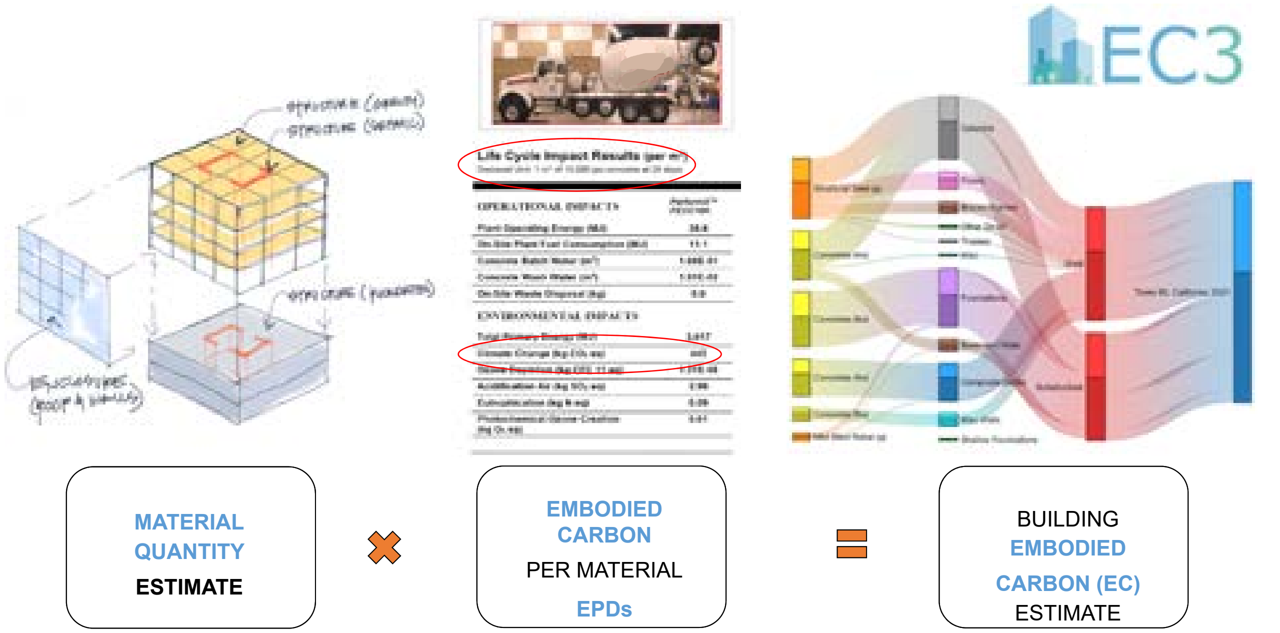


FIGURE 5.4: EC3 LIFE CYCLE ASSESSMENT TOOL

Source: Embodied Carbon in Construction Calculator Carbon Leadership Forum.

would send these valuable building components to a landfill, where LCA's typically assume the wood will decompose. In fact, the EPA estimates that 88 percent of the carbon in landfilled wood is permanently sequestered, and the remaining 12 percent is captured for reuse as fuel, offsetting fossil-sourced fuel usage.[6]

Life Cycle Assessments

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 capture an entire building project. As discussed in the topics above, when calculating the LCA of a timber building, biogenic carbon can be approached with either a decomposition or industrial reuse cycle taken into account.

The Consortium for Research on Renewable Industrial Materials (CORRIM) is a leading resource on LCAs for a variety of wood products. Embodied carbon and global warming potential have been researched and calculated for a number of North American mass timber products, yielding a range of results because of variations in wood sourcing and manufacturing processes. As more research and data are available, the current, educated assumption that wood products can, depending on the source, more than offset the carbon required to produce and install them will be refined.

6 Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM) (2019).

FIGURE 5.5: ENVIRONMENTAL PRODUCT DECLARATION FOR CROSSLAM CLT

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

The Carbon Leadership Forum (CLF) is widely trusted for producing best-practices Whole Building LCAs (WBLCA) for timber structures. In a study for Katerra in 2019, CLF compiled information from a number of mass timber buildings to compare their Global Warming Potential (GWP) from a WBLCA standpoint. **Figure 5.4** shows the buildings' GWP both 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,[7] popular for its ability to plug in to Revit; ATHENA; BEES (Building for Environmental and Economic Sustainability); and, more recently, EC3 (Embodied Carbon in Construction Calculator). EC3 is a free, open-source LCA tool released in late 2019 and developed by a multidisciplinary team led by the Carbon Leadership Forum (CLF), and it promises to be the most sophisticated tool to date. Each tool will vary somewhat in end-of-life options and assumptions, and users of these tools will find that these factors contribute greatly to the output for LCAs for timber buildings.

7 https://kierantimberlake.com/page/tally

CASE STUDY:
CATALYST BUILDING

IMAGE SOURCE: KATERRA.
Image Credit: Benjamin Benschneider

ACHIEVING NET ZERO CARBON WITH CLT

Katerra commissioned the Carbon Leadership Forum (CLF) and Center for International Trade in Forest Products (CINTRAFOR) at the University of Washington to analyze the environmental advantages of their CLT product and the subsequent benefits afforded to the Catalyst Building in Spokane, Washington. The Catalyst is a 15,690 square meter (164,000 square foot), five-story office building that makes extensive use of CLT as a structural and design element.

CLT LIFE CYCLE ASSESSMENT

Generally, the CLT product Life Cycle Assessment (LCA) covered the following three life cycle stages: forestry operations and lumber production, transportation from sawmills to CLT manufacturing facility, and on-site CLT manufacturing

The research team determined that the embodied carbon impact of Katerra's CLT is 130 to 158 kg CO^2 e/m3 (results vary depending on modeling assumptions). This result falls at the lower end of the spectrum of the results from LCA studies of other CLT products in the United States. This lower impact is likely due to a combination of the use of lighter-weight wood species, higher efficiencies of production processes, higher efficiencies in adhesive use, and a higher waste recovery rate. Additional research work could refine the results by gathering more factory data after a year of operations and exploring the effects of varying multiple study parameters.

Figure 1 presents a contribution analysis for the conservative model. When this research was conducted, the CLT facility was not operating at full capacity, but this capacity is expected to increase in the future. At full capacity, this facility is expected to be more efficient than smaller facilities, potentially leading to additional reductions of environmental impact per unit volume of CLT produced.

BUILDING LIFE CYCLE ASSESSMENT

The Catalyst Building core and shell Whole Building LCA (WBLCA) was based on the project's material quantities and covered three life cycle stages: product and construction process, raw material extraction, and transportation of materials from material supply to the manufacturing facility.

Figure 2 presents the Global Warming Potential (GWP) results of the Catalyst Building by building component, color-coded by material category. Overall, the structure has a greater impact than the enclosure, which is expected. However, the project also utilizes CLT as the primary exterior wall material, helping offset other enclosure components that carry a greater GWP. Within the structural system, the glulam and CLT gravity system has the greatest proportion of impacts to GWP reduction, followed by the exterior CLT wall and CLT lateral systems.

The WBLCA estimated the upfront embodied carbon of the building to be 207 kg CO^2 e/m2. This metric is similar to other mass timber buildings; however, the embodied carbon is significantly lower than most office buildings per unit of floor area, according to the Embodied Carbon Benchmark Study. Additionally, the Catalyst Building stores approximately 204 kg CO^2 / m2 of biogenic carbon, nearly offsetting its upfront embodied carbon. The small embodied carbon remainder was met through off-site carbon offsets to

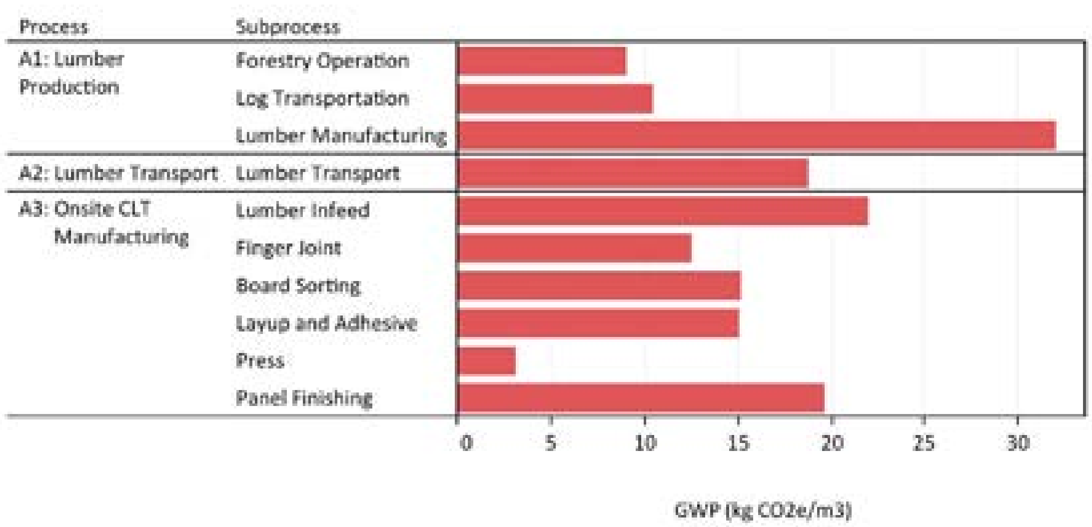


FIGURE 1: GWP RESULTS OF CTA LCA (CONSERVATIVE MODEL) PER CUBIC METER OF CLT PRODUCED

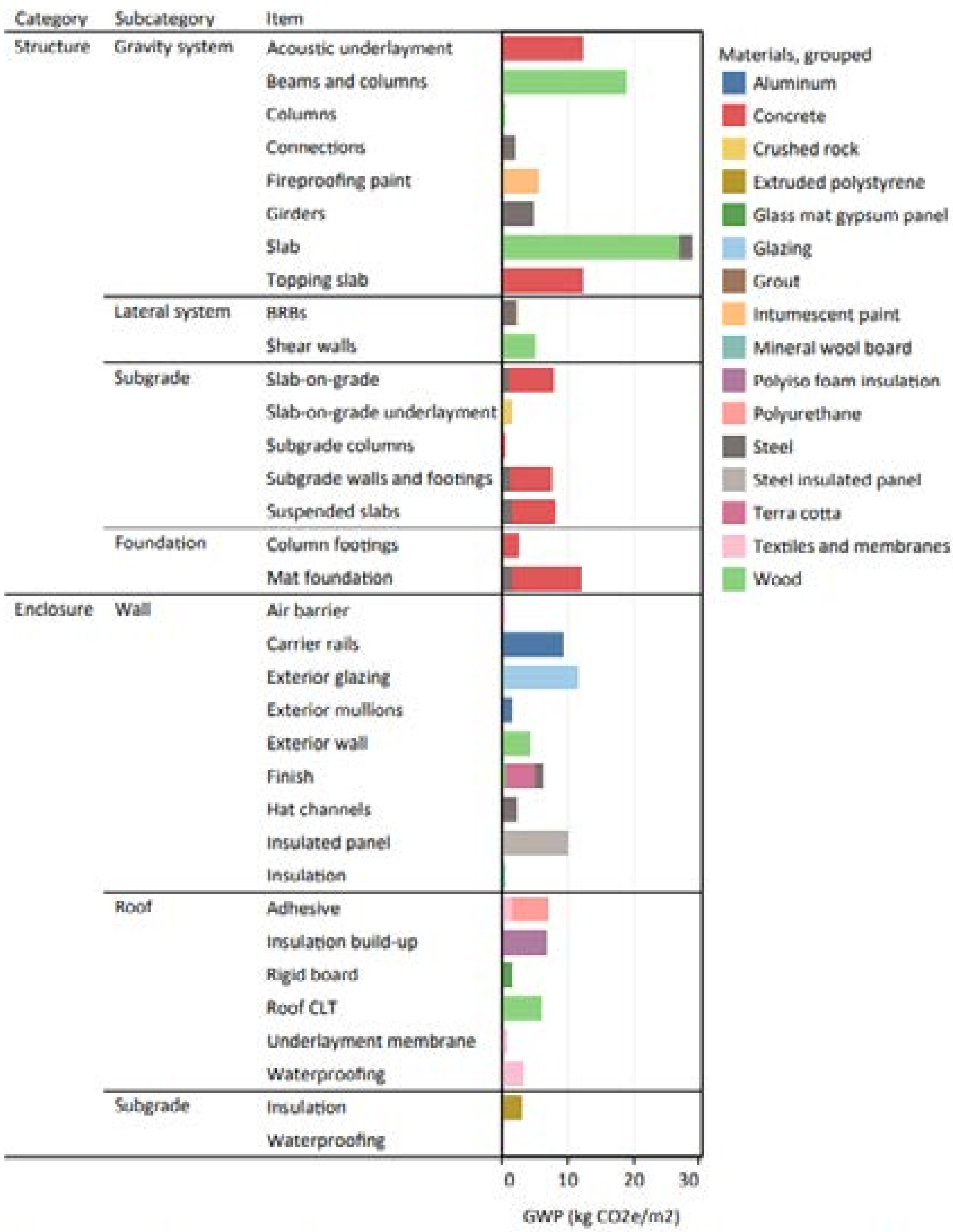


FIGURE 2: GWP RESULTS (LIFE CYCLE STAGE A) OF CATALYST BUILDING LCA, NORMALIZED BY TOTAL FLOOR AREA OF BUILDING

IMAGE SOURCE: KATERRA. IMAGE CREDIT: BENJAMIN BENSCHNEIDER

reach net-zero. This study treated biogenic carbon in accordance with the North America Product Category Rule and the default TRACI impact method.

Designed to Passive House standards to optimize energy use, Catalyst also employs innovative, integrated systems for on-site renewable energy generation using photovoltaic arrays, exhaust heat recovery, and gray water, as well as Internet of Things (IoT) sensors to optimize operation. Combined with CLF's carbon assessment of the mass timber structure, these design features help make Catalyst one of the largest zero energy buildings in North America, and one of the first zero carbon buildings set to be certified by the International Living Future Institute.

Story Credit: CLF and CINTRAFOR, University of Washington

CATALYST BUILDING

LOCATION: SPOKANE, WA

COMPLETION DATE: 2020

CLIENT/OWNER: AVISTA DEVELOPMENT, MCKINSTRY, SOUTH LANDING INVESTORS LLC

ARCHITECT: KATERRA (ARCHITECT OF RECORD) + MICHAEL GREEN ARCHITECTS (DESIGN ARCHITECT)

STRUCTURAL ENGINEER: KPFF

CONTRACTOR: KATERRA CONSTRUCTION

CLT SUPPLIERS: KATERRA, STRUCTURLAM

GLULAM SUPPLIER: WESTERN ARCHRIB

RIB PANEL ENGINEERING AND SUPPLIER: KATERRA

FIGURE 5.6: ILFI'S ZERO CARBON CERTIFICATION REQUIRES EMBODIED CARBON DISCLOSURES

Environmental Product Declarations

Reducing embodied carbon in building products reduces their Global Warming Potential (GWP). Designers can reference the information for products where GWP is measured and published, along with other disclosures like toxicity or land conversion, by reviewing the product's EPD. EPDs report on five categories of environmental effects: global warming potential, ozone depletion potential, acidification potential, smog potential, and eutrophication potential. EPDs completed in compliance with 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 a manufacturer may choose to pursue EPDs specific to their products—especially if they have exceptionally good reports—general EPDs for wood products are available through the American and Canadian Wood Councils. One of the most demanding EPD labels is the Declare label that identifies the most dangerous "red list" ingredients and clearly states when products are free of them. Four CLT manufacturers have achieved this label for their products (listed in the Adhesives section, below).

EPDs are complex to interpret and time-consuming to track down, but they are becoming more accessible as building owners and industry professionals demand nontoxic and low-carbon materials. Some excellent and rapidly expanding resources for designers include the databases Mindful Materials[8] and Carbon Smart Materials Palette,[9] and the organizational tool EPD Quicksheet.[10]

Green Building Certification Programs

The pursuit of environmental certifications is optional for most projects, but these programs and their supporters generally 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 healthier, more enjoyable working/living conditions for tenants.

Options for certification programs include LEED, Green Globes, Passive Haus, and International Living Future Institute's (ILFI) suite of Living Building approaches. Each of these programs has different criteria for certifications. However, all share a mission to construct buildings with reduced environmental impacts. The use of wood as a building material is generally positive within the context of the evaluation processes, though they vary in how wood certifications are viewed and accepted.

8 http://www.mindfulmaterials.com/
9 https://materialspalette.org/palette/
10 https://architecture2030.org/epd-quicksheet/

FIGURE 5.7: LUMBER STRENGTH ILLUSTRATION

Certifications focused on Zero Carbon have emerged in the last several years in response to the growing realization of the importance of neutralizing embodied carbon in the building industry. Internationally, projects can register with ILFI's Zero Carbon Certification program, which requires that, "One hundred percent of the embodied carbon emissions impacts associated with the construction and materials of the project must be disclosed and offset."[11] The Canada Green Building Council's Zero Carbon Building (ZCB) Standard recognizes embodied energy as well as operational energy. To date, ten ZCB Standard projects have been completed. USGBC's LEED Zero currently tracks operational energy only, but LEED's newest Version, 4.1, awards credits for embodied carbon accounting.

These building certification programs, where wood building products are concerned, often tie back into forest management certifications, solidifying the connection between sustainably managed forests and the utilization of wood in new and creative approaches to construction. These systems continually extend the goal of creating human habitat with an ever-smaller environmental footprint, and increasingly recognize that using wood is a significant component of that goal.

5.1.2 BUILDING MARKET DEMAND'S IMPACT ON FOREST CARBON

Many architects who choose to work with wood will be asked about forestry and logging, and that, for many, will be the first time they've had to consider from where exactly their raw building materials come. These questions tend not to come up with inorganic materials like steel and concrete, though, of course, everything comes from somewhere. The emotional connection people have with trees may be behind this investigative imperative.

Land Use

One of the biggest concerns in using forest-sourced products is the fear of causing deforestation or forest degradation. Forest degradation can occur when logging practices cause biodiversity loss or reduce the ecological resilience of an ecosystem. Designers should consider the sources of the fiber they specify, and they can turn to forest certifications as one way to support sustainable forest practices. Chapter 2 contains further discussion on certifications.

The biggest cause of deforestation is actually not forestry, but agriculture and development. When land is not valued as forests, it tends to get turned into something else, all around the world. Thus, counterintuitive at first but economically logical, is the idea that using forest products may actually contribute to an increase in lands used for forestry, and, in turn, increased carbon stores in forests.[12]

11 https://living-future.org/zero-carbon-certification/
12 Reid Miner, retired NCASI, September 9, 2020 Presentation to Carbon Leadership Forum

Forestry Practices

An increased demand for forest products appears to also drive more sustainable forestry practices. According to the Carbon Leadership Forum, "Transitioning construction of low to mid-rise commercial and non-residential 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."[13]

5.2 ELEMENTS OF DESIGN

Wood is one of the oldest building materials. As far back as 6,000 BCE, humans made dwellings using wood. Wooden longhouses sheltering more than 20 people date to at least 4,000 BCE. To build large wooden structures, humans have long taken advantage of wood's natural strength while minimizing any weaknesses. Over the millennia, building techniques and capabilities have improved, most recently with the development of mass timber panel systems.

5.2.1 PANEL SIZE

Mass timber panels are groundbreaking in the engineered wood market because of their scale and use in modular construction. To maximize the benefits of mass timber panels, a building designer must consider the panel as it relates to the building's grid system, in terms of overall dimensions, as well as the number of laminations and panel thickness. Each manufacturer has different fabrication machinery and thus different limitations on size. In North America, a typical panel size might be around 10 feet x 40 feet nominally, with between 3 and 7 laminations. There are, however, many options that exist within and outside of this range. A designer must also consider the actual, versus the nominal, dimensions when designing with mass timber panels.

Panel sizes have developed around transportation requirements. The transport limitations at any given building site should be taken into account when choosing optimum panels sizes for a project.

5.2.2 PANEL STRENGTH

As mentioned in Chapter 1, engineered composite wood products are stronger than solid wood components of the same dimensions because of the redistribution of natural defects in the wood. Mass timber panels truly 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). Products like CLT and MPP take advantage of wood's longitudinal strength by alternating the grain direction in each layer, resulting in a panel that is strong and dimensionally stable in both in-plane directions.

During the ongoing development of mass timber products, testing, including measurements of the strength of various panel styles and assemblies, has been constant. Because there are innumera-

13 https://carbonleadershipforum.org/blog/2020/04/17/mass-timber-optimization-and-lca/

ble panel variables (number of layers, species of wood, lumber sizes and grades, adhesives vs fasteners), the testing has taken two approaches: (1) physically testing specific panel size/layers/species configurations, and (2) extending the physical test results to other untested size/layers/species configurations through analysis and modeling. The combination of an analytical approach and experimental testing has created a baseline understanding of the strength of mass timber products.

For detailed information on design standards for mass timber products, refer to **Table 5.3.**

5.2.3 ADHESIVES

Adhesives are used in most engineered wood products, including plywood, LVL, glulam, CLT, and MPP. Standards have been established to ensure that these adhesives are structurally reliable and safe.

Requirements for adhesives used in glulam and CLT are very similar. Adhesives used in glulam must meet the requirements of ANSI 405 Standard for Adhesives for Use in Structural Glued Laminated Lumber (ANSI 405). Guidance for CLT, under PRG 320, specifies that adhesives in CLT used in the United States must also conform to ANSI 405, with two exceptions. First, Section 2.1.6 of ANSI 405 does not apply because it is intended to ensure glue-bond durability in exterior applications, and CLT is not recommended for exposed exterior applications. The second exception is that for the small-scale flame test under CSA O177 (Sections 2.1.7 and 3.7 of ANSI 405), CLT must be substituted for glulam.

PRG 320 specifies that adhesives in CLT used in Canada must conform to CSA O112.10 and Sections 2.1.3, 2.1.7, 3.3, and 3.7 of ANSI 405 with the same alteration to the small-scale flame test under CSA O177 as is required in the United States. In addition, for both the United States and Canada, PRG 320 specifies that CLT adhesives must conform to Annex B of PRG 320, which lays out standards for testing during elevated temperatures.

In CLT, the most commonly used adhesives are polyurethane (PUR) based, but melamine formaldehyde resins are also used. MPPs use a phenol formaldehyde adhesive similar to those used in plywood and LVL. These adhesives are continually being studied and refined to be both better for the environment and to better meet strength objectives desired by the Industry.

Many mass timber products have EPDs available that demonstrate the safety of their adhesives from a health standpoint. In fact, at least three CLT manufacturers with North American availability have achieved "red-list free"[14] status (and one other is "red-list approved"[15]) by the ILFI's Declare EPD label, the most rigorous of sustainable building standards.

Bio-based adhesives are an area of interest for designers and manufacturers looking for low-toxicity and low-carbon products. A cold-set, soy-based adhesive in development at Oregon State University has been validated under older PRG 320 requirements, but it has yet to undergo the fire testing required under the new requirements. Additional research is also required to determine cost-effectiveness and viability for commercial use.

14 Structurlam, KLH, and Nordic Structures. https://declare.living-future.org/
15 Katerra

FIGURE 5.8: MASS TIMBER CONNECTOR EXAMPLES

Sources: APA, The Engineered Wood Association, Structure Craft (upper right), Oregon Department of Forestry (lower left).

5.2.4 CONNECTORS

As mass timber construction increases, so does the need for proper fasteners and connectors. Connectors are used to join the structural components and to transfer loads throughout a building. There are a variety of considerations when it comes to the numerous connectors in a mass timber building, including the type of joint, the materials being joined, loads carried through the joint, and aesthetics. Connectors range from nails and screws to more complicated bracket systems, and to glued-in, or dry insert, wooden or steel rods. Some of these systems are proprietary, while others are traditional and widely available.

Connectors and fasteners must meet specific engineering requirements that are tested for performance. Two important requirements are shear strength and withdrawal strength. Shear strength is the ability of a material to resist forces that can cause the internal structure of the material to slide against itself (that is, fail) along a plane parallel with the direction of the force. Withdrawal strength, or withdrawal capacity, is the ability of the connector to resist forcible removal, or tear out, from its entry point. The National Design Specification (NDS) for Wood Construction provides design values for most dowel connectors, as well as for shear plates and split rings, while design values for proprietary systems are found in

FIGURE 5.9: CNC JOINERY WITH PREFABRICATED MASS TIMBER COLUMNS AND BEAMS

Tamedia Building, Zurich, Switzerland. Source: Emily Dawson

code evaluation reports, which can be provided by the manufacturer.

With all connectors, it is important to know where to find their applicable design values. The IBC defines the structural property requirements for connectors and fasteners of wood components. Section 2302.1 lists the various sections that cover the actual stress factors required for various building applications. Sections 2304.10.1 through 2304.10.7 of the IBC define the requirements for connectors and fasteners of wood components: what types of fasteners are to be used in what situations, how many, and where they should be placed.

There are two primary families of connections for wood construction: traditional joinery, and mechanical, including dowels, splines, plates, and other specialized, usually metal, components.

