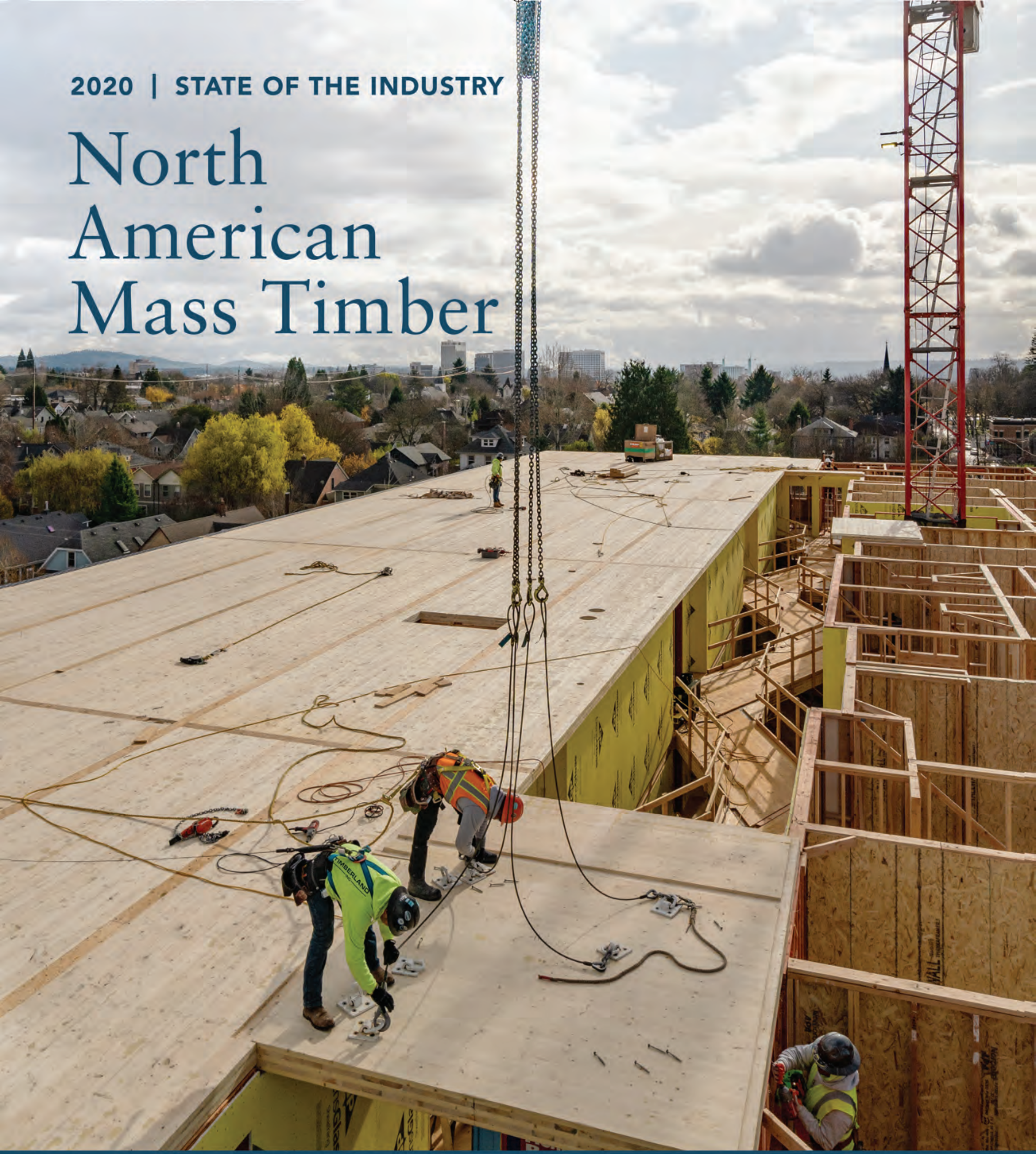
2020 | STATE OF THE INDUSTRY

North American Mass Timber



THE MARSHALL EFFECT What it is and why it matters

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DR JOHNSON WOOD INNOVATIONS

ELEMENT5 MASS TIMBER STRUCTURES

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

INTERNATIONAL BEAMS

Freres LUMBER CO., INC.