Joinery

Joinery uses specialized cutting techniques to form joints between wood components (mortise and tenon, dovetail, etc.). Joinery can create impressive results, both in beauty and strength. Long understood to be a time-consuming manual process that requires a significant amount of skill, today, with CNC technologies, the possibilities have become more accessible to the modern building market. Designs translated into a computer model to be read by the CNC operator can be unique and imaginative, or they can be optimized for material efficiency and speed—or potentially both. The intricacy of a given design will affect the time spent in cutting and assembling custom wood profiles, and that, in turn, will impact cost. Working with a fabricator early in the design process can inform the cost-effectiveness of a joinery-based design approach.

Dowels

The most common type of mechanical fastener, dowel connectors can be made from a variety of materials. Metal dowel connectors are typically steel, and they include staples, nails, screws, and bolts. Dowel connectors perform well at transferring loads, and they are generally easy to install and cost-effective.

While wood dowels can technically provide both a chemical and a mechanical connection, their application is analogous to metal dowel connectors. The NDS for Wood Construction allows design-

FIGURE 5.10: WOOD NAIL COIL AND LIGNIN WELDING
Photo Source: LIGNOLOC®

ers and engineers to calculate the strength properties of dowel connectors. (See also NLT and DLT in Chapter 1.) The benefits of wood doweling as a mass timber connection 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 include added metal or adhesives have an improved LCA profile.

Recent testing at the University of Hamburg identified the phenomenon of "lignin welding," finding wooden nails acceptable for structural applications. Subsequently, a proprietary wooden nail product made from beechwood was developed in Austria, utilizing the lignin welding effect. The German Institute for Construction Engineering (DIBt) recently issued technical approval of load-bearing timber connections using these wooden nails, noting "...[T]he large amount of heat generated by friction when the nail is driven in at a high speed causes the lignin of the wooden nail to weld with the surrounding wood to form a substance-to-substance bond."[16]

FIGURE 5.11: SPLINE CONNECTION MATERIAL EXAMPLES: JOINERY BOARD AND PLYWOOD
KLH 1 inch joinery board. Photo Credit: Scott Noble
Structurlam CLT and plywood splines.
Photo Credit: Emily Dawson

16 BECK, LIGNOLOC® press release, September 23, 2020

FIGURE 5.12: SHEAR PLATE CONNECTOR

Photo Source: Portland Bolt & Manufacturing Co.

Splines

Spline connections combine joinery concepts and dowel connectors to structurally join large mass timber panels together with smaller-scale engineered wood products. A typical spline connection involves routing the connecting edges of two mass timber panels with a shallow groove, laying joinery boards within the groove, and fixing them in place with nails or screws.

Plates

Metal connector plates were developed to help join trusses for floors and roofs. These plates are usually made from sheets of galvanized steel and are die-punched to create teeth that protrude from the underside of the plate's face. This type of toothed metal connector plate is generally not suitable for mass timber applications.

Shear Connectors

Shear connectors, or bearing connectors, include shear plates, toothed shear plates, and split rings.

FIGURE 5.13 OFF-THE-SHELF STRUCTURAL METAL CAST COLUMN CONNECTIONS

Timber End Connectors™, UMass Amherst Integrated Design Building, Source: Cast Connex®. Photo credit: Alex Schreyer

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 flat surface on the other. This connection disperses pressure from a load across the larger radius of the plate. By contrast, a bolt spreads pressure across a significantly smaller area. Shear plates, therefore, can handle heavier loads than bolts. Split rings are like shear plates in both form and function, but are not as heavy duty as the discs.

Structural Metal Castings

The free-form capability of the casting manufacturing process is ideally suited to address 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 that are meant to resist seismic motions. Pre-engineered standardized castings are available off-the-shelf to suit an array of member sizes. Custom-designed cast connections can satisfy specific project objectives and constraints for one-off and repetitive applications.

Table 3.1.1.1 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

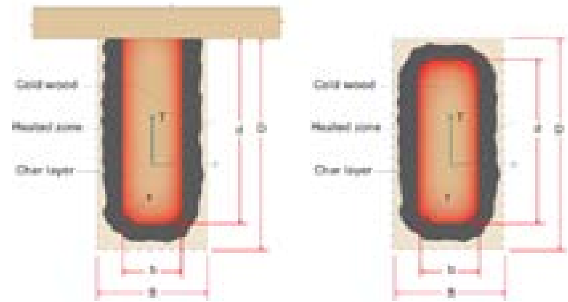


Figure 1-1 Reduction in member breadth and depth over time, t

FIGURE 5.14: REFERENCES FOR FIRE RESISTANCE

American Wood Council Technical Report No. 10 Calculating the Fire Resistance of Exposed Wood Members.

Proprietary Connector Systems

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.

Self-tapping screws are one of the most widely used fasteners in mass timber projects. Proprietary bracket systems are also commonly used to connect beams, posts, and panels. Proprietary systems can be created for a variety of reasons. Some are intended to overcome limitations or weaknesses in existing systems or components when used in mass timber applications. Others are created with aesthetics or ease of installation in mind.

5.2.5 FIRE RESISTANCE

Many mass timber products are large, thick, airtight masses of wood. These properties are inherently fire-resistant. This may seem counterintuitive because it is easy to think of wood as a flammable material. However, test results have proven that large wooden components maintain their structural integrity for extended periods of time, even when exposed to direct flame and intense heat.

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 very slowly, and with each passing moment further insulates the wood at the core. The thickening char layer is removing oxygen from the inner depths of the wood and is, thereby, extinguishing the burning component of the heat. This enables the inner, uncharred core to remain structurally unaffected, allowing the component to maintain much of its original strength.

The IBC references the NDS for Wood Construction produced by the American Wood Council to calculate fire resistance of mass timber elements. This standard establishes a nominal char depth of 1.5 inches per hour. "Effective" char depth includes a 0.3 inch pyrolisis zone, where the wood is heated to the point of losing all moisture and is

Type I	Building elements are noncombustible materials.
Type II	Building elements are noncombustible materials.
Type III	Exterior walls are of noncombustible materials, and the interior building elements are of any material permitted by the code.
Type IV	The exterior walls are of noncombustible materials, and the interior building elements are of solid wood, laminated wood, heavy timber, or structural composite lumber without concealed spaces. Fire retardant-treated wood framing and sheathing complying with Section 2303.2 of the code shall be permitted within exterior wall assemblies not less than 6 inches in thickness with a 2-hour rating or less. Cross-laminated timber complying with Section 2303.1.4 of the code shall be permitted within exterior wall assemblies not less than 6 inches in thickness with a 2-hour rating or less, provided the exterior surface of the cross laminated timber is protected by one of the following: Fire retardant-treated wood sheathing complying with Section 2303.2 and not less than 15/32 inch thick, Gypsum board not less than 1/2 inch thick, or A noncombustible material. Exterior structural members where a horizontal separation of 20 feet or more is provided, wood columns and arches conforming to heavy timber sizes complying with section 2304.11 shall be permitted to be used externally.
Type V	Structural elements, exterior walls, and interior walls are of any materials permitted by the code. Fire resistance rated construction. Non-fire resistance rated construction.

TABLE 5.1: CONSTRUCTION TYPE CLASSIFICATION OF BUILDINGS

no longer structurally viable. The effective char rate per hour slows the longer wood burns, as the char layer insulates the remaining wood from further damage.

The Ascent tower in Milwaukee, Wisconsin, which is now under construction and which pursued permitting via performance-based design, found a slower char rating than the code value. They tested their KLH-supplied panels at the Forest Products Laboratory in Madison and found a char rating of 1.29-1.31 in/hr. This finding has excellent implications for design teams pursuing a performance-based permitting process to reduce fiber and costs on timber projects.

Projects seeking approval through alternate means and methods may find smoke spread governing allowable exposed wood areas. A combination of engineering, computer modeling, and testing may be required, and it is best to start the conversation with the jurisdiction having authority early in the design stages to confirm they will be able to adequately review the approach.

If the code requires fire resistance in addition to the values provided by the wood itself, gypsum products are the most straightforward protective material. The concept of improving fire resistance and reducing smoke or flame spread through the addition of coatings or treatments shows promise for future enhancements, but it is not currently a proven option.

Table 5.1 lists the most widely adopted classification types in the US for buildings and describes their construction elements, including the allowable use of wood in Type IV buildings. See Section 5.2 for 2021 IBC code changes for Type IV buildings, which have already been adopted in some states and jurisdictions. These changes take effect on different schedules depending on local IBC adoption timelines.

5.2.6 STRUCTURAL PERFORMANCE

Foundations

Wooden buildings are much lighter than similarly sized buildings made from steel, concrete, or masonry. Lighter-weight buildings transfer less load to their foundations, leading to smaller, less complex below-grade work, saving on excavation and concrete costs. This is particularly advantageous for building sites with poor soil bearing pressures, and it also improves the ability to build over contaminated soils with minimum disruption. In one project that required deep foundation piles for an all-concrete building, DCI Engineers was able to realize a 30 percent savings in foundation costs by replacing the top three floors of the building with mass timber construction.[17]

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

Grid Layout/Structural Bay

Mass timber panel dimensions and thicknesses, and properties of strength and stiffness vary by manufacturer and product. Often, vibration, which in the United States is a subjective value, 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 during early building layout decisions.

17 1 De Haro, San Francisco, Dean Lewis, DCI Engineers

Manufacturing dimensions of various mass timber panel systems should be considered to optimize material use in plan layouts for cost efficiency. It is advisable to bring a procurement or manufacturing partner on to the team as early as possible to gain the benefits of efficient material use. See Section 5.2 for further discussion and Chapter 8 for considerations when advising building owners on contract options.

Seismic Performance

Some of the oldest wooden buildings in the world are in Japan, which is also the most seismically active country on Earth. At over 122 feet tall, the Horyuji Temple, near Osaka, has survived over 46 earthquakes of a magnitude 7.0 or greater on the Richter scale since its construction in 607 AD. Japanese scholars describe the inherent flexibility in these wooden structures as "Snakedance" theory, enabling them to dissipate significant seismic energy without damage to the building.

Building codes are the main tool for addressing seismic risks with design requirements, varying by region and depending on the historical frequency and magnitude of earthquake activity. The main seismic criteria in building codes is a specification of the minimum lateral force a building must withstand to assure occupant safety. Building codes include an equation in which cyclic seismic forces are represented by a single static force, called *base shear,* 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 used, building height, and building occupancy.

Wood, particularly mass timber, as a structural building material has several characteristics that lead to favorable earthquake performance. They include:

Ductility is the extent to which a material or building can deform without failing. Wood as a material can withstand high-intensity, short-duration loads 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 United States, building codes limit the use of CLT to resist lateral forces from earthquakes, given the low ductility of the CLT shear wall system (R-value of 2). The higher the R value, the lower the lateral force the building is required to be designed to by the building code. Therefore, structural engineers typically design with lateral systems having a higher R-value, such as light-frame timber plywood shear walls (up to R-7).

CLT shear walls and CLT diaphragms now have design requirements defined in the AWC's Special Design Provisions for Wind and Seismic (SDPWS) 2021 edition.[18] 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 provided. It does include a low-seismic, CLT shear wall option with an 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 is working on a CLT Diaphragm Technical Guide that includes worked examples

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

using the new CLT diaphragm requirements. This guide will be published in the first half of 2021.

Recent research and testing of CLT shear walls have resulted in proposals to use an R value of 3.0 to 4.0, depending on the CLT wall aspect ratio. However, this still means designing forces roughly twice that of light-frame plywood shear walls. The R values of 3.0 and 4.0 for the platform framed CLT shear wall system will be published in ASCE 7, 2022 edition.

Research is ongoing on higher R value, lower design force, shear wall systems, including the mass timber rocking wall work led by Shiling Pei of Colorado School of Mines.

Weight: Lighter building weight is an advantage in a seismic event because the inertial force exerted on a building is proportional to 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: In wooden buildings, many fasteners and connectors are typically used 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 for complete structural failure if some connections fail.

Wind Loading

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

Hybrid Systems

Most timber structures use steel-reinforced concrete for foundations and steel components for connections. A project that uses a full-building hybrid approach, however, efficiently combines multiple primary structural materials. Factors such as building height, grid layout, and seismic region may lead a design team toward a hybrid building approach. While wood is very strong by weight in both tension and compression, selectively incorporating concrete or steel, or a combination of both, can mitigate vibration, increase span capacity, reduce structural member dimensions, or increase lateral capacity. While whole buildings are often hybrid designs, component-based approaches, such as hybrid slabs and lateral systems, are also developing in research and in practice.

IMAGE SOURCE: SWINERTON MASS TIMBER

SUSTAINABILITY IS BEAUTIFUL

Like a tree taking root in disturbed soils, Oregon State University-Cascades' newest building, Edward J. Ray Hall, is becoming a reality. Scheduled to open in fall of 2021, the 50,000-square-foot building will provide learning spaces for science, technology, engineering, arts, and math, and will create a student hub with active interior and exterior event and activity spaces.

Currently under construction, the project is designed to exemplify the university's commitment to sustainability with a net-zero energy target and a structure of regionally sourced mass timber. These lofty goals inspired the joint design and construction team of SRG Partnership Inc. and Swinerton to push the envelope in three areas: incorporate locally sourced, sustainably harvested timber products; use systems and design elements to support the net-zero energy goal; and celebrate the intersection of the two.

LOCALLY SOURCED, SUSTAINABLY-HARVESTED MASS TIMBER

The selection of mass timber for the building's structural system reinforces OSU-Cascades' robust commitment to sustainability with the use of a locally sourced renewable material and the low-carbon footprint associated with its production. During design, the team studied numerous column and beam spacings to reduce the overall fiber content of the structure, lowering the cost of the structural system and reducing the amount of concrete needed, further driving down the GWP of the building. The winning combination, a structural grid with 30-foot deep bays with beams spaced 10'-0" on center resulted in use of a 3-ply, E-rated CLT panel. A 4-inch concrete topping slab helps meet lab vibration requirements. The topping slab depth also allowed the design team to place crossing electrical conduits and recess junction boxes throughout the building.

Vaagen Timbers, the selected supplier of the CLT, is known for their use of sustainably harvested wood from

IMAGE CREDIT: SRG PARTNERSHIP

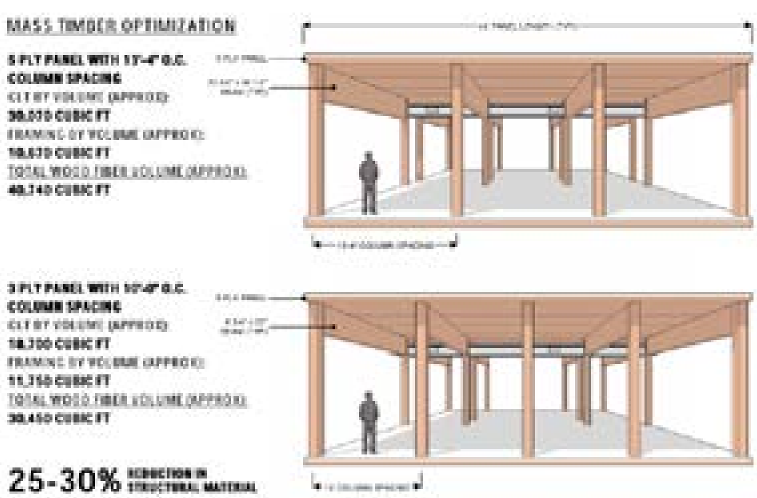
forests around their Colville, Washington, plant. As a result, the mass timber systems selected for the project resulted in a tremendous sustainability story. The carbon stored in the wood is equivalent to 1,149 metric tons, and the avoided greenhouse gas is equal to 2,441 metric tons, for a total carbon benefit of 3,590 metric tons. This is equivalent to removing 759 cars from the road or the energy needed to operate 379 homes for a year.

NET-ZERO ENERGY READY SYSTEMS

Edward J. Ray Hall's east/west orientation and exterior design will contribute to the net-zero energy ready target established by the university. The 10'-0" beam spacing eliminated the need for a perimeter beam and a corridor girder, providing for better daylight as the windows could be higher and allow natural light to penetrate deeper into the building.

CELEBRATING THE INTERSECTION OF MASS TIMBER AND NET-ZERO ENERGY

The natural beauty of the timber structure will be expressed in the building's interior, creating a warm, inviting environment for students and faculty, and visually connecting the building with the broader regional landscape.



OSU CASCADES, EDWARD J. RAY HALL

LOCATION: BEND, OREGON

OWNER/DEVELOPER: OSU CASCADES

ARCHITECT: SRG PARTNERSHIP

STRUCTURAL ENGINEER: CATENA CONSULTING ENGINEERS

CONTRACTOR: SWINERTON MASS TIMBER

MASS TIMBER MANUFACTURER: VAAGEN BROTHERS

FIGURE 5.15: PEAVY HALL: EXAMPLE OF COMPOSITE CONCRETE-TIMBER SLABS

Peavy Hall, Oregon State University. Photo Credit: Evan Schmidt.

Hybrid Slabs

Some building programs require spans that are difficult to accomplish with mass timber panels alone. For example, an efficient classroom building on a 30-foot grid might at first seem to call for solid timber floors with a cost-prohibitively thick section. Such projects could instead consider adding beams, tension cords, or composite slabs, or could decide to rethink standard grid approaches that were developed with other construction materials. Options for hybrid slabs include:

Composite concrete-timber slabs are composed of concrete and timber connected via steel components to create composite action. A concrete diaphragm is poured over a timber slab and connected with reinforcing steel to tie the two materials together. Thickened concrete sections may act as beams. Reinforcing steel can take

FIGURE 5.16: UMASS AMHERST: EXAMPLE OF COMPOSITE CONCRETE-TIMBER SLABS

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

FIGURE 5.17: CLAY CREATIVE EXAMPLE OF POST-TENSIONED TIMBER

Photo Source: 120 Clay Creative, Ankrom Moisan. Photo credit: Ethan Martin.

FIGURE 5.18: POST-TENSIONED CLT AT CHIBOUGAMAU TERMINAL IN QUEBEC

Chibougamau terminal, Nordic Structures and EVOQ Architecture. Photo Credit: EVOQ/Artcad

FIGURE 5.19: CATALYST EXAMPLE OF TIMBER-TIMBER COMPOSITE FLOOR PANEL

Catalyst, Katerra. Photo Credit: Andrew Giammarco

FIGURE 5.20: CLT POST AND BEAM STRUCTURE WITH BUCKLING RESTRAINED BRACED FRAME CORE

Carbon 12, Portland, OR. Photo Credit: Kaiser + Path

many inventive shapes, such as fasteners driven into the timber at an angle before the concrete is poured (see **Figure 5.15**), perforated steel flanges added during the timber manufacturing or glued in on-site (see **Figure 5.16**), or two-way rebar. Several research projects are in progress to determine performance characteristics of composite slabs. For example, testing began in 2020 at the Tallwood Design Institute (TDI) to generate benchmark data to characterize the performance of concrete-composite MPP floors through multi-scale testing of novel shear connectors, MPP floor elements, and full-scale floor systems, including MPP-to-glulam connections.

Post-tensioned timber: Adding steel tension cords to timber beams can reduce overall beam depth or increase structural transparency (see **Figure 5.17** & **5.18**).

Timber-Timber Composite Floor Panel: Timber slabs with thickened timber sections are a recent development to increase span capacity. Catalyst, an office building project 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 5.19**).

Hybrid Building and Lateral Systems: Because of the stiffness of mass timber panels (see **Seismic Performance: Ductility** section above), using hybrid approaches for lateral systems is often cost-effective. Common strategies include:

For mid-rise structures, **light-framed wood shear walls** are a straightforward and cost effective approach.

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

Buckling Restrained Braced (BRB) frame cores and walls, which can be pre-fabricated with steel or glulam cross bracing, have time-saving advantages over concrete in construction. BRB frames can be designed with bolted connections rather than welded connections, working with the mass timber components as a kit of parts for rapid on-site assembly in any weather.

FIGURE 5.21: POST-TENSIONED CLT 'ROCKING' SHEAR WALL INSTALLATION
Peavy Hall, OSU. Photo Credit: Hannah O'Leary

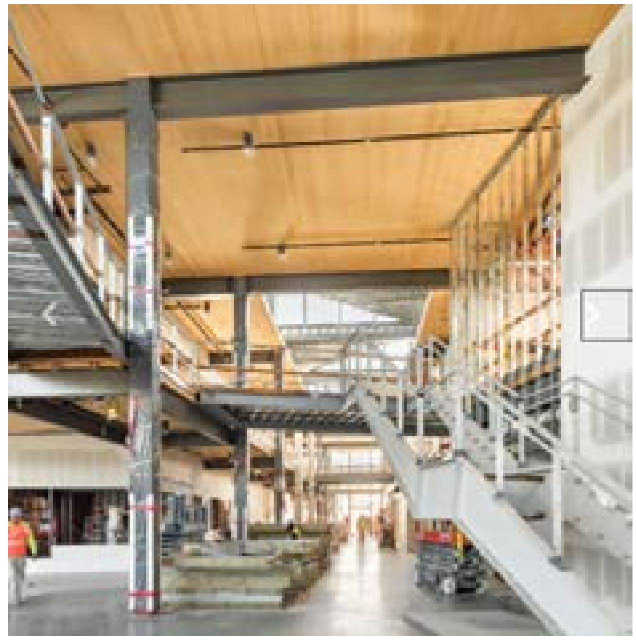
Post-Tensioned CLT shear walls combine strong, rigid wood panels with steel tendons and fuses for added ductility and seismic force dissipation (See also Chapter 8's section on Resiliency). The technology was developed in New Zealand and has been in use there for nearly a decade. Peavy Hall, at Oregon State University, is the first installation in North America (see **Figure 5.21**).

Ongoing research projects seek to find additional lateral systems solutions. For example, another 2020 TDI project[19] will generate benchmark data characterizing the performance of multiple innovative mass-timber shear wall systems from the scale of connectors to full-scale building systems up to three stories. Starting in early 2021, researchers at OSU will begin large-scale testing on the "Innovative Lateral Systems" project at TDI's Advanced Wood Products Lab at OSU. This work will lay the foundation for upcoming 6-story and 10-story mass timber seismic shake table tests, part of a multi-organization research initiative that includes the Colorado School of Mines.

5.2.7 ACOUSTIC PROPERTIES

Mass timber has advantages as an acoustic solution. The massive arrangement of wood helps

19 "Innovative Lateral Systems for Mass Timber," Dr. Arijit Sinha, OSU



TOP LEFT — FIGURE 5.22: LIGHT FRAME AND MASS TIMBER HYBRID

The Canyons, Portland, OR. Source: Kaiser+Path. Photo Credit: Marcus Kauffman, Oregon Dept. of Forestry.

TOP RIGHT — FIGURE 5.23: HYBRID CLT AND STEEL STRUCTURE

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

BOTTOM — FIGURE 5.24: CONCRETE CORES AND PRECAST CONCRETE FRAME WITH TIMBER SLAB AND BEAMS

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

mitigate transfer of low-frequency sound vibrations. Combining mass timber with other building materials can create relatively thin assemblies with high STC (Sound Transmission Class) and IIC (Impact Insulation Class) values.

Some standard assemblies for acoustical performance in mass timber buildings have been developed, as well as an array of proprietary solutions. WoodWorks has an online inventory of 480 mass timber assemblies that have been acoustically tested.[20] Additionally, some guidelines have been developed for floor assemblies. Recently added assemblies and test results include a mass timber floor with raised access floor, a mass timber "dry" build-up, and numerous assemblies specific to the new, 2021 IBC tall mass timber construction types.

A 2019 research project[21] at TDI showed promising outcomes for five common floor assemblies, each with a CLT and MPP iteration, (see **Figure 5.25**). STC and IIC values were above 50 for all floor assemblies with acoustic underlayment and floating floors, except for IIC values on assembly F05, a dry assembly with T+G engineered pine flooring. STC and IIC values for bare timber assemblies and bare timber-composite assemblies fell below 50, but STC values were 49 for bare concrete-timber composite floors.

As with other code-required assemblies, the 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.

Though slightly delayed by the COVID pandemic, the TDI still plans to build a certified acoustic testing facility in Oregon's Willamette Valley, breaking ground in late 2021. This facility will be capable of certified contract testing of full wall and floor assemblies, helping to drive innovation and remove barriers in mass timber design.

Some mass timber panels are specially designed for acoustic performance. For example, StructureCraft produces a sound-dampening DLT panel with insulation-filled grooves engineered to absorb sound waves (see **Figure 5.26**).

5.2.8 THERMAL PERFORMANCE

The thermal performance of a building directly influences not only its energy efficiency but also the 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 detail 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; the measure is independent of the material's thickness. Materials with high thermal conductivity transfer heat more quickly, and thus are generally not useful

20 https://www.woodworks.org/wp-content/uploads/Acoustically-Tested-Mass-Timber-Assemblies-WoodWorks.pdf
21 "Acoustic Testing of Typical Multi-Family Residential CLT and MPP Dry and Concrete-Composite Wall and Floor Assemblies," Dr. Kevin Van Den Wymelenberg, UO

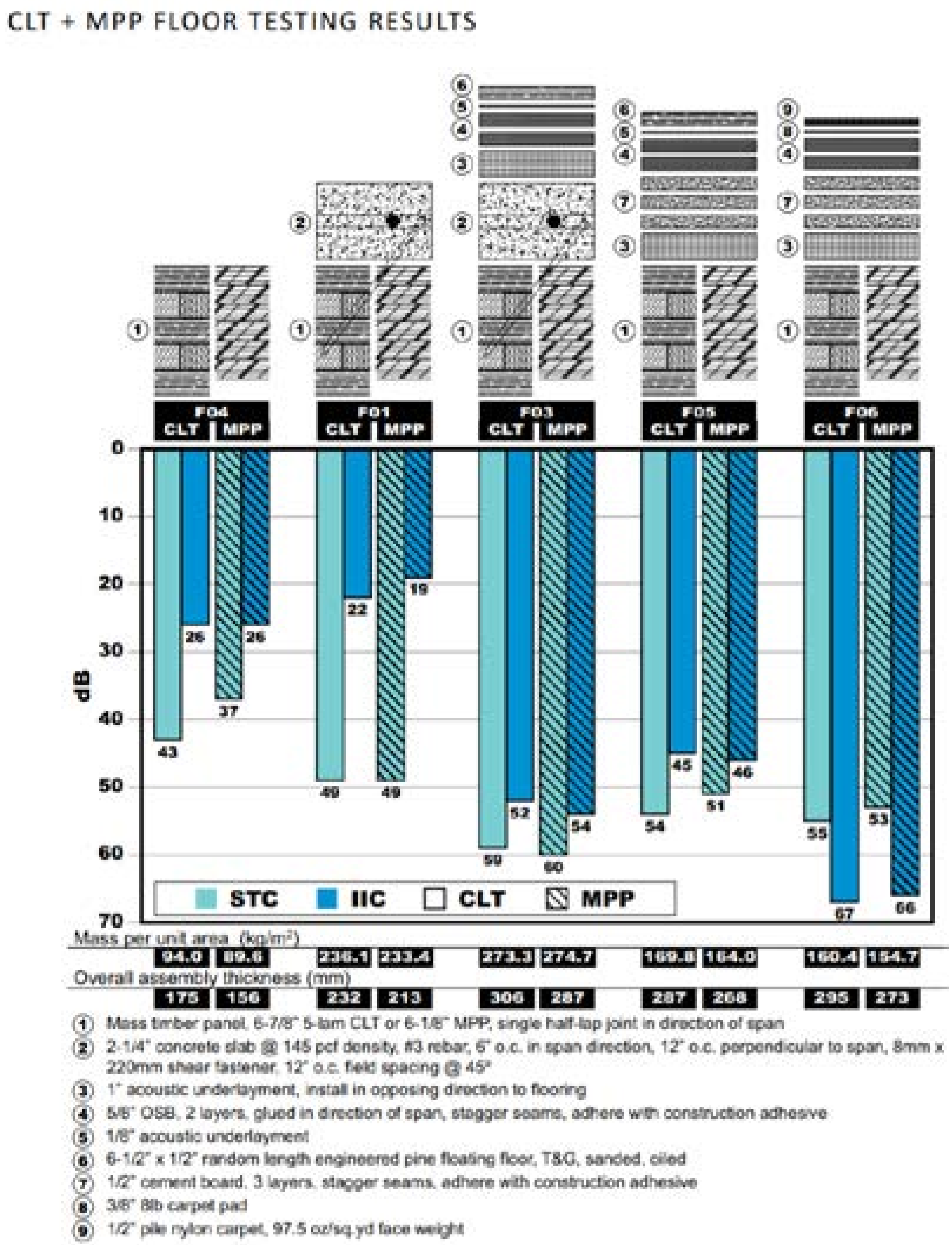


FIGURE 5.25: CLT + MPP FLOOR ASSEMBLY ACOUSTIC TESTING

Source: UofO. Acoustic Lab Testing (ASTM E492-2016, ASTM E90-2016) of CLT and MPP Wall and Floor Assemblies for Multi-Family Residential.

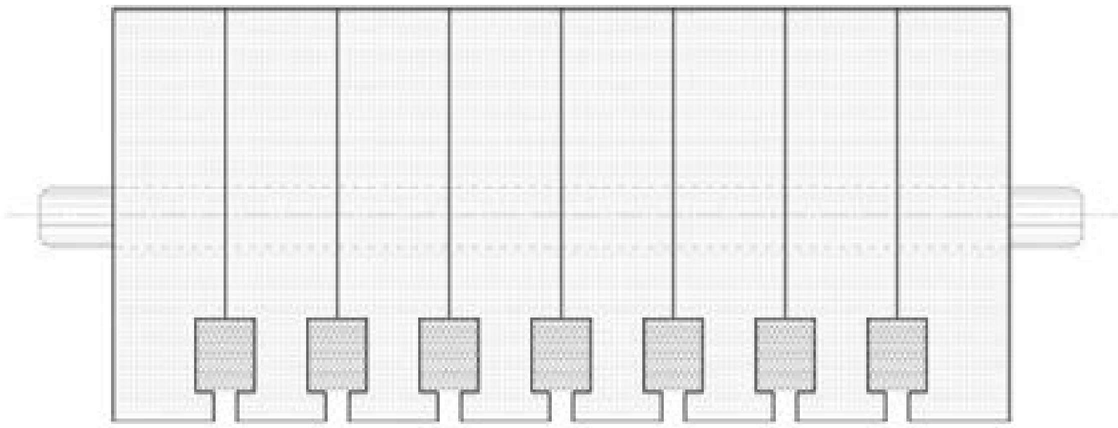


FIGURE 5.26: SIDE VIEW OF ACOUSTICALLY DESIGNED DLT PANEL
Image provided courtesy of Structure Craft

insulators. Materials with low thermal conductivity transfer heat more slowly and are more likely found in insulating applications.

The R-value, known as thermal resistance, can be measured for an individual layer of material. It quantifies the effectiveness of that layer as an insulator, given its thickness. R-value is calculated by taking the thickness of a layer and dividing it by the thermal conductivity of the material. **Table 5.2** shows some common building materials (and other materials for comparison) and their thermal conductivity values.

Solid wood has relatively low thermal conductivity and can, therefore, 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 the life of the building. This provides cost savings for building owners and occupants, and reduces the operational carbon footprint.

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

5.2.9 MOISTURE

A mass timber designer will need to consider concerns similar to those associated with light-frame construction and finish wood products, but there are also a few key differences, outlined in this section. Understanding wood's behavior as an organic material is foundational to establishing best practices.

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 environ-

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 5.2: THERMAL CONDUCTIVITY OF BUILDING MATERIALS
Source: Engineering Toolbox, (2003). Thermal Conductivity of Common Materials and Gases

mental moisture content 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 moisture content 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.

At harvest, the moisture content of a log is about 50 percent (i.e., 50 percent of the weight of the log is water). 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 within the wood cells. For the types of lumber used to make mass timber, industry expectations are that the lumber will be dried to 12 percent moisture (+ or – 3 percent). Drying lumber to this level helps assure dimensional stability during mass timber manufacturing and use, and prevents decay. It is helpful to understand that the ideal moisture content for fungal growth ranges between 26 percent and 60 percent. Factors contributing to the variances include wood species, fungus species, temperature, and time (rate of dry out).

In wet climates, it is understood that wood absorbs moisture during the construction phase, and a building must go through a "dry-out" phase before wood is enclosed—or risk compromise. A building with properly ventilated and dried wood will stabilize during the first two or three years of occupancy to match the ambient moisture content, which is typically 6 percent to 8 percent for wood in interior use applications in the Pacific Northwest. The greater the moisture content differential within a wood member, or between the installed wood and the future occupied building, the greater the impact of shrinkage and checking will be.

FIGURE 5.27: MOISTURE MONITORING CLT FLOORS WITH A HAMMER-IN PROBE

Source: Kaiser + Path. Photo Credit: Kevin Lee

Ongoing research in academia and industry will continue to inform best practices for protection and detailing. Although industry standards are nascent for many of the issues specific to mass timber and moisture mitigation, resources for designers are developing. In early 2020, RDH Building Science published a document advising designers on some aspects of detailing mass timber buildings to protect and recover from moisture exposure.[22]

A "Water in Mass Timber"[23] project is ongoing at TDI via grants from the United States Department of Agriculture (USDA) and the Agricultural Research Service. One aspect of this project is exploring the effects of a variety of moisture exposures (ambient exposure through sustained flooding) on the performance of timber connections and providing benchmark data for engineering models. In early 2020, hundreds of connection samples were prepared and inoculated with 2 different decay fungi, with the first set of specimens harvested in early February 2021. Some testing of water exposed connections has been completed and results will be available soon.

Moisture Management and Monitoring

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 moisture content will validate if panels are ready to be enclosed or encapsulated with other materials.

Massive panels dry at different rates than stick framing (See Chapter 6 on Weather and Weather Protection for more information), and 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, which can be of concern especially where structural wood doubles as a finished surface.

Mitigation

The most effective and low-cost way for a designer to protect a wood building from moisture is through architectural detailing. Treatments or coating products add to the cost, but they may be warranted to protect against 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

22 Mass Timber Building Enclosure Best Practice Design Guide, RDH Building Sciences, 2020
23 "Water in Mass Timber," PI Arijit Sinha, Oregon State University (OSU)

to breathe (release moisture). These details should also protect wood from exposure and contact with materials like concrete that can transfer moisture. Designers should take into account 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 UV 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 specifications for clarity, and for coordination with other specified coatings.

Treated Wood is common for exterior wood structures such as bridges, decks, railroad ties, and telephone poles. Not all treatments are appropriate for occupied structures, as many formulas come with human health risks. Treatments tend to come at a higher cost than coatings, but they are highly effective. Chemical changes at the cellular level alter the composition of the wood, which also can negatively affect strength properties. The mass timber market currently 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 have the added benefit of insect repellent capabilities, expanding the geographic acceptance of the material into regions with termites.

Dimensional Stability

Engineered wood elements like CLT are less susceptible to dimensional changes as a result of moisture and temperature swings than lumber or sawn timber because adhesives and multiple fiber directions hold their overall dimensions stable. CLT and MPP panels, therefore, have an advantage over NLT or DLT if a building is constructed during wet weather. Potential dimensional changes during construction should be factored in when detailing these systems.

The smooth, precise look of a freshly pressed CLT panel is more likely to be preserved if moisture content is stable from manufacture through installation. A CLT panel is manufactured with little to no gap between each board in a lamination. In an undesirable situation where a CLT panel becomes saturated, the added moisture can cause each laminated board to swell and push against the others, while the overall panel width and length dimensions remain stable. The more significant the drop in the moisture content of a panel, the larger the gaps between each board (or cracks in the wood in the case of edge-glued boards) will be. Some European-sourced panels edge-glue the boards together 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.

Building Shrinkage

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

FIGURE 5.28: END-GRAIN TO END-GRAIN COLUMN CONNECTIONS MINIMIZE SHRINKAGE

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

Mass timber elements will contribute to prevention of shrinkage, depending on the detailing and the products being used. For example, if used for floors, CLT will contribute to shrinkage in a platform-framed building using CLT as floors, while this effect could be avoided with a balloon-frame approach. Because shrinkage in the direction of the grain is almost negligible, shrinkage can be largely avoided with details that utilize end-grain to end-grain connections. For example, both the 18-story Brock Commons at the University of British Columbia and the 8-story Carbon12 in Portland were designed with stacked glulam columns with steel connections in between. This becomes more impactful in taller buildings, where the accumulation of floor to floor shrinkage becomes a greater concern because of a greater number of floors.

5.2.10 BALLISTIC/BLAST PERFORMANCE

The United States 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 be a market size of $1.9 billion annually for buildings, housing, and facilities requiring low levels of blast resistance.[24] When designing military buildings, architects are often now required to integrate blast- and projectile-resistant materials into the projects.

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 after significant explosive blasts. Additional testing is underway.

In addition, efforts are underway to understand how mass timber structures perform when struck by projectiles. Georgia Tech University completed studies in which CLT panels made of SPF and Southern yellow pine were subjected to ballistic testing. The results showed that both types of conventional CLT materials' inherent penetration resistance is significantly greater than that of the dimension lumber and plywood now used for temporary military structures. Additionally, the testing showed that U.S. 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.[25]

24 Cross Laminated Timber Blasts its Way into Government Construction. Woodworks.
25 Exploring Cross-Laminated Timber Use for Temporary Military Structures. Kathryn P. Sanborn. Ph.D. Thesis. Georgia Tech University.

5.3 PROJECT MANAGEMENT AND COORDINATION

At these early stages of the introduction of mass timber to North America, design teams need to be well educated about how best integrate the many benefits of these products into their projects. Development teams must include architects and engineers who know well the advantages and disadvantages of these products. CLT is not simply a replacement for concrete. They both have very different characteristics and design considerations.

5.3.1 PLANNING AHEAD

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

Design Partners

For example, early Mechanical, Electrical, and Plumbing (MEP) coordination can have positive aesthetic, cost, and maintenance implications in the final building. Many MEP consultants will typically assume that a diagrammatic design is the desired deliverable, intending the final layouts to be largely field coordinated. In a mass timber building, the structure is often substantially exposed. Thoughtfully exposing utilities where necessary, or desired, requires working with consultants early on to consolidate utilities in carefully planned zones, and to plan for higher quality materials in exposed areas. Penetration locations can be determined before timber components are fabricated, reducing on-site trade conflicts. Planning ahead for more off-site fabricated components can improve scheduling and craftsmanship, and reduce risk.

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

Procurement and Construction Partners

One of the unique opportunities inherent in designing with mass timber is how the new technology 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 is ideally working with a procurement team early in the design process, who can track and advise on market and supply trends as the building design evolves. A building owner should be advised to use collaborative contract models that support effective prebid coordination (see also section 8.2 in Chapter 8).

Site coordination concepts and installation approaches can impact estimated costs significantly. A general contractor who can calculate the cost savings achieved by a modular mass timber approach can advise on overall construction schedule reductions when compared with other construction techniques. Choosing a construction partner who is familiar with the unique time and cost savings mass timber can offer is key to realizing those savings in early cost models or bids.

FIGURE 5.29: INDUSTRY-COLLABORATIVE WOOD RESEARCH INSTITUTIONS IN NORTH AMERICA

Research Partners

For novel and performance-based design approaches, it can be very helpful for design teams to utilize testing and research resources available through collaborative research institutions. The list below identifies not-for-profit, building-industry supportive institutions with physical laboratory facilities and expertise in mass timber specific focus areas.

Northwest

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

Southwest

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

Northeast

12. FPInnovations (Pointe-Claire, QC)
13. Université Laval CRMR Lab (Québec, QC)
14. Forest Products Laboratory: USDA Forest Service (Madison, WI)
15. University of Maine Advanced Structures & Composites Center (Orono, ME)
16. UMass Amherst Wood Mechanics Lab (Amherst, MA)
17. Leheigh University has done some testing

Southeast

18. Clemson Wood Utilization + Design Institute (Clemson, SC)
19. Virginia Tech Sustainable Biomaterials Lab (Blacksburg, VA)
20. Mississippi State University Department of Sustainable Bioproducts (MS)

5.3.2 BUILDING INTEGRATED MODELING (BIM)

Building Information Models (BIM) are virtual models built in 3 dimensions, including detailed or approximated components of all of the elements that will make up a building. BIM are used for coordination and collaboration across architecture, engineering, manufacturing, and construction fields. In the last decade or so, BIM programs have become standard tools for design documentation in most design disciplines, 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 3-dimensional

FIGURE 5.30: THE IZM OFFICE BUILDING IN AUSTRIA WAS FABRICATED ENTIRELY OFF-SITE

IZM Building, CREE and Hermann Kaufmann. Image Credit: Emily Dawson

material intersections. BIM models can be built to a very high level of detail, so it is possible to have the quantities and dimensions of any building component, from conduit to fasteners to mass timber panels, predetermined well before they arrive on site.

5.3.3 PRECISION AND PREFABRICATION

The precision and design control of prefabricated building components appeals to designers around the world. Prefabrication has many benefits for the construction schedule, as discussed in more detail in Chapters 6 and 8. Designing with mass timber 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 is critical to realizing the potential of more complex prefabricated components. A project's location and the availability of prefabrication facilities will also play a role in cost and viability.

Implications for the design team include, as previously discussed, planning for more up-front coordination. The extent of prefabricated components—and how they are sourced, manufactured, and procured—will dictate the amount of extra coordination required.

5.4 BUILDING CODES

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. Historical codes relevant to other construction types (I, II, III, V) allow for the use of wood elements in certain places, if steps are taken to increase fire resistance.

When a building material or construction method is not included in applicable building codes, any building project team desiring to use that material or method must have the building permitted using an "alternate means" approach, to demonstrate to the permitting body that the materials and methods are at least equivalent to adopted codes for the specified use. This process can be costly, time-consuming, and difficult, and it does not have a guaranteed outcome. Therefore, having newly developed mass timber products and methods included in building codes removes significant barriers to that product or technology's adoption in the marketplace. While organizations in the U.S. and Canada develop building codes at the national level (the International Code Council [ICC] and the Canadian Commission of Building and Fire Codes [CCBFC]), it is up to state/provincial and local authorities to adopt these codes, creating a patchwork effect.

In recent years, several building code changes specific to the use of wood structural components have been made at the national, state or province, and local levels.

5.4.1 2015 NATIONAL BUILDING CODE OF CANADA

The 2015 NBC allows the use of wood as the structural frame in buildings as tall as 6 stories for residential, office, and mixed-use occupancies. The previous version of the code allowed wood only in residential buildings, and they were limited to 4 stories. This update also recognizes mass timber for use in podiums, which are considered noncombustible (NC). Two construction types are recognized in this version of the code: 1) combustible (includes heavy timber, but recognized as having NC properties), and 2) NC. Updates to the NBC, which is developed by the CCBFC, come out every 5 years and are adopted on a province-by-province basis. Most regions in Canada have adopted the 2015 code.

5.4.2 2020 NATIONAL BUILDING CODE OF CANADA

The 2020 update of the NBC adds a new construction type: Encapsulated Mass Timber Construction. The addition is 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 noncombustible materials, and limited permissions for exposed structures. The 2020 NBC is expected to be approved for adoption by the end of 2021.

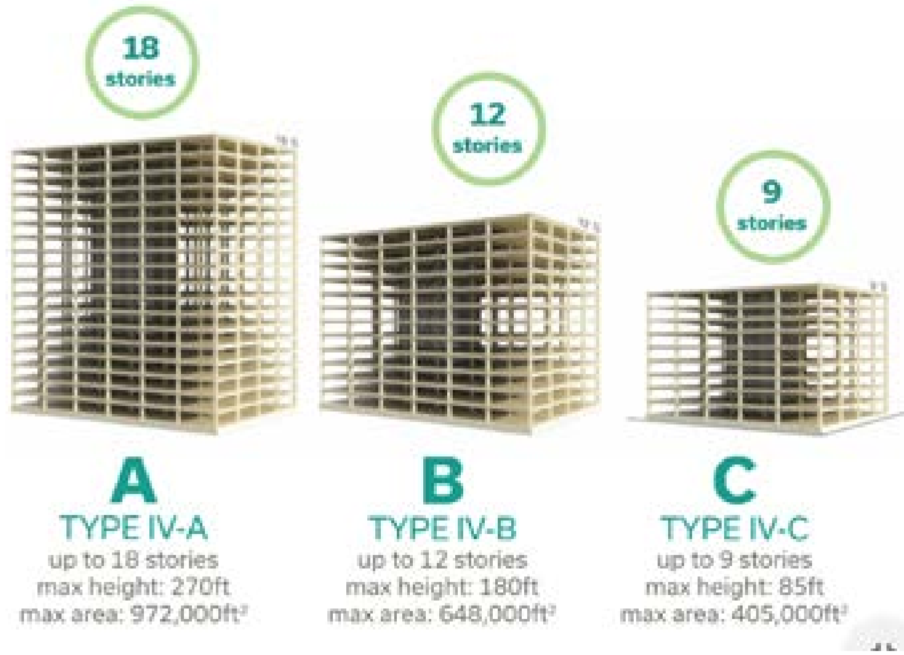


FIGURE 5.31: ADDITIONAL CONSTRUCTION TYPE IV CODES
Think Wood Research Brief Mass Timber 2021 Code

5.4.3 2015 INTERNATIONAL BUILDING CODES

In early 2015, the ICC adopted new codes allowing the use of CLT in buildings up to 6 stories for offices and 5 for residential. However, CLT use in taller buildings was not addressed in this code update. Because CLT is viewed as having the most 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. IBC updates are adopted on timelines determined on a state-by-state basis.

5.4.4 2021 INTERNATIONAL BUILDING CODES

The 2021 edition of the IBC includes major changes to Construction Type IV specific to mass timber. They include provisions for the use of mass timber as a primary structural material in buildings up to 18 stories in height. These changes are often referred to as the Tall Wood Provisions.

Construction Type IV was revised to IV-HT, and now also includes three additional types, distinguished by fire resistance, height, and area restrictions (see **Figure 5.31**).

- **Type IV-HT:** Maximum 6 stories, 85 feet in height, and 108,000 square feet in area. Concealed spaces are now allowed with exceptions for sprinklers, filled cavities, and protection with NC construction, like gypsum.
- **Type IV-C:** Maximum 9 stories, 85 feet in height, and 405,000 square feet in area, and all mass timber designed for a 2-hour fire resistance

may be exposed. Concealed spaces are allowed if protected with NC.

- **Type IV-B:** Maximum 12 stories, 180 feet in height, and 648,000 square feet of area. Exposed mass timber walls and ceilings are allowed with limitations, and concealed spaces are allowed if protected with NC.
- **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.

This groundbreaking advancement of the code is a huge step for the uptake of mass timber in the US, though the encapsulation requirements have been questioned as conservative. Because the requirements add costs and diminish many of the benefits of a mass timber building to occupants and owners, they create cost-effectiveness challenges for taller wood structures. This is seen as an urgent area of research for the industry. Through wood innovations grants, testing to reduce the encapsulation requirements of the new code provisions is ongoing.

5.4.5 TALL WOOD CODE ADOPTION

Some states have taken the lead in the US to adopt the Tall Wood Provisions ahead of the 2021 ICC release. Oregon and Washington have been leaders in the adoption of mass timber construction. In the second half of 2018, both states proactively adopted the Tall Wood CLT Provisions developed by the ICC.

In early 2019, Utah also proactively adopted the provisions, providing for a 4-month period where either version of the code may be applied. In December 2019, Denver, Colorado, also approved the new provisions for adoption immediately. California will be incorporating the provisions into the California Building Code in January 2021, to become effective in July. The State of Georgia is currently exploring early adoption of the provisions, as well.

The City of Vancouver, British Columbia, which recognizes its own code authority autonomously from the province, has adopted the Tall Wood aspects of the 2021 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. Though it has not been considering early adoption, there are several projects over 6 stories planned for construction in the coming year, including an 11-story project in Toronto.

5.4.6 AUTHORITATIVE DATA SOURCES

Table 5.3 lists various authoritative sources referenced throughout Chapter 5 and where they can be found for further research. Many of these must be purchased. However, acquiring up-to-date versions of these guides and standards will ensure the user has access to complete and current information.

STANDARD	WEBSITE
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
National Building Code of Canada Fire Safety Design in Buildings	http://cwc.ca/design-with-wood/building-code/
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
CLT Handbook-Canadian Edition	clt.fpinnovations.ca
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 0177-06: Qualification code for manufacturers of structural glued-laminated timber	https://www.csagroup.org
International Building Code	https://www.iccsafe.org

TABLE 5.3: AUTHORITATIVE SOURCES

CHAPTER 6: BUILDERS

IMPACTS OF THE MASS TIMBER EFFECT

- Embodied carbon will account for 72 percent of all CO² emissions associated with buildings built in the next 10 years.[1]
- Sustainably sourced wood does not necessarily come at a premium, but sources should be vetted before purchase to be compatible with project and industry carbon goals.
- Wood that is renewably sourced can also store rather than emit carbon, contributing to net-zero carbon construction outcomes.
- Collaborative design processes bring designers, builders, and manufacturers together in a scenario that can more closely control sourcing, waste, and embodied carbon emissions of a building.
- Products sourced from rural areas and erected largely in urban centers bridge the urban/rural divide. When sustainably harvested, mass timber products are widely supported and endorsed in diverse communities.
- Building practices that minimize waste, such as modular mass timber and prefabricated components, are often also associated with improved and more diverse working conditions, contributing to the equity and social sustainability of communities.

Mass timber is a disruptive technology with respect to building construction, with implications for increased off-site fabrication and new, highly collaborative construction approaches. As such, many contractors will find the information in Chapter 5 is equally relevant to builders as teams become more integrated, optimizing the design, schedule, and costs together in real time.

We start this chapter with an overview of data for the whole US building market to provide context for where potential growth might occur. Then, a review of each common construction style will help readers understand not only how mass timber fits with other wood construction methods, but also with other building materials. The third section dives into details of how to approach and execute successful mass timber construction projects.

6.1 MARKET CONTEXT

Construction Value

Table 6.1 shows the value of all construction in the United States, per US Census Bureau data. The data is categorized by building use as either nonresidential or residential. The annual value of all construction was over $1 trillion in 2008. It dropped significantly during the Great Recession, but it has since climbed back to nearly $1.5 trillion in 2020. The total value increase of all construction compared to 2019 was 9 percent, very strong when compared to the previous 12 years, with only 2014 and 2015 exceeding 2020's relative gains. While nonresidential construction has always accounted for most of the total value, over this period of time, residential construction value has steadily increased from about 34 percent of the total to just over 40 percent in 2019, and saw a significant jump in 2020 to 47 percent.