KALESNIKOFF TIMBER INSPIRES

NORDIC STRUCTURES

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SMARTLAM NORTH AMERICA

StructureCraft

STERLING

U.S. Endowment for Forestry and Communities

STRUCTURLAM Intelligence In Wood

WoodWorks™ WOOD PRODUCTS COUNCIL

VAAGEN TIMBERS

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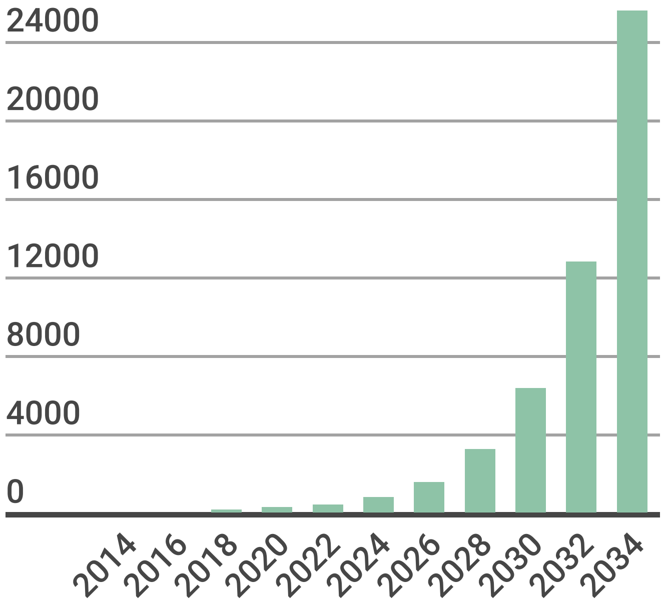
THE MARSHALL EFFECT

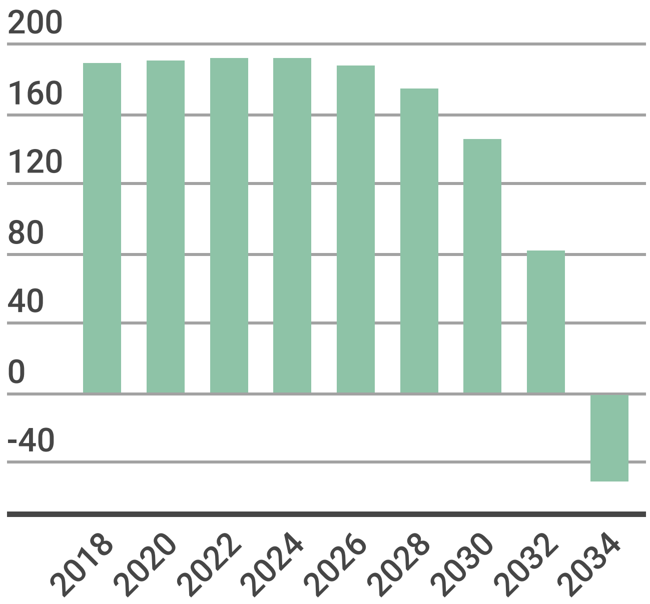
Globally, the number of new mass timber buildings will double every two years.

Data for North America

Mass Timber Buildings Constructed Per Year



Carbon Impact In Millions Of Tons Per Year



The result is that the North American building industry will store more carbon than it emits by the year 2034.

Steve Marshall recently retired after 42 years in the United States Forest Service.

Together with the many other dedicated forest stewards within the USFS, Steve worked to establish the Wood Innovations Program, generated carbon metrics and reporting protocols, and helped author the progressive Timber Innovation Act. The USFS continues as an integral partner in the further advancement of mass-timber products as an environmentally sound, financially feasible, and aesthetically superior way forward.

CHAPTER 1: INTRODUCTION

THE MARSHALL 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.

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

FIGURE 1.2 CLT PANEL[3]

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.

1.2.2.1 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.

2 Source: APA
3 Source: APA

FIGURE 1.3 NLT PANEL[4]

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.

1.2.2.2 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 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.

4 PhotoSource: StructureCraft

FIGURE 1.4 DLT PANEL[5]

1.2.2.3 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 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.

5 Source: StructureCraft

FIGURE 1.5 MASS PLYWOOD PANEL[6]

1.2.2.4 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 similar 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.

6 Source: Oregon Department of Forestry

FIGURE 1.6 GLULAM TIMBERS[7]

1.2.2.5 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.

1.2.2.6 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.

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

7 Source: APA

FIGURE 1.7 POST AND BEAM

1.2.2.7 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 1.8 HEAVY TIBER DECKING[8]