1 Architect Magazine, The Carbon Issue, January 2020, guest edited by Architecture 2030

CONSTRUCTION SECTOR:	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Residential	0.367	0.256	0.252	0.253	0.276	0.329	0.375	0.429	0.474	0.532	0.564	0.551	0.700
Nonresidential	0.711	0.651	0.557	0.536	0.574	0.577	0.631	0.685	0.718	0.714	0.769	0.814	0.790
TOTAL CONSTRUCTION	1.078	0.907	0.809	0.789	0.85	0.906	1.006	1.114	1.192	1.246	1.333	1.365	1.490

TABLE 6.1: ANNUAL VALUE OF ALL CONSTRUCTION, 2008 TO 2019 ($ IN TRILLIONS)

Construction Material

Another way of categorizing building activity is by the type of material used. Each material type has numerous variations, but for this report the basic categorization of four principal structural building materials—steel, concrete, wood, and masonry—is used. Because most buildings are in fact hybrids of two or more of these materials, the market share of each material type is difficult to quantify. However, wood construction has seen steadily increasing uptake in the last decade.

6.2 MATERIALS CONTEXT

The following section provides a high-level overview of key construction systems and how they differ depending on the material used. A key similarity of all construction material types is that buildings typically contain horizontal components (floors and beams), and vertical components (walls and columns), with the arrangement and sizes depending on the material, project-specific loads, and fire-resistance requirements.

6.2.1 REINFORCED CONCRETE

In this type of construction, the horizontal and vertical structural components are all primarily concrete. To resist lateral forces, concrete must be reinforced with embedded steel bars (rebar).

A key advantage of this construction system is the material's strength; the compressive strength of concrete is complemented by the tensile strength of the steel reinforcement. Thus, a reinforced concrete building readily supports its own weight and is resistant to bending and tension forces from wind or seismic activity. It is considered a noncombustible construction type and is dimensionally stable. Another advantage is that the material can typically be produced at or near the building site because cement, aggregate, and water are readily available worldwide, and are relatively inexpensive. Finally, because it is fluid in nature during installation, concrete can be shaped into any size or dimension using forms.

Concrete begins curing almost immediately upon being poured into forms. However, to reach design strength, curing continues for an extended period, and construction schedules must incorporate the cure time required for building components to reach adequate strength. Schedules must also include setting of formwork and steel reinforcing bars, which is labor-intensive and time-consuming. Another significant disadvantage of concrete is the consumed energy embedded in the production of cement and steel, lowering its attractiveness from an environmental perspective. See Chapter 5 for comparative embodied carbon data.

From a durability standpoint, concrete construction is also subject to decay over time. Repeated cycles of drying and wetting can lead to cracking. Although concrete buildings can be durable for centuries, cracks in concrete can allow water to reach the embedded reinforcing, which then can corrode and deteriorate over time unless preventative measures are taken. Rusting rebar can spall concrete if buildings are not maintained or properly detailed. Spalled concrete exposes more steel, accelerating deterioration of both steel and concrete. Compared to other construction types, concrete buildings are very heavy, requiring the foundation and soil at the base of the building to resist more load to withstand the building's massive weight. The weight of a concrete building also can lead to creep, a permanent deformation of the building's shape over time.

6.2.2 STRUCTURAL STEEL

Steel is a mix of carbon and iron and is characterized by its very high tensile strength. Certain mixes, including structural steel, are ideal for building construction. Depending on the percentage of carbon in the mix, steel can be more—or less—flexible.

The advantages of steel are many. Steel buildings require less mass to construct than buildings made of concrete because of steel's high strength- and stiffness-to-weight ratio. Steel is also relatively easy to prefabricate, deliver to the job site, and quickly erect. This approach leads to minimal onsite waste. Additionally, steel is prefabricated in a variety of standard sections, aiding in design and construction efficiency. Fabricated steel beams offer a range of options for joining, including bolts, welds, and rivets. Structural steel buildings are flexible, recovering readily when subjected to wind or seismic forces.

Structural steel must be surrounded by noncombustible materials to be fire-resistant. Unprotected, the material quickly loses strength as it is heated, and in the event of a fire, its structural integrity can be compromised very quickly. Steel can also be prone to corrosion in humid or marine environments. There is also a tremendous amount of embedded energy in the finished product; see Chapter 5 for comparative embodied carbon data.

6.2.3 MASONRY

Masonry construction involves assembling buildings from individual bricks, stones, or concrete blocks bound together by mortar to form load-bearing walls. Roofs and floors in masonry buildings are typically made from some other type of material. In the early 20th century, most buildings were masonry. Although this construction approach is still used for smaller residential buildings, it is rarely used today for larger projects.

Masonry is a well-established construction style, and it is well understood by tradespeople. Masonry units are available in a variety of shapes, sizes, textures, and colors. Masonry is fire-resistant, and its high thermal mass can be an advantage in climates with a large 24-hour temperature differential, or "diurnal swing." Mass helps keep indoor temperatures constant by absorbing daytime heat

FIGURE 6.1: LIGHT-FRAME WOOD BUILDING

Photo Source: APA – The Engineered Wood Association

(or nighttime cold) and releasing it back into the outdoor atmosphere before it reaches the building interior. Masonry buildings also perform well in their resistance to high winds.

In seismic zones, all masonry is required to be reinforced with steel rebar and fully grouted. Older, unreinforced masonry buildings do not perform well during seismic events because the strong compressive strength of masonry is not combined with a material that is strong in tension, like steel, wood, or other fibrous material. The heavy mass shifts under seismic force, but without flexibility, it does not recover. Additionally, masonry construction is labor-intensive. This can lead to slower construction times.

Low-carbon and bio-based masonry units are emerging on the market but are not yet widely used. As with all building materials, the carbon sequestration potential of masonry is directly related to the material it is composed of, and of the energy required to produce, transport, and install it.

6.2.4 WOOD

Wood is uniquely strong in both tension and compression for its weight. 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. Three types of wood construction are reviewed here: light wood frame, traditional heavy timber, and mass timber.

Light-Frame

This type of construction, also known as stick frame, is the most common construction method

FIGURE 6.2: POST AND BEAM BUILDING

Photo Source: Nordic Structures

used for residential buildings in North America. It is also widely used in low- and mid-rise commercial buildings. In this construction style, studs form the vertical components in walls, joists form horizontal components in floors, and rafters form sloping components in roofs, connected with steel fasteners and connections such as joist hangers, clips, nails, and screws. For lateral resistance and spanning between "sticks," plywood or Oriented Strand Board (OSB) sheathing is commonly used (see **Figure 6.1**).

The advantages of this building system are low cost and ease of assembly. Lumber, plywood, OSB, and other wooden building materials are readily available and relatively inexpensive. Additionally, laborers can move the building materials around a job site with relative ease compared to larger and bulkier materials such as steel beams. The tools required for construction are relatively inexpensive and are also lightweight. And wood construction is relatively fast. All these factors contribute to the widespread use of this construction type for buildings that have lower requirements for fire resistance.

A disadvantage of light-frame wood construction is the amount of waste generated on-site. Many of the wooden pieces brought to a building site are cut to smaller sizes, per the specific requirements of the building. This creates waste and increases the cost of materials. Of the building styles discussed here, light-frame wood carries the highest risk of fire damage. Another disadvantage is that, because it is a bio-based material, its strength and appearance can be negatively impacted if subjected to conditions that allow insects, mold, and fungi to thrive.

FIGURE 6.3: MASS TIMBER BUILDING

Heavy Timber

Heavy timber is another traditional method of wood construction, often referred to as "post and beam." In this construction style, large timbers form vertical columns and horizontal beams are connected either with wooden joinery or metal connectors. A key implication of this design is that the columns bear all the building's weight, meaning the walls are not load-bearing (see **Figure 6.2**).

Because the timber columns and beams bear a building's weight, post and beam construction offers greater design flexibility and allows highly customized and open floor plans. Another advantage is quick completion of a building's structure. Many post and beam designs leave the large dimension beams and columns exposed. Many consumers find the natural warmth and elegance of exposed wood surfaces appealing. In addition, the massive size of the timbers used in a post and beam building provides fire resistance.

Like light-frame construction, a disadvantage in post and beam construction is that care must be taken to ensure the posts and beams are not subject to long-term moisture exposure, which would provide a means for insects, mold, and fungi to degrade the wood.

Mass Timber

Mass timber refers to engineered wood members that offer a high level of fire-resistance due to their massive size. Mass timber construction uses primarily mass timber components for the structure of a building. Up to this point, most mass timber buildings in North America have been low- to mid-rise structures. However, US building code changes enacted by the ICC in late 2018 mean three new types of wood construction have been incorporated into the 2021 IBC, including buildings that reach a height of 18 stories (270 feet). Canada has also developed tall wood code provisions, slated for approval in late 2021. For details on regional adoptions of these codes, see Chapter 5. The benefits and challenges of mass timber construction are explored in detail in the remainder of this chapter.

6.3 THE MASS TIMBER BUILDING EXPERIENCE

When mass timber started making headway as a building material in North America, there were virtually no building contractors experienced in its use. This section discusses how contractors have adapted to using mass timber as a building material and some of the lessons they've learned.

6.3.1 BIDDING AND PLANNING MASS TIMBER PROJECTS

Educating building contractors about the process of planning and bidding a mass timber building is an identified industry need. For example, a 2017 report[2] by the British Columbia Construction Association identified barriers to innovation as they relate to using mass timber in buildings. Many barriers were identified, including:

- lack of transparency in the procurement process
- issues over responsibility and allocation of risk
- lack of clear leadership to ensure that construction is properly planned using a design-led approach
- procurement models that inadvertently promote an adversarial relationship among parties
- building contractors who may not be familiar with best practices for managing and mitigating such risks as they pertain to mass timber. When working with mass timber, contract documents should have provisions about weather protection, lifting and storing materials, and fire protection during construction.

Training Resources

Because of the urgent need to train construction teams, WoodWorks has been working on resources to help guide contractors in the United States on the particularities of bidding, planning, and constructing with mass timber. Their "Mass Timber Construction Manual" is coming out mid-2021.

WoodWorks is also moving ahead with development of a workshop program on mass timber installation training. Using WoodWorks' manual as the primary background and source document, the program will consist of various modules allowing multiple levels of detail or training. One 8-hour and one 16-hour module of hands-on training are being developed. Upon completion, this curriculum, along with the WoodWorks standard mock-up drawing kit, will be available for distribution across the US to any company, agency, association, or training center interested in developing their own training program. The curriculum will be made available to any entity seeking to provide mass timber installation training and will also be available by mid-2021.

2 Procuring Innovation in Construction: A Review of Models, Processes, and Practices. British Columbia Construction Association. Accessed at: https://www.naturallywood.com/sites/default/files/documents/resources/procuring_innovation.pdf

The program follows the successful WoodWorks sponsored Chicago Carpenters Training Center (CCTC) mass timber installation training program, which continued through 2020 in Elk Grove Village, IL. The training center will continue to offer remote offerings as well as COVID-restriction compliant in-person training in 2021, while also expanding its contractor training remotely across the US. It is available to apprentice and journeymen carpenters affiliated with union contractors. The program is intended to serve as a model for training throughout the United States, so construction professionals are better able to meet increasing demand for buildings made from CLT and other forms of mass timber.

Optimize During Design

A custom mass timber package can save significant field costs, but the benefits are realized only if the design and procurement/build teams work together as early as possible in the design process. Traditional procurement processes are a barrier to early collaboration among designers, builders, and manufacturers. A building owner considering a mass timber building should first be advised on how to choose a procurement process that supports the close collaboration required for the best value outcome (see also Chapter 8).

Each mass timber manufacturer has specific efficiencies and limitations that should be worked into design and logistics plans. Optimization of a structure's design and erection process is what balances out the premium costs of early planning, higher-unit-cost materials, and prefabrication. If layout and detail optimization is offered later in the process, such as during bidding, significant redesign may be required to achieve an on-budget package. Pushing design work into the construction phase creates cost and schedule risks, and one of the biggest cost advantages of the mass timber construction approach is a dramatic reduction of these risks.

A successful cost model is necessary to begin construction, but the benefits to early coordination go far beyond cost estimating. Efficient field coordination is where schedule benefits are realized, and a savvy contractor will amplify the structural coordination benefits into other trades as well. For example, a high level of coordination during design was an essential part of the construction-phase success of the 8-story mass timber building, Carbon12, in Portland, Oregon. The project team chose a design-build approach, allowing for significant time dedicated to Mechanical, Electrical, Plumbing and Fire systems (MEPF) coordination with the CLT package. Along with optimizing the structure, the MEPF penetrations were also reduced by careful consideration from an installation-sequencing standpoint. A sequencing plan ensured trades were not in conflict during installation, leading to the subcontractors "working together like a well-oiled machine."[3]

For best practices for early coordination, WoodWorks has created a resource, Mass Timber Cost and Design Optimization Checklists, to assist project teams.[4]

Availability and Lead Times

Advantages to contractor involvement in project planning include adding valuable insight into material availability. The number of mass timber manufacturing facilities in North America is

3 www.buildingCarbon12.com
4 https://www.woodworks.org/design-and-tools/building-systems/mass-timberclt-code-related/

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. One of the often overlooked aspects driving lead time is the custom detailing work needed at the manufacturer during production. Selecting and engaging with a manufacturer early can help ensure that the team has plenty of time to coordinate and approve shop drawings.

It is worth noting that while engineered mass timber components are custom products, they are composed of wood fiber that is subject to the fluctuations of a commodity market. Wood fiber prices can change from month to month, or even week to week, and this plays a part in estimating and in timing orders.

BIM and CNC

Mass timber and Building Information Modeling (BIM) (see Chapter 5 for more information) are coming of age together, a synergy contributing to the exponential uptake of mass timber technologies on the market. The planning and coordination required for reducing on-site construction time through prefabrication is well supported by a collaborative virtual building model. BIM's potential to streamline coordination through design, manufacturing, and construction is developing rapidly.

Integrated procurement models are also becoming more common. Procurement barriers discussed in other chapters can limit early coordination for nonintegrated teams, but BIM is also a relatively new technology, and all parties involved are still becoming accustomed to an integrated modeling process. A traditional building contract can also benefit from BIM at all stages.

Today, using BIM to coordinate a mass timber project can be as basic as the timber manufacturer modeling components for the CNC machine that will cut each panel to precise specifications. The process often reaches higher levels of sophistication and can involve each member of the design and build team, depending on the skills of the team and the objectives of the project. Possibilities include detailing down to the level of fasteners, using the model for materials takeoffs and ordering, clash detection for all building systems, and modeling for prefabrication of each building component.

Currently, the most common and effective ways to utilize BIM for mass timber are for the architectural, structural, and MEP designers to create intersecting 3-dimensional models for coordination both in design and in construction. These 3-dimensional models can also be shared with the mass timber manufacturer for direct use in creating shop drawings for fabrication.

Prefabrication

Successful projects that maximize prefabrication are pushing the building industry to reconsider project delivery. The American Institute for Architects (AIA) estimates that modular construction projects reduce construction schedules by 30 to 50 percent.[5] Modularizing an entire structural system has benefits for on-site safety, schedule efficiencies,

5 Design For Modular Construction: An Introduction for Architects

and precision, appealing broadly to installers, building owners, and designers. The confluence of BIM and mass timber is leading to increasing conversations about the potential of fabricating more—and more complex—components off-site. In this way, mass timber has become a catalyst for prefabrication in North America, following successful and diverse European precedents.

Potential for off-site fabrication is huge, but facilities are limited in North America. The most common approach is component-based, where complex, or large, precise elements are manufactured off-site and set immediately in place, reducing installation time and overall schedules. Flat pack wall systems and volumetric strategies seek to install multiple interacting materials, utilities, and finishes in a climate-controlled interior environment. Benefits include a higher level of quality control and very fast on-site erection times. Whatever the approach, local jurisdictional inspection requirements, as well as transportation limitations, should be taken into account when strategizing prefabricated building elements.

As is typical of mass timber, large-scale timber components arrive on site in stacks organized for rapid erection of walls and floors. Because a crane is necessary to move large components into place, it makes sense to take advantage of the investment and look for opportunities where other time-consuming building elements can be fabricated into larger components, such as facades or mechanical systems. This is especially true for sites where transportation and labor costs are high or lay-down and staging space is minimal, such as remote locations or constrained urban sites.

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' strategy. But maximizing prefabrication can also lead to a rapid sequencing that is able to keep up with, and take advantage of, the speed of mass timber structural erection.

The 18-story student residence hall, Brock Commons, at the University of British Columbia 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, providing immediate weather protection and savings in scaffolding, time, labor, and risk on-site. In the fall of 2017, only 66 days from the first panels arriving on site, the building was structurally topped out and enclosed.

Prefabrication and a design-build partnership were key to the significant schedule savings realized at the 4-story residential building Project One, in San Francisco. Located on a very constrained site with no lay-down area, the original structural framing schedule was estimated at 3 months. Using precision-fabricated Mass Plywood Panel (MPP) components from Freres Lumber for the floors and roof, and panelized light framed walls and moment frames, the structure was completed on budget in just 24 working days. The design-build team worked closely with Freres on design coordination and delivery, and the owner deemed the approach a huge success.

A modular building approach naturally leads to less time on-site, cutting down on local disruptions associated with construction like increased traffic, lane closures, and noise. Smaller crews require fewer parking spaces, while reduced or eliminated

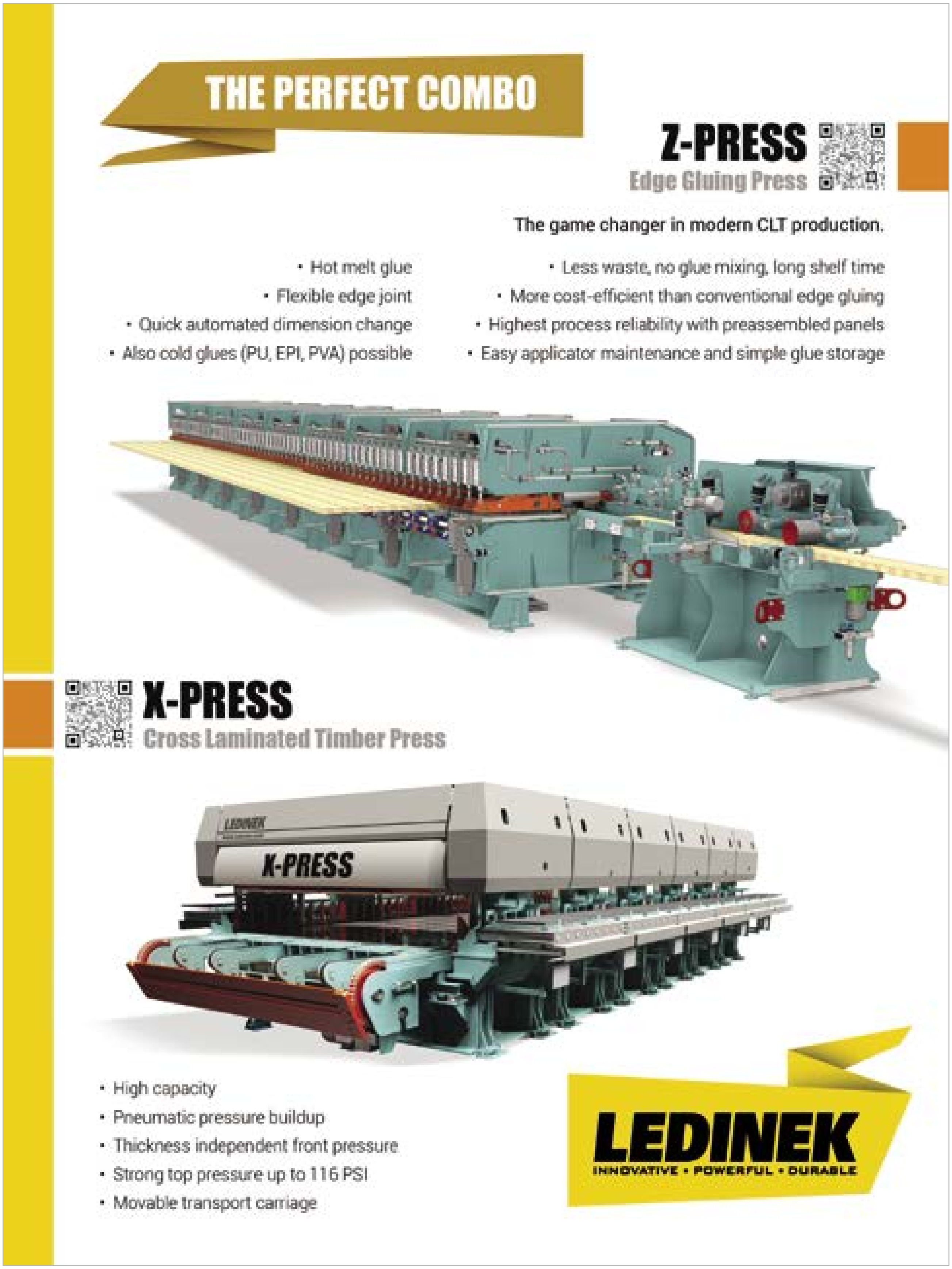
FIGURE 6.4: FACADE PANELS FOLLOW CLOSELY BEHIND STRUCTURAL FRAMING

Brock Commons, University of British Columbia, Vancouver Image: Ralph Austin at Seagate Structures

FIGURE 6.5: PRECISION COMPONENTS QUICKLY ASSEMBLED ON A CONSTRAINED SITE

Project One, San Francisco, CA. Gurnet Point Construction, DCI Engineers, Freres Lumber, Co. Photo Credit:

field modifications make for a very quiet site. Large structural components 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. Less lay-down space is needed when installation coincides with just-in-time delivery, another benefit for constrained or sensitive sites.


THE PERFECT COMBO
Z-PRESS
Edge Gluing Press
The game changer in modern CLT production.
• Hot melt glue
• Flexible edge joint
• Quick automated dimension change
• Also cold glues (PU, EPI, PVA) possible
• Less waste, no glue mixing, long shelf time
• More cost-efficient than conventional edge gluing
• Highest process reliability with preassembled panels
• Easy applicator maintenance and simple glue storage
X-PRESS
Cross Laminated Timber Press
LEDINEK
X-PRESS
• High capacity
• Pneumatic pressure buildup
• Thickness independent front pressure
• Strong top pressure up to 116 PSI
• Movable transport carriage
LEDINEK
INNOVATIVE • POWERFUL • DURABLE

CASE STUDY:
SANTIAM CANYON SCHOOL DISTRICT'S NEW HIGH SCHOOL

CHOOSING MASS PLYWOOD PANELS FOR FUNCTIONALITY, SPEED OF CONSTRUCTION, COMMUNITY PRIDE

Like many public schools across the country, Santiam Canyon School District in Mill City, Oregon, faced aging facilities that no longer accommodated its growing student population. The rural district needed innovative ways to make multiple improvements and to add square footage with quality construction, while holding to a tight budget. The only way to afford capital improvements of this size was to go out for a bond levy.

In a rural timber town, using local wood products was a key factor in gaining community buy-in. Supporting local businesses is a crucial value for the Santiam Canyon community. Voters approved the $17.9 million bond in May 2019; construction began in March 2020.

"Using the locally conceived and produced MPP added an important element of community pride that helped pass a bond levy in a district that had never supported such a levy," said SCSD Superintendent Todd Miller.

OFF-SITE FABRICATION

The district sought new and innovative construction methods, and they looked to local industries to build a new junior/senior high school, add an elementary school cafeteria, add a gymnasium, and make various site improvements. By using Modern Building Systems' factory-built components and Freres Lumber Co.'s new Mass Ply Panels (MPP), the district was able to save money because a significant amount of labor was done off-site, saving on costs and allowing for quicker construction.

VERSATILITY OF MASS PLYWOOD PANELS

The project showcases Freres's MPP throughout the construction, including beams, columns, roofs, and walls. It took 3,500 square feet of MPP to complete the Santiam Elementary servery (cafeteria) walls and

23,000 square feet of MPP to create the Santiam Junior/Senior High School gym walls, roof, beams, and columns. A steel plate splice in the MPP beam supporting the gymnasium roof, engineered by ZCS Engineering, helps achieve the impressive span of 72 feet.

INNOVATIVE CONSTRUCTION PROCESS

The school district chose innovative building solutions including Modern Building Systems' factory-built components and Freres Lumber's MPPs and Mass Ply Lam (MPL) beams. This helped cut costs in two ways: off-site labor that was not subject to prevailing wage, and off-site manufacturing that resulted in a faster construction process. The Santiam Elementary School servery was erected in just 4 days, and the Santiam Junior/Senior High School gym in 15 days.

Story Credit: Freres Lumber

This entire project has been fun to watch, but MPP is the showstopper! We have been amazed by the enormity of the product, the precision of it and the speed at which it is installed. It is almost unfathomable how fast a structure can go from nothing to fully enclosed with MPP.

~ Todd Miller,
Santiam Canyon School District Superintendent

SANTIAM CANYON SCHOOL DISTRICT'S NEW HIGH SCHOOL

LOCATION: MILL CITY, OREGON

COMPLETION DATE: MID 2021

OWNER: SANTIAM CANYON SCHOOL DISTRICT

ARCHITECT: SODERSTROM ARCHITECTURE

STRUCTURAL ENGINEER: ZCS ENGINEERING

CONTRACTOR: GERDING BUILDERS

MODULAR MANUFACTURER:
MODERN BUILDING SYSTEMS

MASS TIMBER MANUFACTURER: FRERES LUMBER

FIGURE 6.6: ASSEMBLING PREFABRICATED COMPONENTS IN A FACTORY SETTING

Source: Katerra. Photo Credit: Kristopher Grunert

6.3.2 RELOCATION OF LABOR

Increased prefabrication of building components has excellent implications for the workforce. When more labor takes place at a manufacturing facility, on-site construction crews become smaller. 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.

Factory environments have health and safety benefits for workers when compared to construction sites.

Safety

In a factory setting, there is a dramatic reduction of the hazards experienced on a construction site. Worker safety is improved, and the likelihood of accidents decreases by about half. According to research from University of Utah, “By moving to prefabrication, the construction industry and its workers can experience a much safer environment by a factor of 2.”[6]

Climate Control

In some climates, harsh conditions are not only challenging for human health but also limit hours available for construction. For example, a framing crew working in a hot climate 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 job site, is stressful to human health and increases safety risks. 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 up to more candidates.

Commute

Construction workers who commute to a job site are at the mercy of the project location and its distance from their home and community. Some remote job sites require temporary accommodations, and laborers travel home only for weekends. Long and always changing commutes are challenging for families and for an individual's health, and often workers must sacrifice family time, sleep, or other healthy habits.

Ergonomics

For repetitive tasks, a factory can provide more ergonomically designed support. For example, a work surface can be set at a comfortable height for tasks that might require kneeling on-site.

6 Prefab Architecture, Ryan E. Smith, (book, 2010) p. 86

FIGURE 6.7: A SMALL FRAMING CREW GUIDES PANEL PLACEMENT

Image: The Canyons. Photographer: Marcus Kauffman, Oregon Dept of Forestry

Diversity

Because of the reasons cited above, factory environments provide increased accessibility to jobs for women, people with health concerns or disabilities, and older workers. Diversity within a company has many proven benefits, including increased productivity, creativity, engagement, and profit, and reduced turnover. The benefits ripple beyond projects and companies into healthier, more sustainable communities.

Skills and Training

In a factory producing complex building components, there are opportunities 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 and have 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 or coordinating BIM processes with external design teams. "[T]he prefabrication architecture laborer is much more skilled than any mass-production laborer in previous generations, moving to more intellectual, computer, or even management tasks."[7] Such a range of job opportunities supports diverse communities—especially beneficial in rural communities with limited job options.

6.3.3 PRECISION AND CONNECTIONS

Custom, engineered timber components are very precise, with tolerances in the range of 1⁄16 inch. If fully coordinated in advance, they should require no field modifications. Interfaces between mass timber components and other building materials should be identified and proper tolerances allowed for in the design details. Designers should identify where greater levels of precision are most critical, and contractors can advise on where constructability issues may arise.

Installation conflicts can be reduced or eliminated through close coordination in advance 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 also an important opportunity to optimize the sequencing of the build to find schedule and cost savings where possible. Common interfaces, where building in tolerances is critical to project success, are listed below.

Concrete

Cast-in-place concrete can incur inconsistencies up to 1 inch. Because foundations are typically cast-in-place, the transition between concrete and other framing materials is a connection point that will occur on virtually 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 where to take special care in areas requiring more precision and also flag details that may not allow room for industry-standard installation practices.

FIGURE 6.9: CLT WALL AND ROOF PANELS WITH STEEL FRAMING

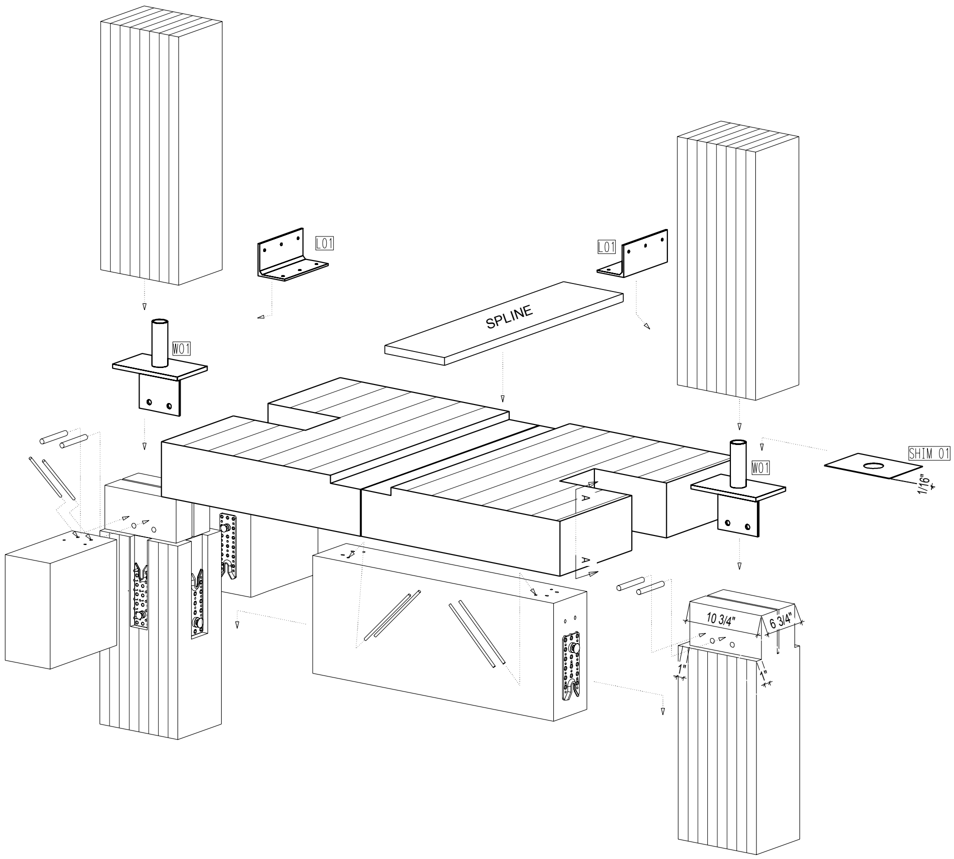
Lincoln City Police Department, OR.
Source: Swinerton Builders

Precast concrete is more precise than cast-in-place concrete. This prefabricated solution is worth considering for exposed components with a high level of finish quality.

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.[8]

7 Prefab Architecture, Ryan E. Smith, (book, 2010) p. 87
8 American Institute of Steel Construction



TOP — FIGURE 6.8: OFF-THE-SHELF BEAM CONNECTIONS AND CUSTOM COLUMN CONNECTIONS

Carbon12, Portland, OR. Source: Kaiser + Path

BOTTOM — FIGURE 6.10: KIT-OF-PARTS ASSEMBLY DIAGRAM FOR TIMBER COLUMN, BEAM, AND CLT FLOOR ATTACHMENTS

Carbon12, Portland, OR. Source: Kaiser + Path

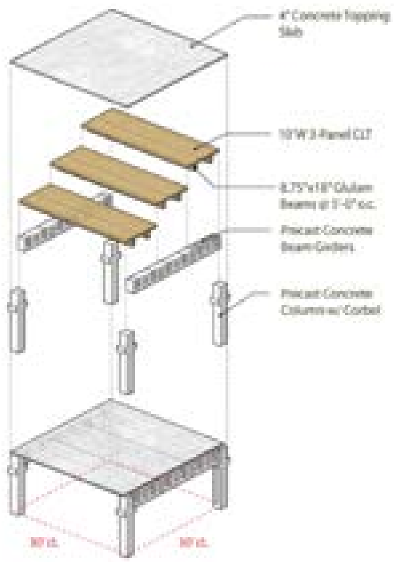


FIGURE 6.11: PRECAST CONCRETE AND TIMBER HYBRID STRUCTURE ADIDAS NORTH BUILDING

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

The design and fabrication method of exposed or concealed steel connectors, especially details that occur frequently, can significantly impact the schedule of a project. Rolled steel connections will require more tolerance, and it may be wise to plan for shims or other field modifications as needed. As with larger structural components, greater length brings more potential for variation. Highly accurate cast-steel connections may have a higher up-front cost, but they may contribute to schedule savings by reducing field conflicts and retrofits.

Rated Connections

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.

Carbon12 is an 8-story, hybrid CLT, glulam, and steel-braced frame building with custom steel floor-to-floor connections, and specialized diecast steel beam-to-column timber connections. The design-build-owner team was under one roof and able to coordinate holistically in preconstruction. The construction manager with Kaiser+Path noted: “In my 30 years of building, I have not seen a building framed as quickly and efficiently as Carbon12. The structural steel core and mass timber elements fit together seamlessly—with very little corrective work.”

FIGURE 6.12: BRENTWOOD LIBRARY

Brentwood Public Library, Brentwood, CA. Source: Holmes Structures. Photo credit: Blake Marvin Photography

FIGURE 6.13: MASS TIMBER MATERIALS HANDLING

Source: Nordic Structures

6.3.4 ON-SITE MATERIAL MANAGEMENT

Perhaps the most important lesson learned from the first mass timber projects developed in North America is that on-site material management is critical for efficient construction. The following topics outline the advantages and challenges specific to 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 a just-in-time delivery system. Such a system takes considerable planning and coordination with both the trucking company and the mass timber manufacturer. The just-in-time approach can be complicated by greater distances between the building site and the mass timber manufacturer, regional restrictions on oversized loads, challenging terrain, or constrained urban sites. Unusually shaped panels are more challenging to balance for transport, potentially increasing the number of trucks required or complicating sequencing. The transport team can advise on route strategies and restrictions and any added costs associated with oversized loads.

The challenges of management of material within a given space at a building site aren't specific to mass timber. Unique to mass timber is that each prefabricated element has a specific location in the building. When panels are loaded for shipping at the manufacturing facility, they are ideally placed with a consideration of the order in which they will be placed. This approach allows for smooth off-load sequencing and installation, without the need for on-site storage. However, efficient and safe loading of the material on the trucks will often take precedence, and it will also be informed by weight distribution on the truck, as well as by panel size and shape. Understanding the loading and shipping approach before the material arrives on-site reduces delivery conflicts. A building design with many similarly sized panels will be more straightforward to coordinate than one with many unique or unusual shapes. In the latter case, some lay-down space for re-sequencing should be set aside.

FIGURE 6.14: MODULAR TIMBER CONSTRUCTION ON CONSTRAINED URBAN SITES

(**LEFT**) *Sideyard, Portland, OR. Contractor: Andersen Construction. Photo Source: Catena Engineers. Photo Credit: Skylab Architecture*

(**RIGHT**) *District Office, Portland, OR. Photo Credit: Andersen Construction*

Coordinating a huge volume of mass timber material has storage, schedule, and liability implications at both the manufacturing facility and the construction site. A recent case study published by the DLR Group[9] 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 using forklifts or similar equipment to move mass timber around the site (really only an option 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 a container, common for materials supplied from overseas, the equipment on-site must be robust enough to lift or pull heavy panels and timbers from the container. Additionally, enough space is needed to safely maneuver around the site.

Most projects will opt to use cranes. This allows for panels or timbers to be "flown" from a truck or site storage into the designated place in the building. A key aspect of this process is the placement, number, and strength of the "pick points," or lifting devices.

Figure 6.16 illustrates a typical lifting device called a Yoke 1T that has been designed and tested specifically for use in mass timber construction. The device is screwed into a mass timber panel using ½-inch screws and is designed to safely lift panels of up to 7,000 pounds. Other lifting devices are available that are designed for lighter or heavier panels. A key to efficient construction is placing the lifting devices on the panel in a way that allows the panel to balance plumb and level, easing installation. The pick points also enhance safety

9 Tall With Timber: A Seattle Mass Timber Tower Case Study. DLR Group. November 2018. Accessed at: http://www.fastepp.com/wp-content/uploads

FIGURE 6.15: CLT PANEL ON TIMBER FRAME CRANE INSTALLATION

District Office, Portland, OR. Source: Andersen Construction. Photo Credit: Pete Eckert

FIGURE 6.16: PANEL LIFTING DEVICE

Source: https://mtcsolutions.com/ (formerly My-Ti-Con)

by serving as a place for construction workers to "tie-in" after the panel/timber is in place.

Waste Management

Because mass timber is premanufactured, there should be little to no field cutting of material, resulting in very little wood waste at the job site. Builders report that this contributes to enhanced safety because the site stays clean, and storage and removal of waste doesn't require management's attention.

Panels often come wrapped in plastic for protection during transport and on-site storage. While lightweight, this plastic currently comprises the bulk of on-site waste volume associated with mass timber, and it is destined for the landfill. There is potential for this waste stream to be reduced or eliminated if the protection can be reusable or multifunctional.

Metric Units of Measurement

Although the capacity of North American mass timber manufacturers is ramping up, some building projects are utilizing mass timber produced in

FIGURE 6.17: TIMBER FRAME AND STEEL CORE PROGRESSING IN COLD, SNOWY WEATHER

Carbon12, Portland, OR. Source: Kaiser + Path

Europe, where the measurement units are metric, rather than the imperial system used in the United States. Several builders who dealt with this issue reported that they (and their carpenters) were initially very worried about the differing units of measurement. Initially, crews were supplied with tape measures showing both imperial and metric measurements. That approach was not successful, as it created confusion. The solution reported by all builders was to use tape measures calibrated only in metric units. The crews quickly adapted to metric measurements.

6.3.5 WEATHER PROTECTION AND MOISTURE MANAGEMENT

Mass timber has both inherent advantages and challenges associated with weather. Unlike concrete, which has curing limitations around temperature and precipitation, and steel, which requires certain conditions for proper welding, mass timber components can be installed regardless of weather conditions. This has excellent implications for reducing weather delay contingencies during time lines that overlap challenging weather months.

For example, the framing for Carbon12 took place between December 2016 and February 2017, which was one of the wettest and coldest winters in recent history in Oregon. While most of the construction sites in town were closed for several days at a time through the season, this project was only delayed for one day, when key members of the 4-person framing crew were unable to travel to the jobsite due to road conditions.

Once in place, wood components require some protection against exposure to wet weather to prevent moisture uptake.

Short of coordinating construction around a dry season, which is only occasionally a viable option, having a moisture management plan in place 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 that will be on-site during wet weather. Top concerns include staining, swelling, shrinkage, and decay, which can all be avoided by following a well-considered protection and mitigation plan.

Industry standard practices for moisture management in mass timber buildings are developing. In early 2020, RDH Building Sciences published a document advising on moisture risk management for mass timber builders.[10] Meanwhile, experienced builders are also developing best practices. While constructing both George W. Peavy Forest Science Center and District Office during Oregon's wet months, Andersen Construction created a four-part Moisture Management Plan for wood structures: Sealers, Stain Prevention, Moisture Control, and Dry-Out. Each is elaborated upon below.

Sealers

Shop-applied sealers can protect against moisture intrusion during construction, and some 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. Facility capabilities vary, 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 need protection from staining. Moisture uptake is quickest at the end-grain, where timber components are the most vulnerable. It is also where components are typically joined together, creating hidden conditions with less air-circulation for dry out. Often, for protection during transport and installation, a temporary wax coating will be applied by the manufacturer to edges where end-grain is exposed.

Stain Prevention

Managing construction activity on a mass timber structure intended for finish exposure is critical for preventing stains. Communication is an important component of a stain prevention plan, as many trades are unaccustomed to working around finished surfaces. Some superficial stains can be cleaned or sanded, but proper stain prevention will avoid the risk of permanent marking, as well as reducing cleanup time and expense. Because multilevel buildings often have repeating floor layouts, penetrations and panel seams can create pathways for water to move from floor to floor. Water readily transports pigments from debris, such as rust from metal-work shavings or other untreated metals, or even a spilled beverage.

Moisture Control

Two basic concepts are paramount to controlling moisture in structural wood. First, protect wood

10 Moisture Management for Mass Timber Buildings, RDH Building Sciences, 2020

FIGURE 6.18: DISTRICT OFFICE IMPLEMENTED A MOISTURE MANAGEMENT PLAN
District Office, Portland, OR. Source: Andersen Construction

from prolonged exposure to water. Secondly, 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 moisture content, depending on the environment to which they are exposed. Mass timber manufacturers are responsible for protection during transport, which is commonly accomplished by durable plastic wrap. Once the timber is delivered to a project site, the contractor is then responsible for protection, whether stored or in place.

Strategies for protection may be holistic, as in a tented approach, or local, such as tape at panel seams and penetrations. Fully tenting a structure would eliminate the need for many of the practices described in this section, but it is usually 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 prepare for dewatering activities by having adequate equipment and personnel on-site following rain events, as well as a planned approach for continuous wet weather.

In addition to protection, the basic principles of any approach must allow for wood to release

FIGURE 6.19: CLT PANELS PROTECTED WITH WRAP FOR TRANSPORT AND ON-SITE STORAGE

Hillsboro Community Center, Hillsboro, OR. Source: Swinerton Builders. Photo credit: BREWSPHOTO LLC

excess moisture at an appropriate rate until the structure has reached equilibrium with ambient environmental moisture during occupancy (see also Chapter 5.1.8 on moisture).

Dry-Out

Industry standard best practices for acceptable moisture content mass timber have not yet been established. However, in the Pacific Northwest, where wet winters impact construction sites significantly, teams have found that mass timber components that are above about 14 percent Moisture Content (MC) should not be enclosed or encapsulated, but given a controlled opportunity to release moisture.

Mass timber naturally dries out more slowly than light framing because of its larger dimensions. Because of this greater volume, there is more potential for moisture content 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, which, while typically structurally insignificant, can be aesthetically undesirable.

6.4 QUANTIFYING COST SAVINGS

This chapter has discussed the many reasons that mass timber buildings can be less costly than other construction types. However, cost estimating is traditionally based on a wealth of data from past projects, and few contractors in North America have a body of mass timber data to draw from yet. As previous sections have illustrated, early estimates that are not holistically coordinated with the design, procurement, and logistics teams will very likely be inaccurate.

One of the most quantifiable ways to estimate the difference, and one that will have many ripple effects on cost for the building owner, is through the schedule. Mass timber construction happens much more quickly and with less on-site labor than a comparable building of steel or concrete. A challenge associated with validating this claim is that there is rarely a case where identical buildings are constructed using different structural materials, thereby allowing an apples-to-apples comparison. There may be cost comparisons between structural materials, but they are based on plans and estimates, not on actual construction costs. In addition, developers may want to test using different structural materials for the same project, and then perform a comparative cost analysis. In a process like this, 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 critical when comparing mass timber with other building materials. Just as important is considering

PAL PORTFOLIO	TYPICAL NEW PAL HOTEL (ACTUAL*)	REDSTONE ARSENAL (ACTUAL)	DIFFERENCE
Gross Square Feet (SF)	54,891	62,688	+ 14 %
Labor (Average Number of Employees)	18 (peak 26)	10 (peak 11)	- 43 %
Structural Duration (Days)	123	78	- 37 %
Structural Person Hours	14,735	8,203	- 44 %
Structural Production Rate (SF/Day)	460	803	+ 75 %
Overall Schedule	15 months	12 months	- 20 %

TABLE 6.2: COMPARISON OF LENDLEASE PAL MASS TIMBER HOTEL; CONSTRUCTION WITH TYPICAL HOTEL CONSTRUCTION

material reductions throughout the building, such as reduced foundations and excavation costs, and the elimination of drywall, framing, and painting at exposed wood surfaces.

The following sections review several studies that analyzed the cost of mass timber versus other building materials.

6.4.1 CANDLEWOOD SUITES HOTEL, REDSTONE ARSENAL, ALABAMA[11]

Lendlease is an international property and infrastructure group headquartered in Sydney, Australia, and operating in Australia, Asia, Europe, and the Americas. The company has extensive experience constructing buildings from a variety of materials. In 2015, their Timber and Innovations Group, based in Nashville, Tennessee, completed construction of a 92-room, 4-story hotel (62,688 square feet) on the Redstone Arsenal military base in Alabama. The hotel was built of mass timber (CLT).

Why mass timber? Lendlease saw a decreasing labor supply as a significant long-term issue. Mass timber construction was part of the solution because of the top five most difficult construction jobs to fill (heavy equipment operator, welder, pipefitter, carpenter, and ironworker), mass timber construction either eliminates (ironworker) or significantly reduces (carpenter) the number of workers required.

Lendlease has a 50-year agreement with the U.S. Army to construct Privatized Army Lodging (PAL) on army installations, so private sector lodging is available to guests on military bases. So far, Lendlease has hotels at more than 40 installa-

11 Case Study: Construction Advantages Sell Hotel Developer on CLT - CLT Builds Faster and More Safely with Fewer Workers. Accessed at: http://www.woodworks.org/wp-content/uploads/4-Story-CLT-Hotel-WoodWorks-Case-Study-Redstone-Arsenal-01-05-16.pdf

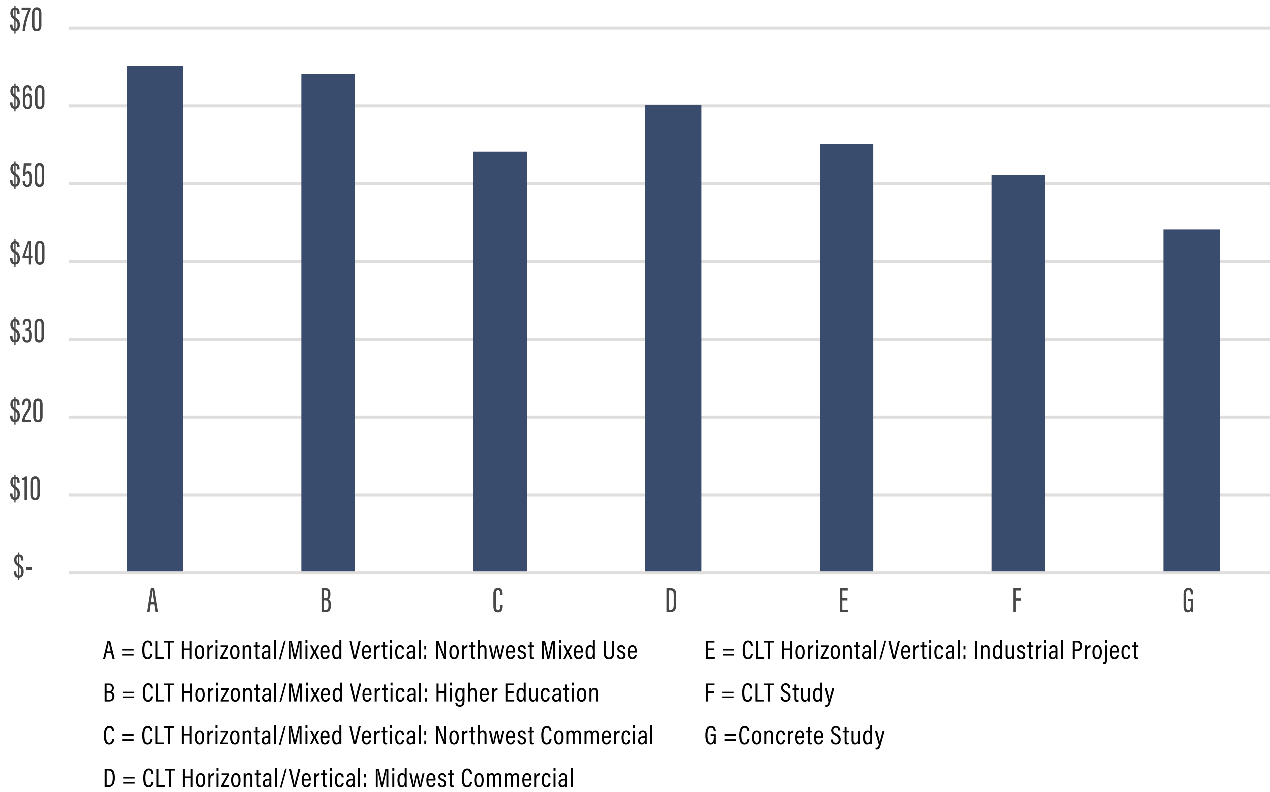


FIGURE 6.20: COST PER GROSS SQUARE FOOT STRUCTURAL FRAME ONLY

tions and joint bases. After the mass timber project at Redstone Arsenal, Lendlease compared the "constructability" of the mass timber hotel with past hotels of similar size but of different building materials. Lendlease defined constructability as the ease and speed of construction. Results of the comparison are shown in **Table 6.2**.

The mass timber building was erected 37 percent faster with 44 percent fewer worker hours than Lendlease typically experienced at other hotels. The Redstone Arsenal hotel was completed with an 11-person crew—3 experienced carpenters and 8military veterans. They were trained on the Redstone job site. Importantly, these savings were achieved even though the mass timber building was 14 percent larger. In addition, the overall construction schedule for the mass timber building was 3 months quicker (20 percent). Lendlease's analysis concluded that mass timber materials would cost more than other construction materials. But the faster construction time and reduced labor saved money. Additionally, the shorter construction time allowed the building to begin earning revenue more quickly. The Lendlease analysis was based on one completed mass timber project. Results could differ on other projects.