8 Source: Southern Wood Specialties

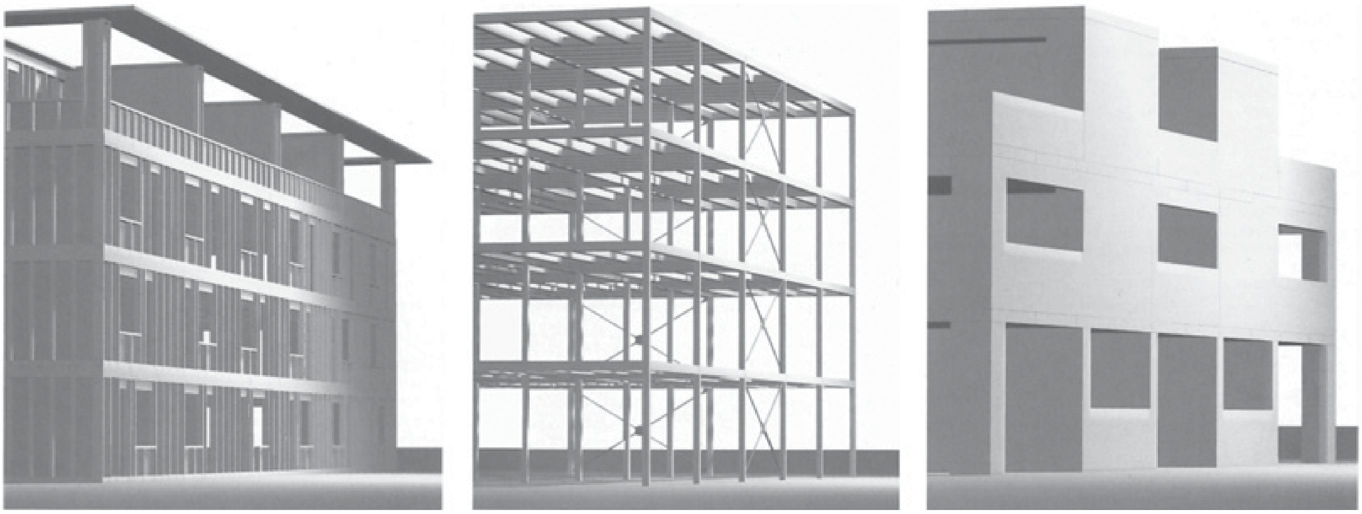


FIGURE 1.9 WOOD-BASE BUILDING CONSTRUCTION SYSTEMS[9]

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.

9 Image courtesy of Fast and Epp

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.

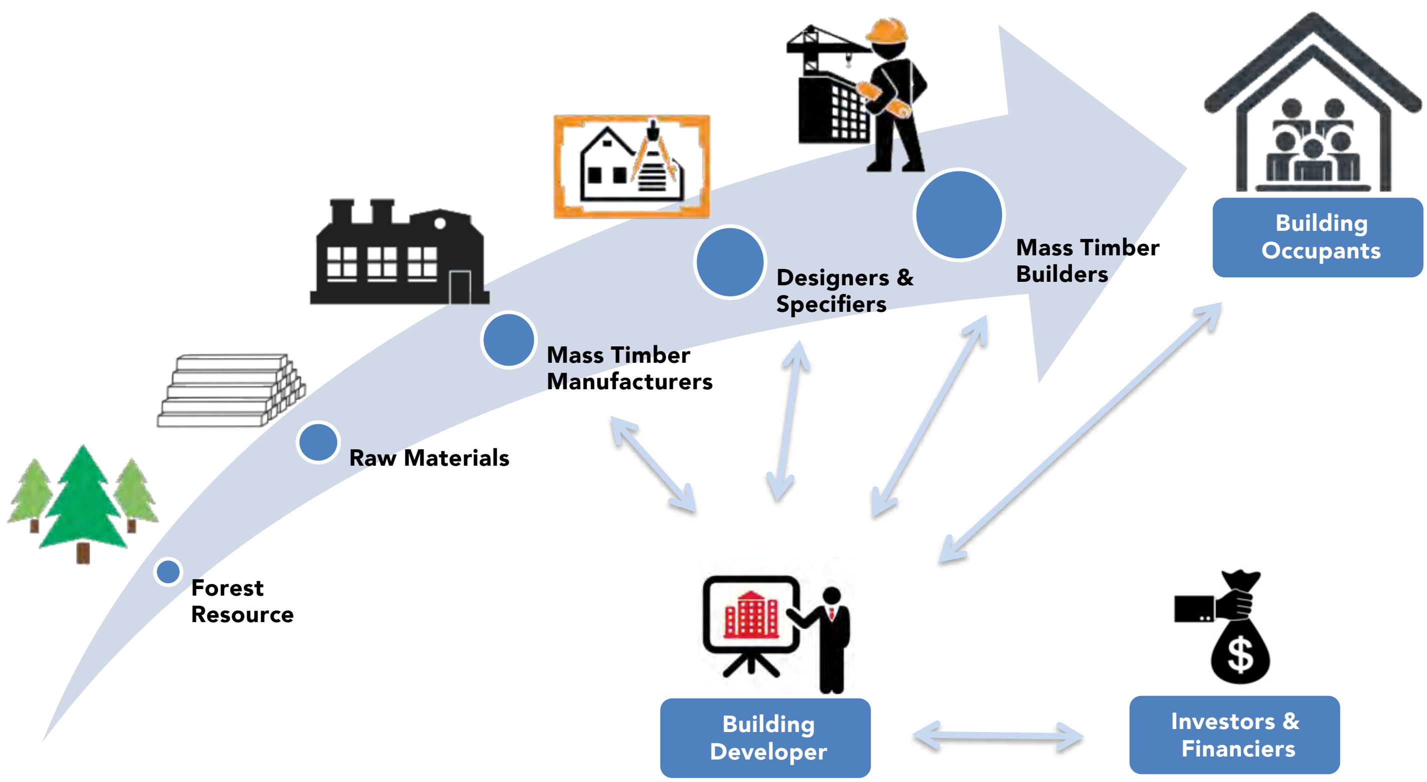


FIGURE 1.10 MASS TIMBER SUPPLY CHAIN

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

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 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.[10] 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.

10 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.