Lendlease also concluded that mass timber construction enhanced safety because fewer workers were within the radius and swing fall of the crane. Additionally, the crew built handrails on the floor decks while they were still on the ground. This provided an immediate barrier to prevent falls from upper floors.

6.4.2 CROSS-LAMINATED TIMBER FEASIBILITY STUDY[12]

In February 2018, Cary Kopczynski & Company, a structural engineering firm based in Seattle, Washington, completed a study comparing the cost of CLT and reinforced concrete structures. The comparison was based on a hypothetical 10-story building constructed in the Pacific Northwest, with one version using CLT and the other using cast-in-place concrete. Based on a survey of contractors knowledgeable with CLT, the cost of the erected CLT building was estimated at $48 to $56 per gross square foot, excluding the cost of acoustical and fire protection systems. Adding those supplemental systems increased the cost by an estimated $2 to $6 per square foot. The completed structural frame cost for the concrete option was estimated at between $42 and $46 per square foot. No supplemental fire protection was needed for the concrete option, but acoustical dampening might be required in certain building areas, at a cost of $1 to $2 per square foot. The results are displayed in **Figure 6.20**.

A key conclusion was that the concrete building was more cost effective. The authors noted, however, that a CLT building could have more desirable sustainability characteristics and that over time, CLT may become more economical as availability, competition, and contractor familiarity increase. The study also did not take into account the increased market value of the premium finishes resulting from an exposed wood structure. The authors also cautioned that because CLT is a new technology, there are few completed buildings to use as a basis for developing cost estimates. Therefore, readers were advised "to use judgement when drawing conclusions from the data presented in this report. This is especially true for cost and constructability, since the available CLT information is limited and costs vary widely from region to region."

6.4.3 CLT VERSUS CONCRETE/ STEEL COST COMPARISON CASE STUDY[13]

In late 2016, researchers at the University of Minnesota's Department of Bioproducts and Biosystems Engineering compared the cost of building with CLT versus concrete and steel. The study methodology involved interviewing three representatives from a US architectural firm and representatives of construction and estimating firms about the material selection process. The interviews focused on comparing the cost of constructing a 40,000-square-foot performing arts center in 2008 near Napa, California, a high seismic activity zone. The building was constructed using cast-in-place concrete for the slabs and walls of the main theater and studios. Steel beams supported a composite steel floor deck and special steel trusses were designed to create an 84-foot span without intermediate columns. Also inherent in the design was the need for flexible, unobstructed open spaces, and the use of materials that provided good acoustical performance.

The cost evaluation compared the building as constructed (concrete, structural steel, and light-steel

12 Cross Laminated Timber Feasibility Study: A Comparison Between Cross Laminated Timber and Cast-In-Place Concrete Farming for Mid-Rise Urban Buildings. Accessed at:http://buildingstudies.org/pdf/related_studies/Cross_Laminated_Timber_Feasibility_Study_Feb-2018.pdf

13 Cross-Laminated Timber Vs. Concrete/Steel: Cost Comparison Using a Case Study. Maria Fernanda Laguarda Mallo and Omar Espinoza.2016. World Conference on Timber Engineering. Vienna Austria. Accessed at: https://www.researchgate.net/publication/320739097_CROSS-LAMINATED_TIMBER_VS_CONCRETESTEEL_COST_COMPARISON_USING_A_CASE_STUDY

ELEMENT	CONCRETE/STEEL OPTION	CLT OPTIONS			
		BASIC CLT OPTION 1	BASIC CLT OPTION 2	GREEN OPTION 1	GREEN OPTION 2
	Concrete Walls/ Roof, Steel Beams, Light Steel Frame	CLT Walls/Roof, Steel Beams, Light Steel Frame		CLT Walls/Roof, Glulam Beams, Wood-Frame	
Structural Walls ($)	1,071,680	624,417	414,901	624,417	414,901
Concrete Slab ($)	256,416	256,416	256,416	256,416	256,416
Roof System ($)	600,975	427,809	289,339	427,809	289,339
Interior Walls* ($)	155,304	155,304	155,304	297,666	297,666
Steel Beams ($)	506,575	506,575	506,575	n/a	n/a
Glulam Beams ($)	n/a	n/a	n/a	29,022	29,022
Extra CLT Walls ($)	n/a	n/a	n/a	115,407	84,977
Extras for CLT ($)**	n/a	595,241	595,241	654,768	654,768
Total($)	*2,590,950*	*2,565,763*	*2,217,777*	*2,405,506*	*2,027,091*
Square Feet	*40,065*	*40,065*	*40,065*	*40,065*	*40,065*
Cost *($/Square Foot)*	*64*	*64*	*55*	*60*	*50*

TABLE 6.3: COST COMPARISON OF CLT VERSUS CONCRETE/STEEL

**Interior walls for concrete and basic CLT options are in light-steel frame construction. Interior walls for CLT Green options are in wood-frame construction*
***Extras for CLT include labor costs and connectors for CLT*

frame construction) versus four variations using CLT as a key component of the structural building elements. CLT quotes were obtained from two different manufacturers, which is why there's Option 1 and Option 2 for the Basic CLT and Green scenarios. Results of the cost comparison are summarized in **Table 6.3**. Using CLT instead of concrete/steel could have saved up to 22 percent because of reduced labor costs and faster construction time. However, as noted by the study's authors, cost comparisons vary greatly depending on the type and complexity of a project. Thus, these results should not be assumed for all building projects.

CHAPTER 7: OCCUPANTS

IMPACTS OF THE MASS TIMBER EFFECT

- Demand for comfortable, healthy interior spaces drives a market for sustainably sourced wood buildings.
- Exposed wood surfaces support biophilic responses in building occupants, promoting health and productivity benefits in all building types.
- Unfinished wood has antibacterial, hypoallergenic, and hygroscopic properties that contribute to human health and well being.
- Spaces that give occupants a "sense of place," such as visible locally sourced wood, are correlated with environmentally conscious behavior[1], multiplying the benefits of a carbon-sequestering wood building.

Indoor Environmental Quality (IEQ) is a measurement of how a building affects its occupants' comfort and health. An Environmental Protection Agency (EPA) study[2] found that in the US, respondents spent about 87 percent of their time inside buildings and an additional 6 percent in cars, for a total of 93 percent. Canadians fare about the same, at 94 percent, and Europeans spend only slightly less time indoors, 90 percent. The study suggests that people should spend more time outside because a growing body of scientific evidence links interactions with nature and greater levels of health and happiness. It also suggests that interior spaces and the materials used to make them should incorporate natural elements as much as possible to ensure health.

Critical to understanding the powerful influence of all the aspects of indoor environments discussed in this chapter is the concept of biophilia, the innate human love for natural forms and for nature. Our bodies, biological organisms, are supported by biophilic spaces.

Mass timber buildings can boost building residents' health, well-being, comfort, productivity, and prosocial behavior. Human health, comfort, and behavior are very closely related, but they are divided into three sections in this chapter. The first section, Health, looks at our acute biological responses to indoor environments, whereas the following section on Comfort reviews universal characteristics of those spaces, and human preferences. Finally, in the Behavior section, we consider how indoor environments influence how we interact with each other.

7.1 HEALTH

The focus on 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.

7.1.1 BIOPHILIA

The idea of enhancing human health through building design has been described as the application of biophilia in the built environment. Bio-

1 https://www.stockholmresilience.org/research/research-news/2017-05-30-a-better-sense-of-place.html

2 The National Human Activity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants. Neil E. Klepeis, et al. 2001. Accessed at: https://indoor.lbl.gov/sites/all/files/lbnl-47713.pdf

philia is a term coined by biologist Edward O. Wilson, a University Research Professor Emeritus at Harvard. He defined it as the urge to affiliate with other forms of life in nature. Biophilic design in buildings connects 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 outdoors and nature.

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.[3] According to studies cited in the report, nature-oriented design improves health by lowering stress and blood pressure, improves mental functions, stamina, and focus, improves moods and learning rates, and decreases violent and criminal activity.

7.1.2 STRESS REDUCTION

A study[4] by FPInnovations connected the use of wood to supporting human health in the built environment. The study documented a lowered sympathetic nervous system response when occupants could see more wood surfaces in a mock office environment. Stress, as measured by heart rate and skin conductivity, was lowest for the participants in the office with the wood design. If 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[5] in 2007, monitored subjects' physiological responses to different ratios of wood surfaces in an environment. They discovered that a moderate ratio (45 percent coverage) was subjectively "comfortable" because it lowered blood pressure and increased pulse rates. A large ratio (90 percent) "caused significant and large decreases" in blood pressure in test subjects.

7.1.3 RECOVERY AND HEALING

Another emerging area of occupant health is evidence-based design, involving the analysis of the design of a building to assess how it impacts human health. Already, architects specializing in the design of healthcare buildings are utilizing 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.[6]

Biophilic design in healthcare environments is linked to shorter hospital stays, faster recovery rates, fewer negative comments from hospital staff, and reduced medications.[7]

7.1.4 INFECTION CONTROL

The year 2020 brought an increased awareness of how the air and the surfaces around us contribute to our safety or exposure to contagion. An ongoing Finnish study has shown that "the

3 The Economics of Biophilia: why designing with nature in mind makes financial sense. Terrapin Bright Green, 2014

4 Wood and Human Health. FPInnovations 2011.

5 Tsunetsugu, Y., Miyazaki, Y. & Sato, H. Physiological effects in humans induced by the visual stimulation of room interiors with different wood quantities. J Wood Sci 53, 11–16 (2007).

6 Wood as a Restorative Material in Healthcare Environments. February 2015. FPInnovations.

7 The Economics of Biophilia, Terrapin Bright Green, 2014. The Economic Advantage of Biophilia in Sectors of Society

contagiousness of coronaviruses decreases much more rapidly on a wooden surface than on other materials, such as plastics."[8] Wood is an effective antibacterial surface, especially when compared to materials like glass or plastic. Another Finnish study found that pine, spruce, and birch surfaces effectively prevent the growth of pathogenic bacteria common in hospitals, such as the kind that cause staph infections.[9]

The Institute for Health in the Built Environment (IHBE) at the University of Oregon also has ongoing research that observes how the unique natural properties of wood could make it difficult for different pathogens to survive or be transferred to occupants on wood surfaces. Wood has a porous surface that can both sequester moisture and dessicate. Wood also contains aromatic organic compounds found in many plants, called terpenes, that appear to have antiviral effects. These IHBE studies are investigating the effect of wood species, coatings, humidity, and simulated flooding events on the surface and air microbiome in exposed wood buildings. Other IHBE studies have shown promise for wood to promote healthy bacteria and support diverse indoor biomes that contribute to human health.

These studies have the potential to significantly increase the use of wood in healthcare environments.

7.2 COMFORT

IEQ in relationship to occupant comfort is multidimensional, including thermal comfort, indoor air quality, acoustics, visual comfort, and safety. In the simplest terms, when a person feels comfortable in a built environment, they also tend to be more healthy and productive. Mass timber buildings can enhance occupants' comfort in several ways.

7.2.1 INDOOR AIR QUALITY

Many factors contribute to healthy Indoor Air Quality (IAQ) that are beyond the scope of this report, including ventilation rates, filtration systems, outdoor air quality, and occupant behavior. We focus here on providing information about how utilizing exposed wood in interior spaces can support high IAQ characteristics as part of a complete healthy building system.

7.2.2 TOXICITY

Wood is considered hypoallergenic, meaning it is very unlikely to cause allergic reactions, and its smooth surfaces are easy to keep clean and free of particles. Mass timber panels are manufactured using resins that result in virtually no formaldehyde off-gassing. Many mass timber products are "red-list" free[10] and approved for use in Living Buildings.

Relative Humidity

Relative Humidity (RH) is the percentage of potential moisture held in the air as it relates to the

8 Antti Haapala, University of Eastern Finland

9 Tiina Vainio-Kaila, doctoral thesis, Technical Research Centre of Finland

10 The RED List contains twenty-two classes of chemicals prevalent in the building industry, which the International Living Future Institute has designated as worst-in-class.

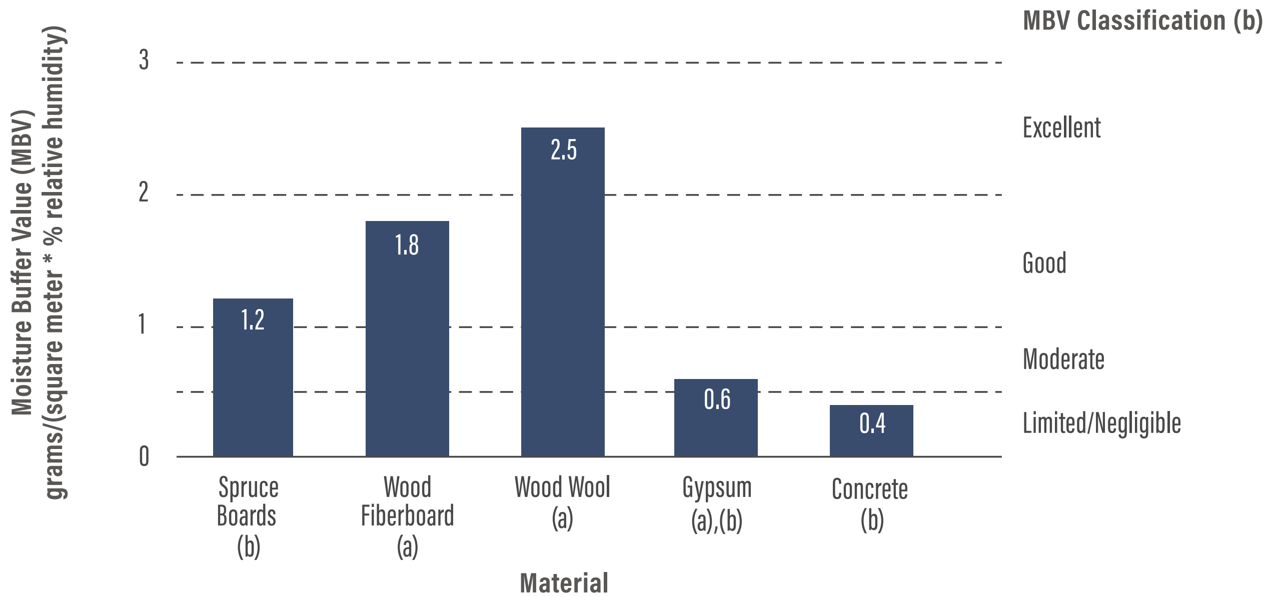


FIGURE 7.1: MOISTURE BUFFERING VALUES OF COMMON BUILDING MATERIALS

(a) A New Carbon Architecture, Bruce King et al, 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, 2006, Moisture Buffer Value of Building Materials.

temperature of the environment. The optimum range for human health is 40 percent to 60 percent RH, coinciding with the least optimal range for human health-challenging organisms like bacteria, viruses, fungi, and mites. Similar to how materials with high thermal mass, like stone or concrete, absorb heat on a sunny day and release it in the cool of night, so, too, can different materials contribute to balancing humidity levels.

Because wood is a hygroscopic material, it assists in moderating humidity levels by absorbing moisture during periods of high humidity and releasing moisture during periods of low humidity. The ability of any given material to perform this function is measured by its Moisture Buffering Value (MBV). Values over 1 (g/[m²%RH]) are considered good, and materials with values over 2 are excellent at buffering moisture. As illustrated by **Figure 7.1**, wood products perform very well, 2 to 5 times better than other tested common indoor materials, including gypsum board and concrete.

7.2.3 ACOUSTICS

Acoustics from an occupant's perspective can be classified in two ways: structure-borne, and ambient. Buildings with design features that control for both can significantly enhance occupant satisfaction. Adding mass to an assembly is an important aspect of acoustic mitigation in buildings. The sound-dampening qualities of solid wood have long been recognized, and mass timber performs well in managing structure-borne sound.

An ambient sound experience can be managed with sound-absorbing materials to control reverberations of noises in a space. Furnishings, and the occupants themselves, can absorb sound, as can architectural finishes. Wood is a porous material and contributes well to the absorption strategy of a space. It also has an interesting impact on an occupant's perception of noise. A 2019 study[11] at the University of Oregon investigated how wood affects ambient sound comfort by collecting biometric data from building occupants, measuring galvanic skin response, heart rate, and emotional response using facial recognition software. They compared masonry and mass timber in office environments, and they found that the exposed wood in mass timber buildings may provide an "acoustic forgiveness factor" when occupants are exposed to similar distracting stimuli throughout the day. That means that the same sounds that irritate a person in a masonry building may not have the same negative effect on someone in a space with significant biophilic features, in this case, wood.

7.2.4 THERMAL COMFORT

Wood-framed buildings perform well thermally because wood is a natural insulator. This gives designers increased flexibility when detailing insulation to meet energy efficiency codes, making *actual* thermal comfort a feature of a well-designed wood building. Wood additionally contributes to a *perceived* sense of thermal comfort, broadening acceptable temperature ranges, saving on operational carbon emissions and energy costs.

A study performed by the Energy Studies in Buildings Laboratory (ESBL) at the University of Oregon provides evidence that exposed wood supports the thermal and visual comfort of building occupants. The study found that "...visually 'pleasant' or 'warm' surroundings can improve perceived thermal comfort, even when the space may call for cooling."

Researchers investigated the perception of thermal comfort in the presence of wood versus white painted drywall in a climate-controlled chamber. After a 40-minute acclimation period in which the materials were covered with black curtains, the drywall or wood surfaces were exposed. At intervals, the test subjects answered survey questions related to comfort and perception. With no other variables altered, in the wood room, participants were 25 percent more likely to desire no change in thermal environment, or, in other words, to be comfortable. An even stronger response was measured with a word association test. Participants related word pairs, "reveal[ing] that people found the wood walls to have more favorable qualities all-around than the white." The researchers found that "wood was considered more 'natural' than white walls or the control. Wood was also significantly more 'liked' than 'disliked' as compared to the white walls. Wood was also found to be significantly more 'expensive,' 'pleasant,' 'sturdy,' 'unique,' 'interesting,' 'new,' and 'clean' than the white."

7.2.5 VISUAL COMFORT

Key factors in the visual comfort of building occupants are visual access to nature and the amount of daylight that enters the structure. Research shows a link between access to daylight and improvements in mood, productivity, and sleep patterns. Views can dramatically affect mood and productivity as well. A building designed to maximize daylight access for occupants

11 Bain, Montiel, Summers, Yauk. Auditory visual perception: acoustic distractions in mass timber versus concrete office spaces. 2019

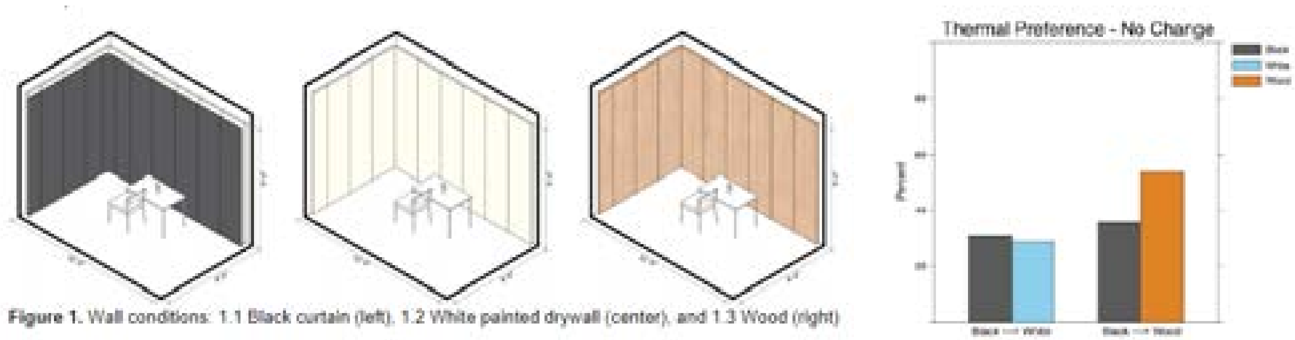


FIGURE 7.2: STUDY FINDINGS ON THERMAL COMFORT

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

will be oriented to take advantage of daily and seasonal sunlight patterns. It will also limit floor plate depth, so occupants spend most of their time near the perimeter of the building where daylight is most prevalent. Mass timber supports good design practices with thin floor plates for higher ceilings and two-way spans that can eliminate perimeter beams. Both qualities allow for plentiful, taller windows to allow daylight further into a building. Mass timber often inspires building designs with open atriums that are visually appealing and filled with natural light.

7.2.6 LIFE SAFETY

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 goes even further by contributing to highly "resilient" designs. Resilient buildings recover quickly from disaster events such as earthquakes, fire, or flooding. Buildings that can be safely occupied following a disaster are invaluable to recovering communities, a fact made painfully clear every time a large-scale disaster displaces a large number of people for long periods.

7.3 BEHAVIOR

When people are healthy and comfortable, they are much more likely to exhibit behavior that benefits them and the people around them.

7.3.1 ECONOMIC BENEFITS

The "Economics of Biophilia" states: "The main causes for deficient productivity include absenteeism, loss of focus, negative mood, and poor health. The built environment, though not always the cause of these stressors, when well-designed, can be a reliever of these undesirable symptoms." and that "10% of employee absences can be attributed to architecture with no connection to nature." Many employers understand the financial and social benefits of a healthy workplace on employee productivity and will seek spaces that best meet their needs.

Benefits are likewise present in retail environments. "Retail customers judge businesses surrounded by nature and natural features to be worthy of prices up to 25% higher than businesses with no access to nature." An environment where customers feel both relaxed and stimulated

FIGURE 7.3: FLOOR-TO-STRUCTURE WINDOWS ALLOW DAYLIGHT DEEP INTO THE FLOORPLATE
First Tech Federal Credit Union, Hillsboro, Oregon. Source: Swinerton Mass Timber

will be more conducive to spending, contributing to the success of a business. The study above in the section on thermal comfort also found that test participants perceived wood surfaces as being "expensive" and "pleasant," which also has implications for customer behavior.

Building maintenance is an expense, and occupant behavior can have a direct impact on maintenance costs. Occupants who enjoy a space, and feel respectful toward a building, will be less likely to be careless or destructive to that space.

7.3.2 SOCIAL BENEFITS

The same effects that the presence of trees and green spaces has on lowering violent and criminal behavior in communities can be seen inside buildings as well, reducing vandalism and other aggressive behavior.

One mass timber example is the William Perkin Church of England School, completed in 2014. It is constructed with exposed CLT walls and floors as an economic strategy to meet a very tight 12-month construction schedule. The new building replaces an outgrown and dilapidated predecessor and serves a student body with noted behavior issues. There was a concern about how the new building would be treated, as vandalism may be as, or more, tempting on the new exposed wood walls than in the previous building, but even more challenging to remove. Before the new building opened, a behavior strategy of quiet voices was planned for and encouraged in the halls using graphics, words, and quotes that reminded students to be peaceful and wise. To the administration's delight, the students were remarkably calm and respectful in the new space. Behavior issues and subsequent disciplinary actions have decreased significantly. Students report feeling as though the space makes them feel valued.

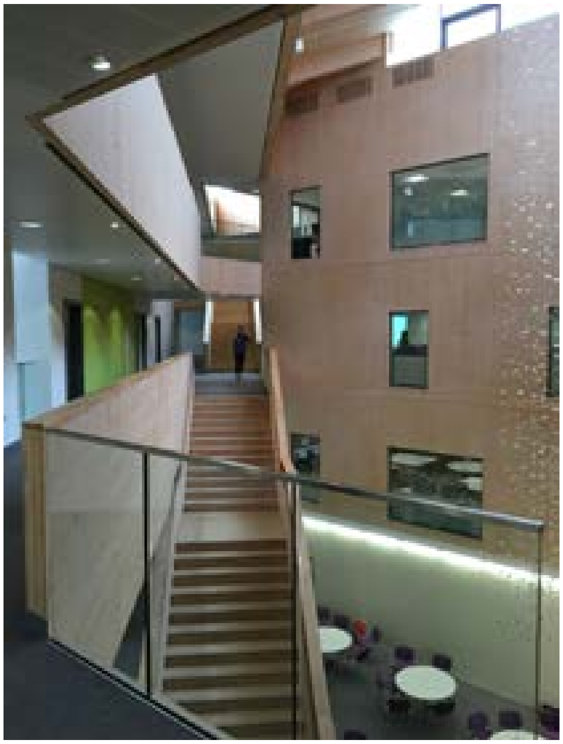


FIGURE 7.5: WILLIAM PERKIN CHURCH OF ENGLAND SCHOOL
Photo credit: Emily Dawson.

A survey in British Columbia found, similarly, that wood surfaces are less likely to be vandalized than other surfaces.

Though more research has been done on office environments and hospitals, focusing on productivity or infection, researchers of biophilic effects agree that it follows that the potential for schoolchildren to benefit from the healing effects of natural materials is very promising.