1.6 KEY REPORT TAKEAWAYS

This report covers a broad range of topics along the mass timber supply chain. Some of the key takeaways included are:

- Forests cover roughly one-third of the United States and Canada. That forestland acreage has been stable for more than 100 years.
- Over 100 million acres of U.S. forestland is reserved from timber harvest because it is set aside for other uses, including wilderness, parks, and recreation.
- Sustainable forest management practices provide more timber growth than harvest each year.
- In less than 18 hours, U.S. timberlands can regrow all the wood fiber consumed from all North American mass timber produced in 2019 (includes mass timber used for both construction and industrial matting).
- If the mass timber industry lumber demand reaches 3.25 billion board feet by 2030 as predicted by The Marshall Effect, U.S. timberlands can grow that volume of wood in about 130 hours.
- Wood as a construction material combines aesthetic beauty, superior strength, and light weight.
- Mass timber products perform well in fire, blast resistance, and ballistic situations.
- People enjoy wood environments for living and working, citing visual aesthetics, acoustics, and a feeling of warmth.
- Recent building code changes paved the way for continued expansion of CLT's use in large buildings.
- From 2016 to 2019, mass timber construction expanded rapidly in both number of projects and total square footage in the United States, with square footage quadrupling.
- In 2019, approximately 78 mass timber buildings were constructed in the United States, representing 4 million square feet of space.
- For mass timber panels such as CLT, NLT, and DLT, the primary raw material is dimension lumber, with #2 grade 2-by-6s used most frequently.
- Dimension lumber is widely available across North America. Current mass timber demand levels represent about 1 percent of 2019 North American lumber consumption.
- While lumber supplies are adequate, there are opportunities for MTP manufacturers and sawmills to work more closely to improve efficiencies in wood utilization.
- Lumber is the largest cost component in mass timber production, and lumber prices can be very volatile, creating challenges for mass timber manufacturers.
- North American MTP manufacturing capacity grew tenfold from 2010 to 2020, and continues to expand rapidly.
- In addition to MTP for buildings, there is a substantial and growing market for industrial matting used in environmental protection.
- To aid designers and builders in the mass timber supply chain, mass timber manufacturers offer a variety of services and related products, in addition to producing panels.
- Due in part to shorter construction times and lower labor requirements, mass timber can be cost competitive with traditional building methods and materials. Designing with wood's properties in mind is key to success.
- With just-in-time delivery of mass timber materials and panels designed for specific sequencing of placement in a structure, logistics planning and building materials storage and management are critical.

CHAPTER 2: FOREST RESOURCE

IMPACTS OF THE MARSHALL EFFECT ON THE FOREST RESOURCE:

- Every 1 million board feet of increased lumber demand will lead to adding 3,000 acres of new working forest land.
- By 2034, the 12.9 billion board feet of new lumber demand arising from mass timber will have led to the establishment of nearly 77 million acres of new forest land.
- As perspective, that would be an increase of about 4% of the current North American forest land area.
- It is estimated that, on average, each acre of working forest land can sequester a total of about 13 tons of carbon over a rotation, but only 50% of that amount is credited against carbon emissions since about half of a tree's merchantable volume is utilized as long-lived forest products.

2.1 FORESTED REGIONS OF UNITED STATES AND CANADA

North America is home to some of the most extensive and well-managed forests in the world, vast acreages widely valued as sources of clean air and water, wildlife habitat, recreation, and carbon storage. From these forests come the raw materials—logs and lumber—that form the first link in the mass timber value chain. As the use of mass timber in construction increases and cities are reimagined as carbon sinks, critical questions must be answered:

- Will North American forests be decimated by the increased demand?
- How will wildlife habitat and watersheds be protected as timber harvests increase?
- If deforestation is a concern, why even consider a new use of wood in construction?

In this chapter, we will address these questions and provide the broader context.

This section describes the amount of forestland, ownership patterns and key species of trees in various regions of the United States and Canada. Forestland is defined as an area of land at least 120 feet wide and 1 acre in size with at least 10 percent tree cover. Timberland is a subgroup of forestland capable of growing a minimum amount of wood (20 cubic feet per acre per year) and not reserved from timber harvest by law, regulation or agreement. Timberlands are a key category of forestland in the United States because they supply the raw materials for wood-based construction and other wood products. This section focuses on timberlands to address the question of how increased wood use for mass timber construction will affect the timber supply. First, however, contextual descriptions of all forestlands are provided to illustrate how much acreage is reserved from timber management to fulfill other values society has for forests, such as recreation, biological diversity, and the preservation of natural processes.

2.1.1 UNITED STATES

2.1.1.1 United States Forestland Area

The United States stretches across 2.261 billion acres of land area. According to the U.S. Forest Service's Forest Inventory and Analysis publication, U.S. Forest Facts and Historical Trends,[1] there were 766 million acres of forestland in the United States in 2012. Thus, about one-third of the United States is covered in forestland, an acreage that has remained relatively stable since the early 1900s. Of that total forestland, 106 million acres (14 percent) are reserved (wilderness, parks, etc.) or inventoried roadless areas where timber harvest is restricted. Another 172 million acres are considered low-productivity forestlands where managing for timber is not a priority. The remaining 489 million acres (64 percent) are classified as timberlands. **Table 2.1** shows the acreage of each type of forestland in the three major regions of the United States (**Figure 2.1**).