CHAPTER 8: OWNERS AND DEVELOPERS

IMPACTS OF THE MASS TIMBER EFFECT

- In the near future, the carbon impact of any investment will factor into its market value.
- Development of forest carbon markets have the potential to inform timber use in the building industry.
- Sustainably harvested wood fits naturally into a Circular Carbon Economy.
- Mass timber consumers who support sustainable forestry practices and policies will push the wood market toward the maximum carbon storage potential of forest products.
- Resilient, high-value buildings support communities facing natural disasters by providing immediate, or quickly available, safe, functioning shelter.
- At this stage in the evolution of mass timber, building owners are the true pioneers in adopting a relatively new building technology, while necessarily exploring evolving financing and procurement systems. Contractors, designers, and engineers, depending on the region, may have limited experience with wood structures, though educational resources are rapidly being established nationwide. This chapter explores the owner's role, the benefits of choosing a mass timber system, key development issues, and best practices.

8.1 CARBON CONSIDERATIONS

Quantifying carbon from a materials investment standpoint is simple in theory: if a thing takes less carbon to produce and deliver than the carbon embodied in its material makeup, it is a carbon storage device. Bio-based materials that pull carbon from the atmosphere while they grow are fundamentally intriguing as carbon storage mechanisms. A bio-based product potentially has value in a market that values carbon. Buildings are massive materials repositories, driving significant investigation of the potential to quantify and capitalize buildings within the context of a carbon market.

Developers interested in this potential should become familiar with the concepts of carbon markets, carbon offsets, and a carbon economy. We explore them in the following sections.

For more definitions of many concepts around tracking and evaluating embodied carbon options, it may also be helpful to review the Carbon Considerations section in Chapter 5.

8.1.1 THE CARBON ECONOMY

It is likely that in the near future, the carbon impact of any investment will factor into its value. Carbon taxes, carbon credits, and low-carbon incentives are not yet the norm, but they likely will be increasingly incorporated into the overall economy. According to Architecture 2030, "It's now possible for every new building to have zero-net-carbon operations. We must also dramatically reduce the embodied carbon in infrastructure, buildings and materials—in the next 10 years."[1]

Future-minded organizations within the building industry are laying the groundwork for meaningful engagement with a carbon economy through education, tool kits, and evolving policies that sup-

1 Architect Magazine, The Carbon Issue, January 2020, guest edited by Architecture 2030

port sustainable construction. Sustainably sourced mass timber buildings can potentially neutralize or even offset the carbon emissions required to construct a building. This is something to be aware of and to consider for projects projected to start a permitting process in the coming years.

Carbon Taxes, and Cap and Trade

The philosophy behind taxing carbon emissions is to increase the inherent value of efficient and sustainable industrial processes. Large emitters pay penalties for the carbon they use, and they, therefore, have an incentive to reduce their carbon use and the associated taxes. This approach is currently used primarily in Canada and Mexico.

Cap and trade recognizes a market price for emissions, provides credits to companies that invest in reducing their emissions, but maintains a cost on remaining emissions. Companies can agree to trade credits to allow one company that pollutes more to purchase credits from another that pollutes less. The lower-emitting company, therefore, has an inherent market value simply by being more energy efficient.

North American cap and trade markets happen primarily through auctions held by trade groups: the Regional Greenhouse Gas Initiative (RGGI), which comprises 10 northeastern and mid-Atlantic states; and the California Air Resources Board (CARB), which trades with Quebec and Ontario. Revenues are typically applied directly toward emissions reduction projects. These entities establish a "cap," or carbon allowance, based on the size of the participating regions, and reduce the allowance over time to meet certain targets. Carbon credit values are on the rise; RGGI reported a 23 percent rise from 2018 to 2019, and it expects the growth to continue into 2021.[2]

Carbon Offsets and Banking

Carbon offset programs are also growing as carbon accounting becomes more important to economies around the world. Forest-based carbon offsets are rapidly developing to provide landowners with an inherent value for sustainably managed land holdings. Placing a high intrinsic market value on land that might otherwise be converted to other uses is one of the many benefits of this paradigm. Finite Carbon is one such program, and it reports a portfolio of 3.1 million acres and $720 million.

A forest, then, may in fact provide a landowner with the most value as a carbon bank. Inquiries about using mass timber buildings as carbon banks are developing, though the complexities around quantification of the multitude of products and material sources within a building make this less straightforward.

A Circular Carbon Economy

The Consortium for Research on Renewable Industrial Materials (CORRIM)[3] recognizes wood as a material uniquely poised to solve global economic, environmental, and social pressures associated with the building industry. The consortium engages researchers and practitioners to identify the carbon impact of wood products from extraction to disposal or reuse, and propose methods to improve industry practices to maximize the "triple-bottom-line" benefits. CORRIM describes the circular economy as a way to minimize or eliminate waste across the life cycle

2 Annual Report on the Market for RGGI OC2 Allowances: 2019, Potomac Economics, May 2020
3 www.corrim.org

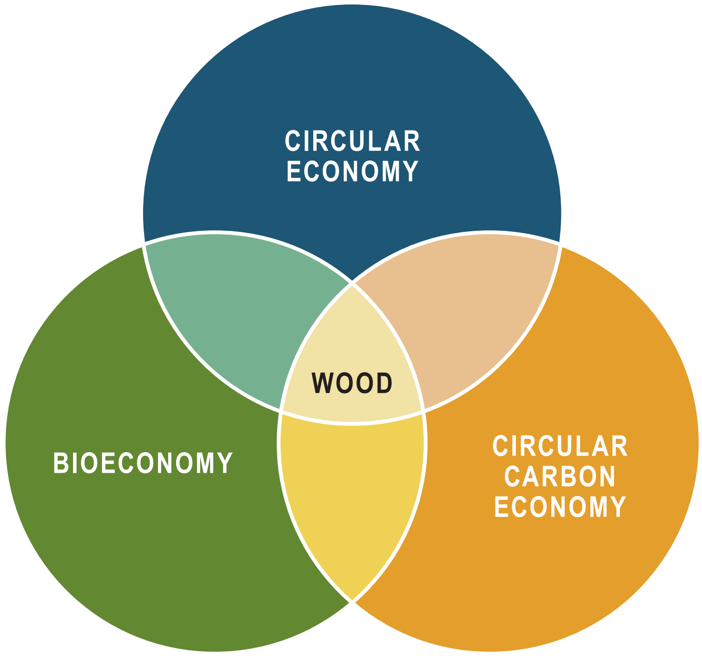


FIGURE 8.1: WOOD AT THE NEXUS OF SUSTAINABLE AND REGENERATIVE ECONOMIES

of a product or material. It has identified wood as fitting centrally within a framework that also considers a bioeconomy (renewable biological materials) and a circular *carbon* economy.

CORRIM notes that wood as a building material is unique because it "can be designed to be cycled through both technical and biological cycles" and also because "circularity is further extended from the waste stream through the uptake of greenhouse gases during new forest growth."

Quantifying Carbon in Wood Structures

Recycled material and Volatile Organic Carbon (VOC) content data is now commonly provided by materials manufacturers. Disclosing embodied carbon values likewise will soon be expected, with the growing understanding in the building industry that this information is critical to meeting global atmospheric carbon reduction goals. In the meantime, LCA tools approximate the embodied carbon and carbon emissions of wood products. Because sourcing techniques vary widely, most LCA tools use aggregate assumptions that may or may not accurately reflect any one specific wood product. See Chapter 5 for more details on using LCA tools for wood structures.

8.2 MARKET DEVELOPMENT: US MASS TIMBER PROJECTS

The COVID-19 pandemic defined 2020 as an economically turbulent year worldwide. The economy-sensitive building industry indicators are not surprising: overall, US architectural billings decreased and construction unemployment was

CONSTRUCTION BEGAN IN AUGUST, 2020

Photo Source: New Land Enterprises. Photo Credit: C.D. Smith

TALLEST MASS TIMBER BUILDING IN THE WORLD

What drives a developer to decide to use mass timber for a tall building? New Land Enterprises cites superior aesthetics, differentiation, and biophilia as their top incentives for choosing CLT and glulam for the structure of the new Ascent apartments in Milwaukee, WI, which broke ground in August 2020. The project will leap above the previous North American tall timber ceiling by 7 stories, and stretch over the tallest European projects by several meters as well. The LEED-accredited building boasts a PEFC-certified wood timber package from KLH and Wiehag, due to arrive on site in May 2021.

The $125MM project consists of 259 luxury apartment units in an exposed wood structure over a 6-story concrete parking podium. New Land is already finding that the decision to use wood is proving out successfully on the market, notes Managing Director Tim Gokhman, "[the team] opened pre-leasing a few months ago and was met with a wave of inquiries. The firm has already secured a number of reservations, including 3 penthouses."

Because exposing the wood structure was important to the prospective tenants the team was targeting, they chose a performance-based path to code compliance. Early collaboration with, and the forward-thinking nature of the Milwaukee code officials and fire marshall was key, notes Jason Korb, of Korb + Associates, the architect for the project. The team considered using the new provisions in the 2021 IBC, but ultimately chose the 2015 IBC as a familiar path forward everyone could be comfortable with. The final design allows for 50 percent exposed columns, beams, and slabs, which are expressed preferentially in the apartment living and shared amenity spaces. During the fire resilience investigations, the team was delighted to find that the structure performed better in the tests, with a char rate of 1.29"-1.31" per hour, than the prescriptive code burn rate of 1.5" per hour.

ASCENT IS 19 STORIES OF TIMBER OVER A 6-STORY CONCRETE PODIUM

Photo Source: New Land Enterprises. Image Credit: Korb + Associates

25TH FLOOR SUNSET LOUNGE

Photo Source: New Land Enterprises. Image Credit: Korb + Associates

ASCENT

LOCATION: MILWAUKEE, WISCONSIN

COMPLETION DATE: SUMMER 2022

OWNER/DEVELOPER: NEW LAND ENTERPRISES AND WIECHMANN ENTERPRISES

ARCHITECT: KORB + ASSOCIATES

STRUCTURAL ENGINEER: THORNTON TOMASETTI

FIRE SAFETY & CODE: ARUP

GENERAL CONTRACTOR: C.D. SMITH, CATALYST CONSTRUCTION

MASS TIMBER CONTRACTOR: SWINERTON MASS TIMBER

MASS TIMBER MANUFACTURERS: KLH (CLT) AND WIEHAG (GLULAM)

Because concrete construction is so inexpensive in Milwaukee, it was critical for early cost comparisons to realistically quantify all the possible savings that a light, modular structure could afford. Swinerton Mass Timber was engaged early in a design-assist role. They determined a schedule savings of approximately 4 months using mass timber, of which 2 months was on foundations alone. Additionally, investing in more up-front design work allowed for a very high level of precision in the timber fabrication; all penetrations were pre-drilled in the factory. The development team was attracted to the concept of "de-risking" construction by focusing on off-site fabrication. With shorter construction durations and fewer people on site, the project is less susceptible to labor shortages and human error. "We think mass timber [is] the construction material of the future," says Gokhman.

high.[4] Globally, nearly all building market sectors experienced a loss in activity, with the exception of data centers, healthcare, and infrastructure. The market effect of the pandemic on the building industry is expected to be more apparent in 2021 because of its relatively low impact on in-progress construction activities last year, but a reduction in planned projects overall. Governmental stimulus activities may help buffer this delayed impact.[5]

Despite the uncertainties, the number of timber buildings in design and construction continued to grow in 2020, particularly in the multifamily sector. The following data was provided by WoodWorks, which offers free one-on-one project assistance related to nonresidential and multifamily wood buildings. Technical experts offer support from design through construction, on issues ranging from allowable heights and areas for different construction types to structural design, lateral systems and fire- or acoustical-rated assemblies. WoodWorks has provided input on most of the mass timber structures designed and/or built in North America in recent years. The organization also tracks details related to mass timber projects.

Similar data for Canadian projects was not available at the time of publication.

The following figures illustrate the development of the mass timber industry in the United States and provide insights on the popularity of primary materials, the regional popularity of mass timber, occupancy types, building sizes, and the total square footage and number of projects constructed from 2013 through 2020. **Figure 8.2** illustrates the rapid growth of mass timber building projects, broken out by mass timber type. On a project count basis, most of the growth has been in the use of CLT.

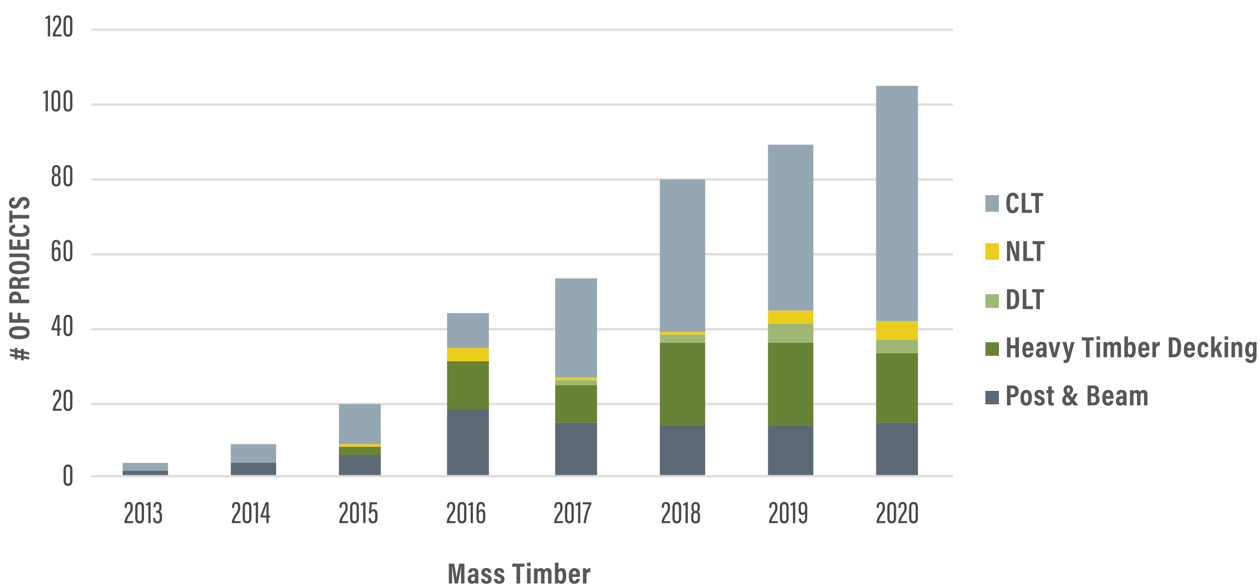


FIGURE 8.2: UNITED STATES PROJECTS BY PRIMARY MASS TIMBER MATERIAL

4 North America Quarterly Construction Cost Report, Fourth Quarter 2020, Rider Levett Bucknall
5 COVID-19 Global Sector Report, Issue 7, Rider Levett Bucknall

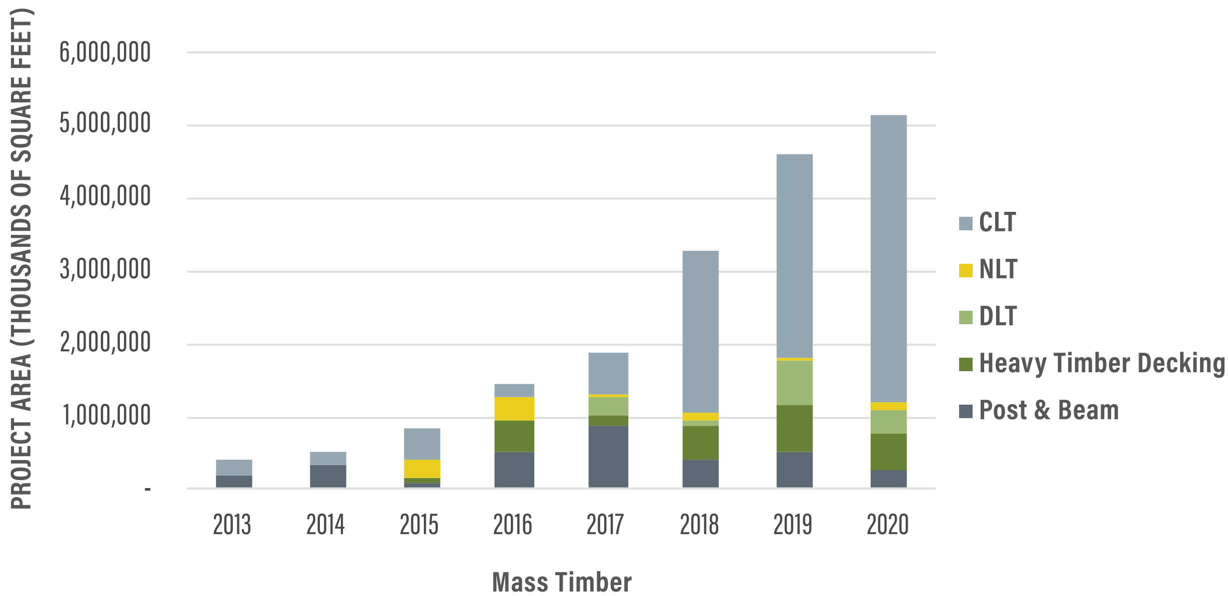


FIGURE 8.3: UNITED STATES BUILDING SQUARE FOOTAGE BY PRIMARY MASS TIMBER MATERIAL

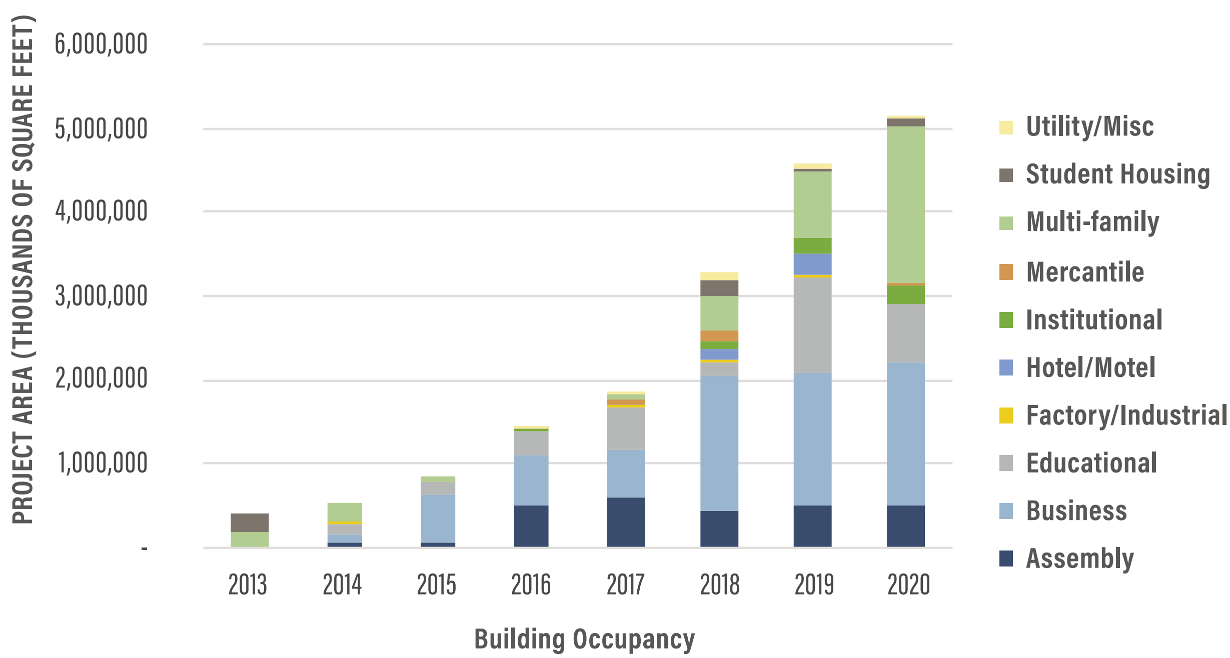


FIGURE 8.4: UNITED STATES MASS TIMBER BUILDING SQUARE FOOTAGE BY OCCUPANCY

Figure 8.3 shows the same information, but rather than reporting the number of buildings, this report is based on total constructed square footage. In 2020, mass timber projects totaled 5.1 million square feet. Combining data from these two figures reveals the average project in 2020 was over 48,000 square feet. CLT accounts for 77 percent of the square footage, but only about 60 percent of the building projects, indicating that buildings using CLT tended to be larger.

Figure 8.4 illustrates the mix of mass timber building occupancies in the United States as the total constructed square footage each year (by construction start date) for each use type. While business occupancies are still a significant portion of the market at 32 percent, that sector was eclipsed this year by multifamily areas, nearly doubling from 2019, and now representing over 36 percent of the year's total square footage. Educational and assembly uses follow as the next largest sectors, at 14 percent and 10 percent respectively.

Finally, **Table 8.1** shows the number of mass timber projects in the United States, by state. The number of projects that are either under construction or completed nearly doubled from last year, with a 186% percent increase in total building stock in the US. The count of proposed projects continued to grow as well, despite pandemic-related market hesitation, indicating that growth of the mass timber market will continue for the foreseeable future.

The West Coast is leading the country, with California, Washington, and Oregon comprising 36 percent of built projects and over 30 percent of to-

TABLE 8.1: US MASS TIMBER PROJECTS BY STATE ►

STATE	CONSTRUCTION STARTED/BUILT	IN DESIGN	TOTAL
AK	0	2	2
AL	6	14	20
AR	6	10	16
AZ	1	2	3
CA	57	102	159
CO	18	19	37
CT	6	6	12
DC	5	6	11
DE	1	1	2
FL	19	34	53
GA	9	21	30
HI	2	1	3
IA	3	6	9
ID	5	5	10
IL	11	16	27
IN	3	0	3
KS	2	2	4
KY	3	0	3
LA	1	2	3
MA	22	31	53
MD	3	5	8
ME	3	13	16
MI	2	9	11
MN	9	4	13
MO	8	11	19
MS	1	3	4
MT	8	11	19
NC	22	30	52
ND	0	1	1
NE	3	5	8
NH	1	3	4
NJ	1	8	9
NM	1	1	2
NV		1	1
NY	11	29	40
OH	6	9	15
OK	2	2	4
OR	50	19	69
PA	5	6	11
RI	2	2	4
SC	15	10	25
SD	1	1	2
TN	6	3	9
TX	27	42	69
UT	5	7	12
VA	7	7	14
VT	2	9	11
WA	59	48	107
WI	18	16	34
WV	2	0	2
WY	2	0	2
	462	595	1057

FIGURE 8.5

Source: Microsoft, Holmes structures. Photo Credit: Blake Marvin Photography

tal US projects. Notably, these are the states that have adopted the new IBC tall wood code provisions. Texas, Massachusetts, North Carolina, and Florida are also showing significant uptake in both completed and proposed projects, implying jurisdictional awareness of mass timber benefits in those regions. In 2020, all states for the first time have at least one mass timber project either completed or in design.

8.3 RATIONALE AND MOTIVATION

It is important to understand an owner's rationale and motivation for selecting mass timber as a building technology. In a 2014 survey[6] of tall wood building owners worldwide, the 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 investment and the need to deliver a building within the allotted time frame, all while ensuring the safety of construction workers and building occupants. As expertise grows in the Architecture, Engineering, and Construction (AEC) community and more mass timber projects go to market, established successes are helping allay the perceived risks.

8.3.1 BUILDING VALUE

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. However, mass timber buildings have been shown to perform well in terms of lease-up rates, tenant retention, sales, and market premiums. It is very likely that these buildings perform well because of the topics discussed in Chapter 7, the biophilic and human health benefits of being near natural materials.

Buildings of the Future

Environmental and carbon sequestration credentials will be attractive to a growing market of environmentally conscious tenants and buyers, particularly in the home and corporate markets. Additionally, these buildings may have a place in the carbon markets discussed in the opening section of this chapter.

Lease-up Rates and Premiums

Because of the increased demand for biophilic buildings, as stated above, the leasing period for exposed mass timber buildings can be lower than for a typical concrete or steel building with traditional finishes. Securing tenants early allows

6 Survey of International Tall Wood Buildings, 2014. Perkins + Will

FIGURE 8.6: RADIATOR BUILDING
Photo Credit: Andrew Pogue Photography

the building to more quickly reach stabilization, when the building is at full occupancy and generating regular income. After stabilization, the loan payment (including the interest) is covered by the income, allowing a building owner and/or investor to begin recouping their investment. 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 ROI.

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 due to the strength and spanning capacity of the panels and the beauty of exposing the structural deck. Factors like these contribute to higher lease rates for little to no added construction cost, translating to a higher sale price for the building long-term.

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 Canyons, a 6-story apartment building completed in late 2020 in Portland, Oregon, compared a CLT structure to light framing and painted drywall. The team discovered that the payback period for the premium structure was just over 3 years, and the project proceeded with the mass timber option. Ensuring premium market differentiation with a short payback period justified the relatively small capital cost increase.

Tenant retention

A multiowner mass timber development completed in 2014 in Portland, Oregon, consists of three buildings on one block that share an internal courtyard. The buildings, called One North and The Radiator, added 150,000 square feet of Class A office and ground floor retail in a primarily residential area. The exposed Douglas fir glulam and tounge-and-groove decking appealed to several key anchor tenants who signed leases before groundbreaking. Even with unprecedented 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. Since occupancy, only one office space has been turned over, with a negligible vacancy period.

End-of-Life Value

A building that consists of high-quality modular components that can be easily re-appropriated for new uses will have an inherently higher value at the end of its life than a building slated entirely to go to the landfill at demolition. Design for disassembly is

FIGURE 8.7: ONE NORTH DEVELOPMENT
Source: Kaiser + Path

a growing area of understanding for designers and builders, one that a building owner may be inclined to pursue as a point of interest for future buyers.

Though it is far too early to have data on deconstruction advantages of the recent wave of mass timber construction, reuse potential is likely to be a uniquely valuable asset as these buildings age. Most other primary structural systems are difficult and costly to salvage, and often total demolition is the only viable solution from a cost standpoint. Currently, when salvage is possible, reuse is not usually used as a complete element but rather as recycled material within newly formed components. But, similar to large steel members, salvaged and reused mass timber elements could very well have viable market use with much less reconfiguration.

8.3.2 INCENTIVES

Incentives for sustainable and low-carbon buildings vary by jurisdiction and project type. Choosing mass timber construction may have associated financing or zoning incentives (such as increased Floor Area Ratio [FAR]) for reduced embodied carbon or innovative technologies.

8.3.3 MAXIMIZE ALLOWABLE BUILDING AREA

Mass timber structures create opportunities within established zoning constraints, as well. A timber building on average weighs only 20 percent of a steel or concrete structure. On sites with challenging soil conditions and bearing pressure limitations, a lighter building could be built larger, or taller, than a heavier building. This can be particularly true in high-seismic-activity regions. In areas where foundations to support a heavier building are prohibitively expensive, a lighter building may be the difference needed to make a project viable.

Another opportunity for overall building area increases is added floors because of reduced floor-to-floor heights. Mass timber floor sections can be designed more thinly than other options, and they have inherent fire resistance, requiring no added fireproofing layers at certain building heights.

8.3.4 TALL TIMBER AND COST-EFFECTIVENESS

Because light framing is competitive for many low-rise buildings, and mass timber is consistently cited as competitive with concrete under 20 stories, a so-called “sweet spot” has emerged for mass timber somewhere between 4 and 18 stories, depending on the market in question. With increasing urban density, the largest market growth for new buildings in the coming years is projected to be in the mid-rise range, between about 3 and 8 stories. Mass timber is poised to be a competitive option for a majority of foreseeable increases in building stock.

FIGURE 8.8: SIDEYARD

Source: Project: Sideyard, Photo Credit: Skylab Architecture

While mid-rise construction will continue to be the most common new building stock for all construction types, buildings over 20 stories are impactful from a both a market and an environmental resource standpoint. Using mass timber for tall buildings has increasing potential. Currently, the tallest mass timber buildings in the world use CLT and glulam as the primary structural materials and concrete for cores and/or additional mass:

- 18 stories, 174 feet (53 meters) - Brock Commons, University of British Columbia, Vancouver, BC
- 24 stories, 276 feet (84 meters) - HoHo Vienna, Woschitz Group, Vienna, Austria
- 18 stories, 279 feet (85 meters) - Mjøstårnet, AB Invest, Brumunddal, Norway
- 25 stories, 284 feet (87 meters) - Ascent, New Land Enterprises, Milwaukee, WI

Additionally, a growing number of studies and proposals are validating the effectiveness of timber structures up to 40 stories.

Allowable timber building heights will be increased in the 2021 IBC to 9, 12, and 18 stories, with varying amounts of exposed wood allowed (see Chapter 5 for more information). However, building codes evolve more slowly than research demonstrating the structural and fire safety of mass timber buildings. Well-designed taller wood buildings are viable and safe, and depending on the jurisdiction having authority, may be permissible through an alternate means and methods, performance-based permitting approach.

The Council on Tall Buildings and Urban Habitat (CTBUH) has ongoing development of resources for project teams pursuing tall mass timber buildings, supported by grant funding from the US Forest Service. The group worked to establish the inclusion of timber projects within the CTBUH Height Criteria and created *Timber Rising*, a publication combining the best research and resources specific to tall timber projects.

8.3.5 CONSTRUCTION RISK REDUCTION

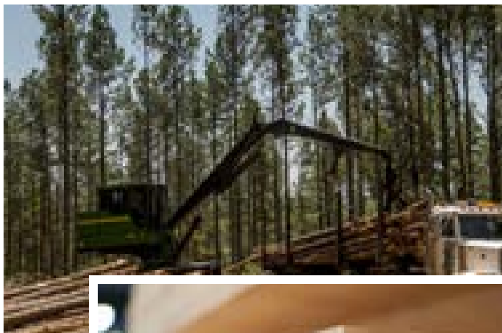
The modularity, precision, and beauty of large engineered timber components has refreshed conversations around the benefits of off-site construction for other building components. When a modular structural system like CLT is assembled in half the time of a traditional structure with lower risk and a higher level of craftsmanship, designers and builders start to look for ways to shift the fabrication of other building components into more controlled environments.

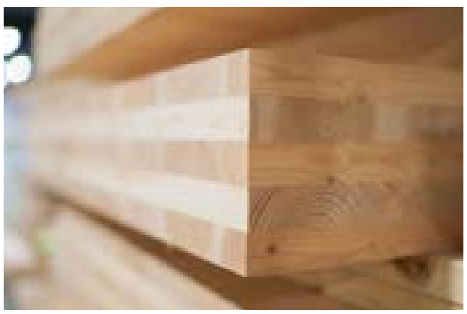
Site-built construction is often challenged by weather, traffic, noise ordinances, labor shortages, and any number of physical site constraints. Customized prefabrication can alleviate these issues to varying degrees depending on the project and the extent to which the design and build team can plan and coordinate off-site construction. The resulting building can have a higher level of precision over site-built structures because of the increased quality control afforded by climate, controlled interior factory environments.

Chapters 5 and 6 go into depth on the advantages of off-site fabrication and the design processes and collaboration necessary to achieve success. In short, taking more time upfront in the design phase pays off in construction-phase speed and predictability. Precision of custom components and a highly organized, modular structural package contribute to expedited construction with fewer field modifications, change orders, and delays.

Considering that a building's superstructure is usually about 20 percent to 25 percent of the total building construction cost, investing in a highly predictable assembled structure has significant risk reduction potential. Mechanical, Electrical, Plumbing, and Fire (MEPF) systems account for another 30 percent to 35 percent of building cost, or for core-and-shell projects, about 15 percent. These systems may or may not also be fabricated off-site for schedule savings. If well coordinated with the structure in advance, the associated change risk of these systems also goes down. Change cost contingencies could potentially be reduced by up to 50 percent using a highly coordinated approach.

Other associated benefits with schedule reductions include fewer potential weather delays and lower costs associated with traffic disturbances.



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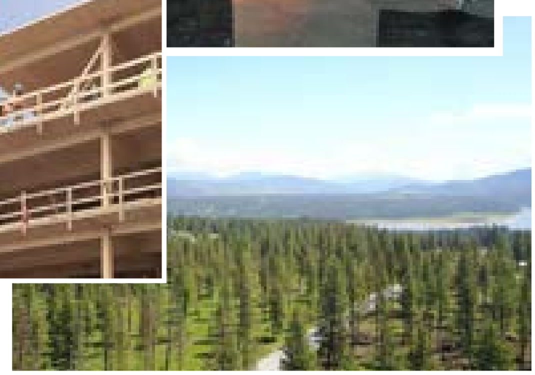

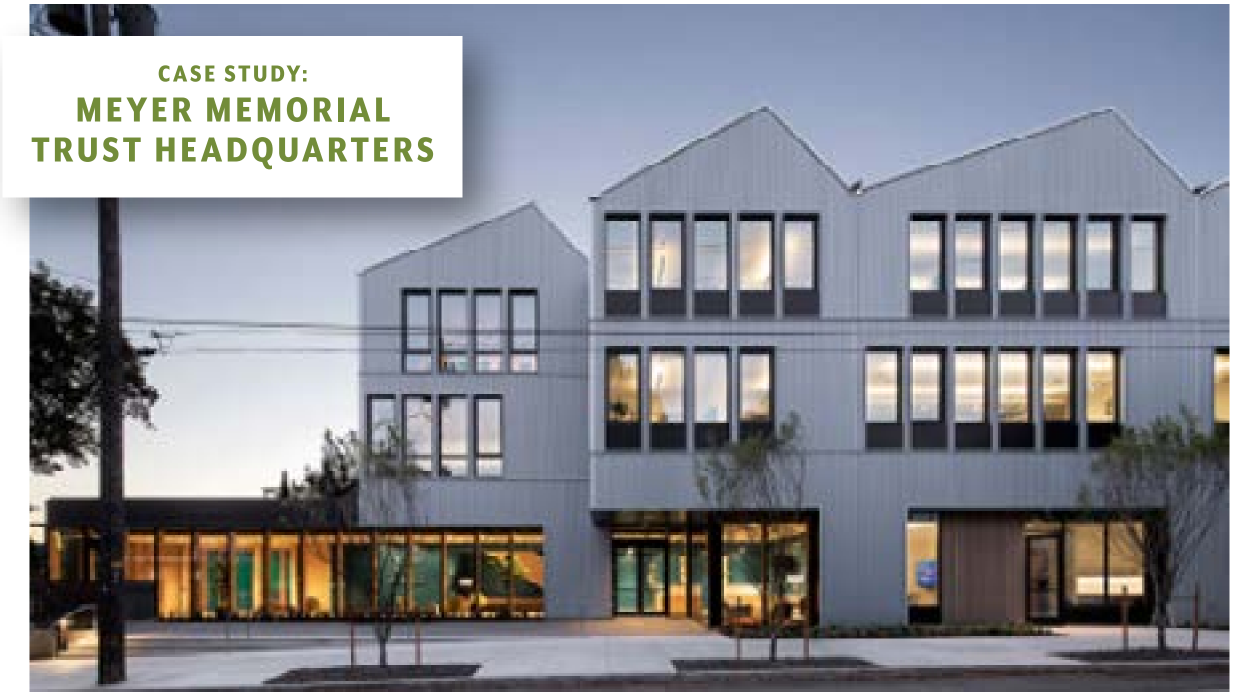

BUILDING EXTERIOR AND PUBLIC ENTRY
Image Credit: Jeremy Bitterman courtesy of Meyer Memorial Trust

WOOD PROCUREMENT FOR COMMUNITY, EQUITY, AND CONSERVATION

The construction of Meyer's headquarters was an opportunity to use intentional wood procurement as a vehicle to advance the foundation's mission. The project identified forest management attributes and sourcing criteria that optimized economic, social, and environmental outcomes. Additionally, Meyer has committed to supporting rural forestry-based jobs, rural communities, and innovation in Oregon by constructing parts of the new building with wood. Their approach focuses on achieving the greatest positive impact. This orientation intentionally avoids defining what is not sustainably sourced wood. The project team believes all forestland and jobs associated with wood products provide value related to one or more of their stated project goals.

SOURCING CRITERIA

The sourcing criteria followed three scenarios:

Scenario 1 included wood products from supply chains when the fabricator and source forest are known. The criteria established greater preference for buying wood products fabricated and sourced locally from rural communities, Tribal enterprises, and historically disadvantaged businesses, and ensuring ecological forest management.

Scenario 2 included wood products from supply chains where the source forest is unknown. The criteria established greater preference for Forest Stewardship Council (FSC) certified wood, wood connected to ecological forest restoration, recycled wood, and urban salvage trees.

IMAGE SOURCE: LEVER ARCHITECTURE

PROJECT LEADERSHIP (LEFT-TO-RIGHT): Michelle J. Depass, President and CEO of Meyer; Toya Fick, Chair of Meyer's Board of Trustees; Anyeley Hallova, Partner at Project; Chandra Robinson, Project Director at Lever; and Marurice Rahaming, Principal in Charge at O'Neill/Walsh Community Builders.

Photo Credit: Fred Joe

Scenario 3 is for when fulfillment of Scenarios 1 or 2 is not possible, or the premium was too great. The project prioritized wood products from Oregon first, the Pacific Northwest second, and North America as a third choice. Sourcing options that met criteria in Scenarios 1 or 2 were to be purchased any time options were available for less than an 8 percent premium. Materials with a 9 percent to 25 percent premium were considered pending funding availability and value.

MEYER MEMORIAL TRUST HEADQUARTERS

LOCATION: PORTLAND, OREGON

COMPLETION DATE: OCTOBER 2020

OWNER: MEYER MEMORIAL TRUST

DEVELOPER: PROJECT

ARCHITECT: LEVER ARCHITECTURE

WOOD SOURCING ADVISOR: SUSTAINABLE NORTHWEST

STRUCTURAL ENGINEER: KPFF

CONTRACTOR: O'NEILL/WALSH COMMUNITY BUILDERS

MASS TIMBER MANUFACTURER: FRERES LUMBER

PROJECT SUCESS	
Wood from PNW forests	12 of 12
Wood from Oregon forests	7 of 12
Wood products from PNW companies	12 of 12
Wood products from Oregon companies	10 of 12
Wood products from minority owned companies	6 of 12
Wood products from small businesses	7 of 12
Wood that supports ecological forest management	9 of 12
Wood products traceable back to its forest of origin	3 of 12

WOOD PRODUCT	SUSTAINABLE WOOD AVAILABILITY	SUSTAINABLE WOOD FROM OREGON AVAILABILITY	ANTICIPATED PRODUCT PREMIUMS
Finished Carpentry			
Acoustic Wood Ceiling	Available	Yes	Likely Increase
Cabinetry/Casework	Available	Yes	Price Neutral
Flooring	Available	Yes	Price Neutral
Trim	Available	Yes	Increase
Siding	Available	Yes	Price Neutral
Doors	Available	Yes	Increase
Beams	Available	Yes	Increase
Lumber and Plywood	Available	Yes	Likely Increase
Mass Plywood	Not Possible	No	N/A
I-Joist	Possible	Variable	Increase
Trusses	Possible	Variable	Increase
Decking	Available	Yes	Price Neutral

Available: supply chains with multiple options or a provider that sells FSC product as a major part of their business

Available: supply chains with at least one regular provider of FSC certified materials

Possible: supply chains where the project may have to be creative to deliver a conformant product

Not Possible: there may not be a conformant product available

CHOICES

An overarching choice that was made early on with ramifications throughout the project was the choice to be okay saying no to options that were possible but not practical. The project was interested in exploring where money could be spent to get the greatest return (mission-aligned value) for the investment. This approach meant each wood product received "green, yellow, or red light" status based on availability, cost, and conformance with wood sourcing criteria. This approach allowed the project team to capture significant value with modest expense. This approach also meant deciding to say no to two conformant structural wood options with unreasonable premiums.

The design choice to use MPPs was pivotal. Freres Lumber is the only company in Oregon currently making MPP, with no fully conformant wood sourcing option available to the team. MPP was chosen for its local sourcing, community investment goals, and its innovation in wood material production.

OUTCOME AND LESSONS LEARNED

The project team set wood sourcing goals early in the design phase and hired Sustainable Northwest to inform and support project partners. Setting goals independent of building certification standards enabled the team to design procurement to deliver unique outcomes and maintain flexibility. It is critical to build support and experience into the project team to support the creation of wood sourcing goals, help ensure all options are available to the team, and to problem solve and avoid unnecessary costs. The 3 percent premium paid to ensure the project's wood product procurement was minimal ($24,650 of a $754,000 total wood package), and achieved Meyer's community, equity, and conservation goals.

Story Credit: Sustainable Northwest

FIGURE 8.9: CLT ROCKING SHEAR WALL WITH STEEL FUSES FOR DISSIPATING SEISMIC FORCES. BROKEN FUSES ARE EASILY REPLACED.

Source: Project: Oregon State University Peavy Hall Replacement. Photo Credit: Andersen Construction

Carrying Costs

The construction cost savings of a modular approach, such as CLT, will be multiplied if financing impacts are considered in addition to construction overhead and other capital savings. 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. Reducing carrying costs by even a month or two translates to tangible savings that should be included in comparative cost models.

8.3.6 RESILIENCY

Resiliency is a term used to describe a building's ability to recover from a disaster event like an earthquake, fire, hurricane, or flood. Mass timber has several resiliency advantages over steel, concrete, and light-framed structures.

Mass timber is both strong and flexible, and, therefore, 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, like radar or core drilling. Being able to quickly verify the safety of a building after an event hastens reoccupancy.

Mass timber components that show signs of compromise are more easily replaced. Rather than condemning an entire building, areas requiring repair can be isolated and retrofit.

An innovative earthquake-resisting "rocking" shear wall design has been tested and installed in Peavy Hall at Oregon State University. The design allows the wall to shift and return to place during a seismic event, with the added flexibility of steel tension rods that run the height of the wall and energy dissipating steel "fuses" connecting panels together. The easily replaceable fuses are designed to break under high force, rather than allowing destructive forces to transfer into the building structure. The fuses are located so as to be easily accessed, and they are low-cost to replace if necessary. Seismic building damage is then confined to these easily replaceable components.

FIGURE 8.10: ROCKING SHEAR WALL FUSE
Peavy Hall. Photo credit Hannah O'Leary

8.3.7 MAINTENANCE AND BUILDING MANAGEMENT

Operational ease and savings can be explicitly planned for more easily when executing a modular mass timber building because of a more collaborative design phase and a construction phase with very few changes. While timber has material-specific upkeep, such as coatings, the natural beauty of wood offers some surprising benefits.

Utilities

Exposing 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 can and should 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 within a building with ingenuity and precision, and 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 as protection from Ultraviolet (UV) light and weather, as an aesthetic choice, or to be more easily cleaned. Coatings on any surface require some upkeep and reapplication. Maintenance timelines vary by product, application method, and exposure; the better protected wood is from weather exposure, the longer the coatings will last.

Wood naturally changes color over time, 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 beautiful, varied texture on a building's facade. In the US, it is more common to seek a controlled, even look. The preference is cultural, as wood that is given sufficient protection through good architectural detailing will take a long time to degrade, even without protective coatings.

Because wood is a porous surface, many building owners are concerned about occupant damage such as staining, impact damage, or vandalism. Owners of wood buildings have reported higher levels of occupant care with wood surfaces and dramatically reduced occurrences of vandalism. (See Chapter 7's section on occupant behavior for more.) Staining can often be easily sanded away. Depending on the species, wood surfaces may be more or less susceptible to visible damage from minor impacts. Some variation and patina will happen over time, and again it is more a matter of preference whether this is considered negative or positive. Materials that reflect the passing of time may be preferred.

8.4 EXECUTING AN INNOVATIVE PROJECT

While mass timber uptake in North America continues at an exceptional rate, for the vast majority of markets on the continent, it is still an emerging technology. Finding an experienced team is one effective way to mitigate risks associated with innovative approaches, but strong goals and leadership on the ownership side are just as critical. This section identifies key issues that building owners/developers face when utilizing mass timber in the construction of a building.

8.4.1 CHOOSING A TEAM

The British Columbia Construction Association (BCCA) sponsored a study of innovative technologies and strategies in building construction procurement.[7] Qualities of successful projects include:

- A highly effective and collaborative project team that puts the interests of the project first.
- Consider multi-project engagements of consultants and contractors to foster collaboration, learning, and team cohesion.
- Greater collaboration is more likely to lead to successful outcomes and high-level team performance.
- The procurement process should allow collaboration to start as early as possible in the project for creative ideas to blossom.
- The project team should be allowed input on when opportunities for research and development and tours and project documentation activities can best occur from the perspective of maintaining an efficient and safe site.
- Construction Management at Risk or Single Purpose Entity for Integrated Product Delivery contracts (such as Multi-Party Agreements) that encourage collaboration may be best suited for innovative projects that are not well defined in scope.
- Require evidence of qualification of individuals as part of the evaluation process. The names of key project team members (including important trade companies) need to be written into the contract documents to ensure their expertise is being applied to the project and not passed to others in their company.
- The owner should ensure 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 in the project process.
- Businesses of all sizes should be encouraged to participate because some small- to medium-size enterprises (SMEs) are the most innovative.
- Reduce barriers to participation by simplifying the procurement process as much as possible. For example, bidders could be admitted who may not have directly relevant project experience but may have transferable expertise with a similar project type… focusing on the quality of the references rather than quantity.

7 Procuring Innovation in Construction: A Review of Models, Processes, and Practices. British Columbia Construction Association. 2016.

In summary, highly collaborative, nimble teams who are eager to innovate and willing to problem solve are more likely to achieve success with new approaches.

8.4.2 DESIGN-PHASE-FORWARD PLANNING

Mass timber is a catalyst for unique design-phase-forward planning that can have significant impacts on construction schedules. An experienced team will plan for adequate coordination time before construction starts to reduce costly field labor and project overhead. Advantages to investing in early coordination include:

- Precision in locations of Mechanical, Electrical, and Plumbing (MEP) penetrations. This means fewer trade conflicts on-site, and the ability to fabricate components off-site for rapid sequencing.
- A custom mass timber package is predictable to install, and precise to a ⅛-inch tolerance. If fully coordinated, it should require no field modifications.
- Change orders associated with the structure and MEP trades are minimized by up-front coordination.

Understanding the schedule savings and reduced on-site risk is critical for producing an accurate cost model. According to Swinerton, “A large scale mass timber project can be up to 2% higher in direct costs, but a minimum of 20% lower in project overhead costs. The net result is cost-neutrality and higher value.”[8]

It is advisable to invest more time into the design phase to reduce construction time and increase construction predictability. This may have implications on how the project is financed, increasing up-front soft costs, but decreasing hard costs and interest payments in construction.

8.4.3 PROCUREMENT PROCESSES

Standard procurement processes can be a barrier to maximizing the cost benefits of mass timber.

A traditional Design-Bid-Build (DBB) procurement process in building construction is common and, as such, is preferred by many investors. For the purposes of this section, the issues are similar to a Construction Manager/General Contractor (CM/GC) process, typically:

(1) Design a building to a given program, budget, and the requirements of the local jurisdiction. (2) Request bids from building contractors who seek best value from a variety of installers and manufacturers. (3) 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 only be incorporated into early cost estimates accurately if an experienced team is consulting. It is possible to design a mass timber building with average assumptions about efficient fiber use, fire ratings, cost, and availability. However, this approach carries risks because possible delays and costs associated with redesign further along in

8 Erica Spiritos and Chris Evans, Swinerton Builders, Mass Timber Conference 2019 presentation: Mass Timber Construction Management: Economics & Risk Mitigation

the process, including design fees, permit revisions, constructability issues, and materials availability. The earlier a procurement and installation team is brought on board, the more refined and cost-effective the design and construction process will be.

One option within a traditional DBB contract model is to partner with a manufacturer during the design phase using a separate contract or a Letter of Intent (LOI) to select that manufacturer during bidding. This can be done as an agreement with the owner, or with the CM/GC. Advantages of this approach include design optimization, detailed pricing feedback during design, and early assurance of product delivery dates. Risks of this approach include lack of precedent, which could result in limited manufacturer availability during design for fabrication teams who are unaccustomed to design team integration. Also, 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, more inherently collaborative procurement model altogether to avoid these issues and support an integrated design process. For example, Design-Build, where the contractor and the design team are chosen and contracted together, or Integrated Project Delivery (IPD), where all parties are incentivized for project success, will naturally support early and efficient coordination. Having a design optimized early will help ensure fabrication timelines will be met if market demand is high. An experienced procurement team will be able to navigate these challenges.

8.4.4 INSURANCE

Insurance companies have little experience with mass timber buildings. According to a Perkins+Will study[9], mass timber has yet to be fully recognized by the insurance industry as comparable to a concrete-and-steel structure. Additionally, the insurance industry perceives all wood buildings similarly. So light-frame structures may be grouped with mass timber structures, despite markedly different performance with regard to fire, seismic, and water damage. Efforts are underway in the insurance industry to recognize mass timber as a unique structural building category, but those efforts need greater support.

8.4.5 COST UNCERTAINTY

The cost uncertainty associated with mass timber building projects today is attributable to a combination of factors stemming from limited experience all along the supply chain. As the industry evolves, there is growing evidence that, although the materials cost for a mass timber building may be higher than 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.

The marketplace for mass timber products is increasingly competitive as the number of manufacturers grow, both in North America and abroad. The learning curve to construct with timber is relatively easy to overcome, but inexperienced builders will have difficulty estimating the savings associated with using mass timber and with learning to be a part of an up-front planning process.

9 Mass Timber Influencers: Understanding Mass Timber Perceptions Among Key Industry Influencers. Perkins+Will. October, 2018.

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.

8.4.6 PUBLIC PERCEPTION OF MASS TIMBER

According to a 2015 public survey[10] by Perkins+Will, the general public perceives the greatest barriers to wider adoption of mass timber as:

- 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 are still often an obstacle building developers must address.

8.4.7 SOURCES OF RELIABLE INFORMATION

While WoodWorks and other organizations have provided extensive support to mass timber building projects, a lack of reliable information about mass timber is still cited as a barrier to wider adoption of this technology. Resources in the form of handbooks, standards, best practices, case studies, and more are growing exponentially with the expansion of the market.

10 Perkins+Will Research Journal. Tall Wood Survey. Volume 08.01 2016.


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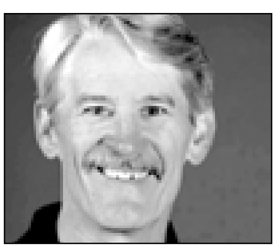

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Henkel