1 2012 is the most recent published version of US Forest Facts and Historical Trends and a companion document titled Forest Resources of the United States, 2012: A technical document supporting the Forest Service Update of the 2010 RPA Assessment.

FORESTLAND CLASSIFICATION	REGION			TOTAL UNITED STATES
	North	South	West	
Timberland	167	210	112	489
Reserved	7	4	95	106
Other	2	31	139	172
Forestland Total	176	245	346	766

TABLE 2.1 UNITED STATES FORESTLAND AREA BY CLASSIFICATION TYPE AND REGION (MILLIONS OF ACRES)*

** The Western timberland and reserved lands were adjusted to reflect the 32 million acres of inventoried roadless areas that are reserved from regulated harvest.*

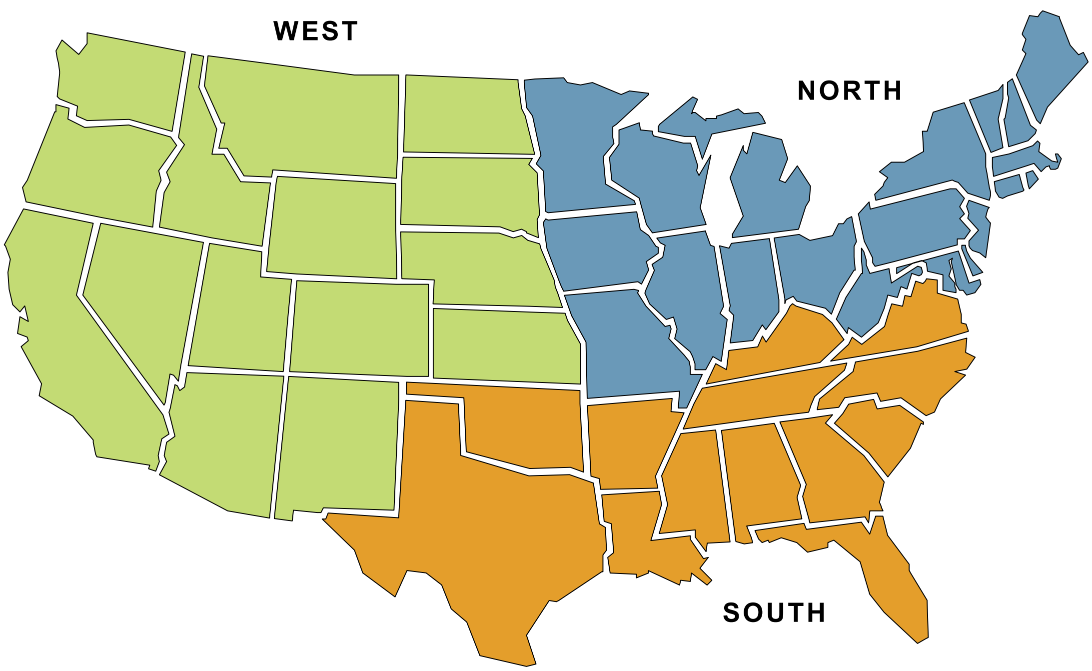


FIGURE 2.1 MAP OF UNITED STATES FOREST REGIONS

NOTE: Not shown in the table or included in the area descriptions are an additional 53 million acres of woodland, acreage that supports trees with an average stature limited to less than 16.4 feet in height at maturity. The trees in woodlands have little commercial value. The woodland area is about evenly split between the West and the South. Thus, the total wooded land area in the United States is about 819 million acres.

The Forest Inventory and Analysis (the basis for this data) was established in the 1930s. Under the program, permanent plots were established across all forestland in the country. Each plot is measured every 10 years and the data resulting from the measurements are used to monitor trends and changes in growth, mortality, species composition, soil, lichens, insects and diseases, and more in the nation's forests.

2.1.1.2 United States Forestland Ownership

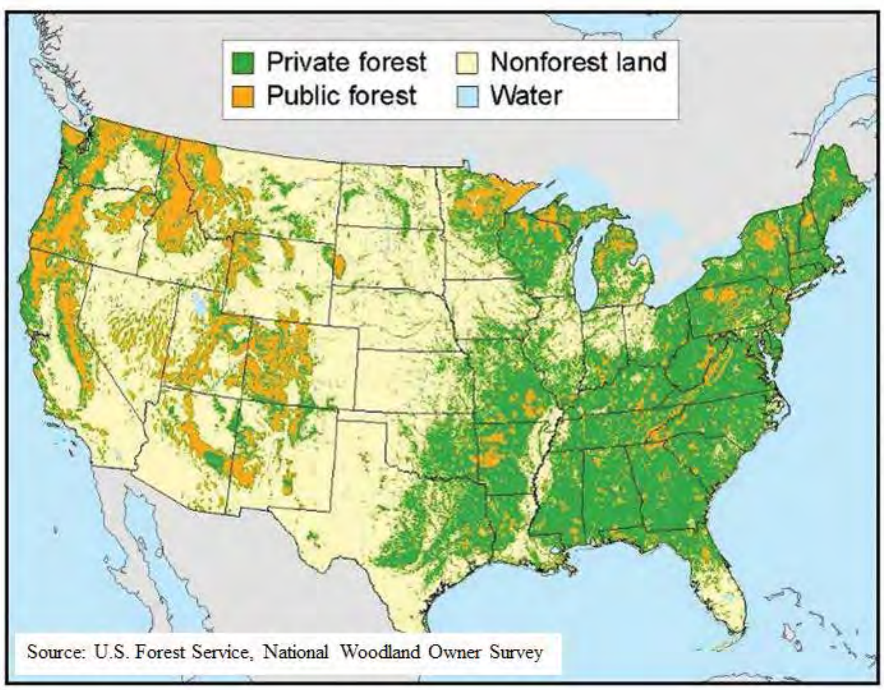
In the United States, the majority of forestland is privately owned—about 445 million acres out of the total 766 million acres, or about 58 percent. Of the privately held land, about two-thirds is owned by individuals (family owned forests that are typically small parcels of 40 to 200 acres). The balance is under corporate ownership, typically large, industrial timberland owners.

The balance of forestland in the United States is in public ownership and totals about 321 million acres, or about 44 percent. Of the public land, about 75 percent is owned and managed by federal agencies such as the Forest Service and the Bureau of Land Management. The remaining 25 percent is a mix of tribal, state, and local government ownership. Public land is highly concentrated in the West, as shown in **Table 2.2** and **Figure 2.2**, which summarize acres of forest by ownership and region. The reserved lands mentioned earlier in this chapter are concentrated mostly on public lands in the West.

REGION	OWNERSHIP TYPE					
	Federal	State	County & Municipal	Private: Corporate	Private: Non-Corporate	TOTAL
North	15	23	9	29	100	**176**
South	22	8	3	65	147	**245**
West	202	39	1	53	51	**346**
Total	**238**	**69**	**13**	**147**	**298**	**766**

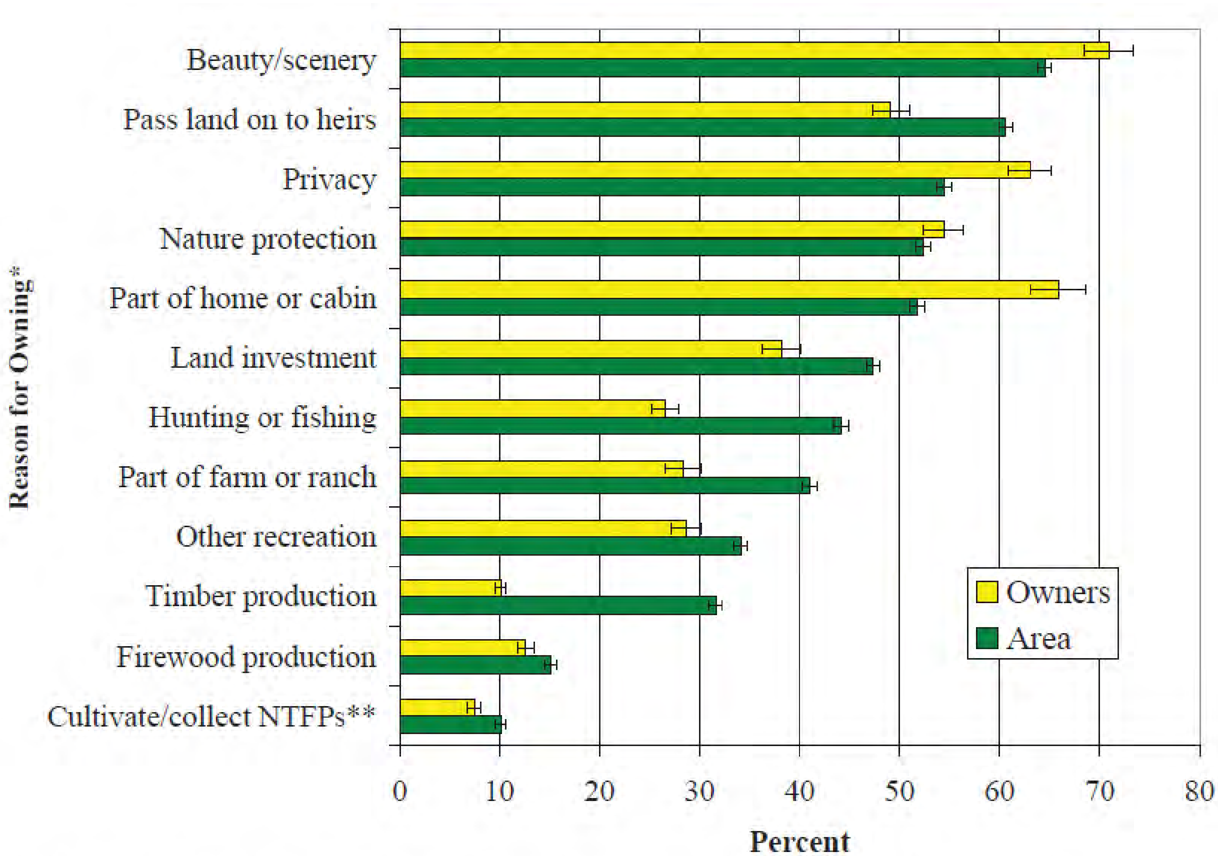
TABLE 2.2 UNITED STATES FORESTLAND OWNERSHIP BY REGION AND OWNERSHIP TYPE (MILLIONS OF ACRES)

FIGURE 2.2 UNITED STATES FORESTLAND OWNERSHIP



Private landowners differ significantly in their management objectives. Corporate owners (19 percent of all forestland) are mostly large, publicly traded companies that manage their land to maximize return on investment for shareholders. For this group of forest owners, wood production is a primary source of return, which means intensive forest management. Corporate landowners also generate revenue via recreation fees, mining leases, easements or leases for communication towers and power lines, and real estate development. Most of the corporate forests in North America are certified as sustainably managed by one or more of the recognized sustainability programs.

By contrast, non-corporate, family forest owners have diverse reasons for owning forestland. **Figure 2.3** ranks those reasons, as cited in a national survey. Family landowners rank beauty, privacy, protecting nature, a legacy for their heirs, and other reasons well above timber production. Family forest owners who identify timber production as an objective account for just over 10 percent of those surveyed. And those who do cite timber production tend to own larger acreages of timberland, representing about one-third of the family-owned tracts. That means two-thirds of the non-corporate private lands do not have timber production as a primary ownership goal. That prioritization, though, does not preclude all timber harvest; rather, it is simply not a reason for the family's ownership. The most common forest management certification program for non-corporate private timberlands is the American Tree Farm System, but most have no forest management certification.



* Includes owners who rated the specific objective as very important (rating = 1) or important (rating = 2) on a seven point Likert scale with one defined as very important and seven as not important.

** Nontimber forest products

FIGURE 2.3 REASONS FOR OWNING FORESTLAND AMONG PRIVATE NON-CORPORATE FORESTLAND OWNERS[2]

2 Source: Butler, 2008 NRS GTR-27 USDA Forest Service

Historically, about 90 percent of the timber harvested in the United States comes from private lands. And most of that comes from corporate lands and a third of the acreage in the family forest category. **So that means about 90 percent of the timber harvested in the United States comes from about one-third of the timberland base.** The remaining two-thirds of U.S. forestlands are mostly managed for other purposes, while producing a small but important amount of timber for the marketplace. This circumstance is illustrated in **Figure 2.4**, which shows the large disparity in the western United States between the percentage of land publicly owned (67 percent) and the commercial timber pulled from public lands (30 percent). In all other parts of North America, the timber harvest within a region is well balanced with the percentage of land that is public or private.

2.1.1.3 United States Standing Timber Inventory by Key Species

Timberland is evaluated for its volume of standing timber and mix of species. At the most basic level, standing timber is divided into hardwood and softwood. Mass timber products are made almost exclusively from softwood (conifer) species. Among the most common are Douglas fir, SPF (spruce-pine-fir), and Southern yellow pine (SYP). In the softwood lumber industry, species with similar strength characteristics are frequently grouped together when sold as lumber (e.g., SPF and SYP). Hardwoods are sometimes used in mass timber, but that use is limited to application as finish layers to achieve aesthetic qualities desired by the client. For additional information on species and types of wood used in mass timber products, see Chapter 3 of this report.

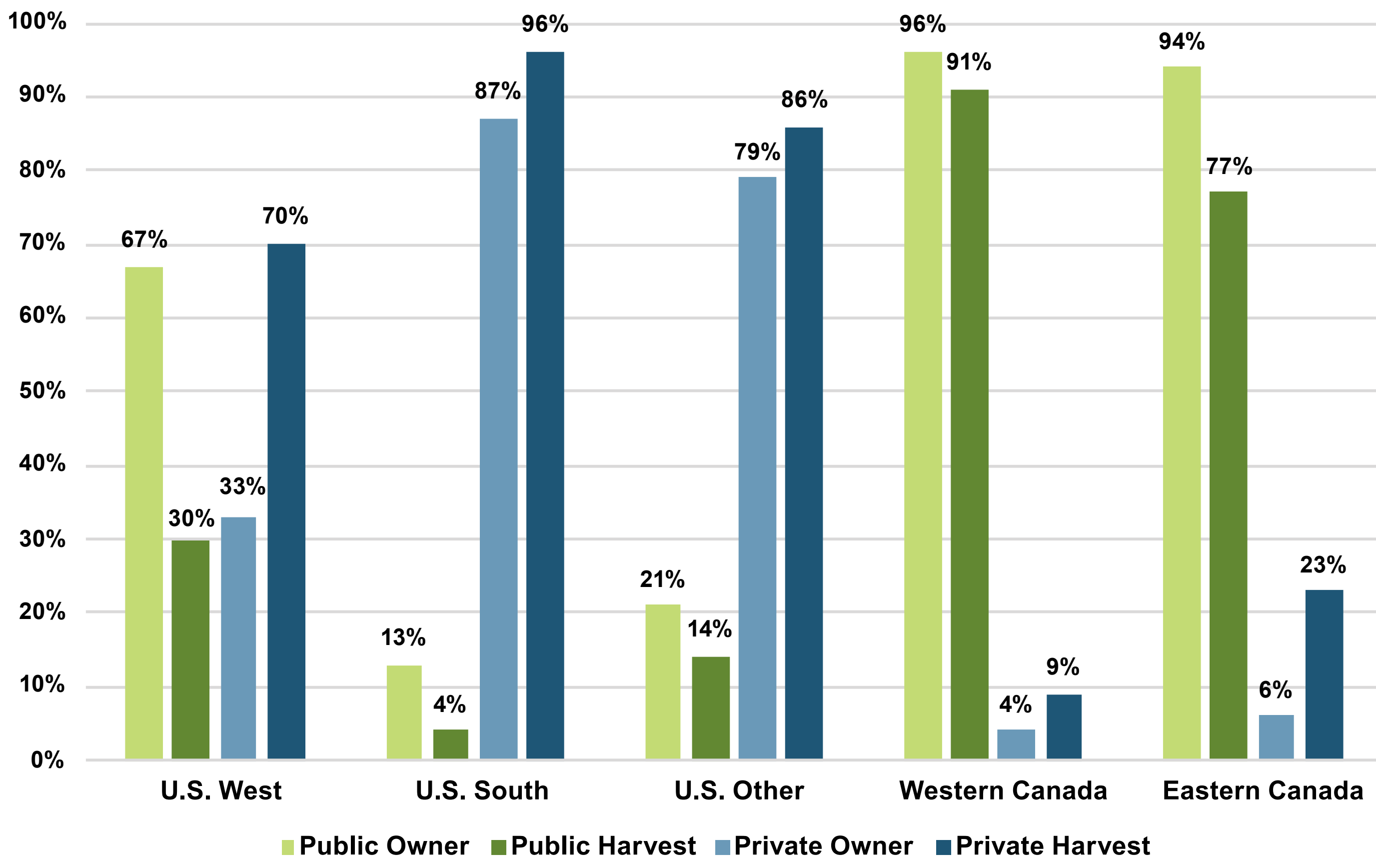


FIGURE 2.4: COMPARISON OF PUBLIC AND PRIVATE HARVEST VOLUME AND LANDOWNERSHIP PERCENTAGE FIGURE 2.4 COMPARISON OF PUBLIC AND PRIVATE HARVEST VOLUME AND LANDOWNERSHIP PERCENTAGE BY REGION OF NORTH AMERICA[3]

3 Sources: US Forest Service FIA and StatsCan

REGION	SPECIES TYPE		TOTAL
	SOFTWOOD	HARDWOOD	
North	65,956	242,505	**308,461**
South	136,280	222,288	**358,568**
West	390,332	44,192	**434,524**
TOTAL	**592,568**	**508,985**	**1,101,553**

TABLE 2.3 UNITED STATES STANDING TIMBER VOLUME BY REGION AND BY SPECIES TYPE (MILLIONS OF CUBIC FEET)

Table 2.3 shows the standing timber volume in the three United States regions by hardwood and softwood, measured in millions of cubic feet. There are roughly equal amounts of hardwood and softwood standing timber in the United States. However, the softwood species are overwhelmingly dominant in the West. Hardwood is most prevalent in the North. The data show more than 1.1 trillion cubic feet of standing timber in the United States.

2.1.2 CANADA

2.1.2.1 Canadian Forestland Area

Canada encompasses 2.467 billion acres of land area. According to Natural Resources Canada, there are about 858 million acres (347 million hectares) of forestland and another 101 million acres (41 million hectares) of woodlands. So as in the United States, a little more than one-third of all land in Canada is forested. Canada's forest acreage has been stable for at least the last 25 years. About 7 percent of those forestlands are in various types of reserves where timber harvest is restricted.

Table 2.4 illustrates how Canada's forested acreage is split between eastern and western Canada, as roughly defined by **Figure 2.5**. Acreages shown in the table are from Canada's National Forest Inventory program.[4]

4 Canadian National Forest Inventory. Accessed at: https://nfi.nfis.org/en

CLASSIFICATION	REGION		TOTAL CANADA
	WESTERN CANADA	EASTERN CANADA	
Forestland	166,628	692,249	**858,877**
Other woodland	18,761	82,220	**100,981**
Total	**185,388**	**774,470**	**959,858**

TABLE 2.4 CANADIAN FORESTLAND AREA BY CLASSIFICATION TYPE AND REGION (THOUSANDS OF ACRES)

2.1.2.2 Canadian Forestland Ownership

As shown in **Table 2.5**, Canada's forest ownership pattern is markedly different than that of the United States. The vast majority of Canadian forestland is in public ownership, with 92 percent publicly owned (Crown, federal, and territories). About 2 percent is owned by First Nations (indigenous). Just 4 percent of Canadian forestland is privately owned. More than 80 percent of the forestland is in eastern Canada.

Given the overwhelming amount of publicly owned land in Canada, the forest management laws, regulations, and policies that guide forest operations are of critical importance. Perhaps most significant among these is Canada's forest tenure system. Under the tenure system, the right to harvest a public resource (timber) is transferred to a private entity. While 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) the private company must comply with in exchange for the right to harvest timber.

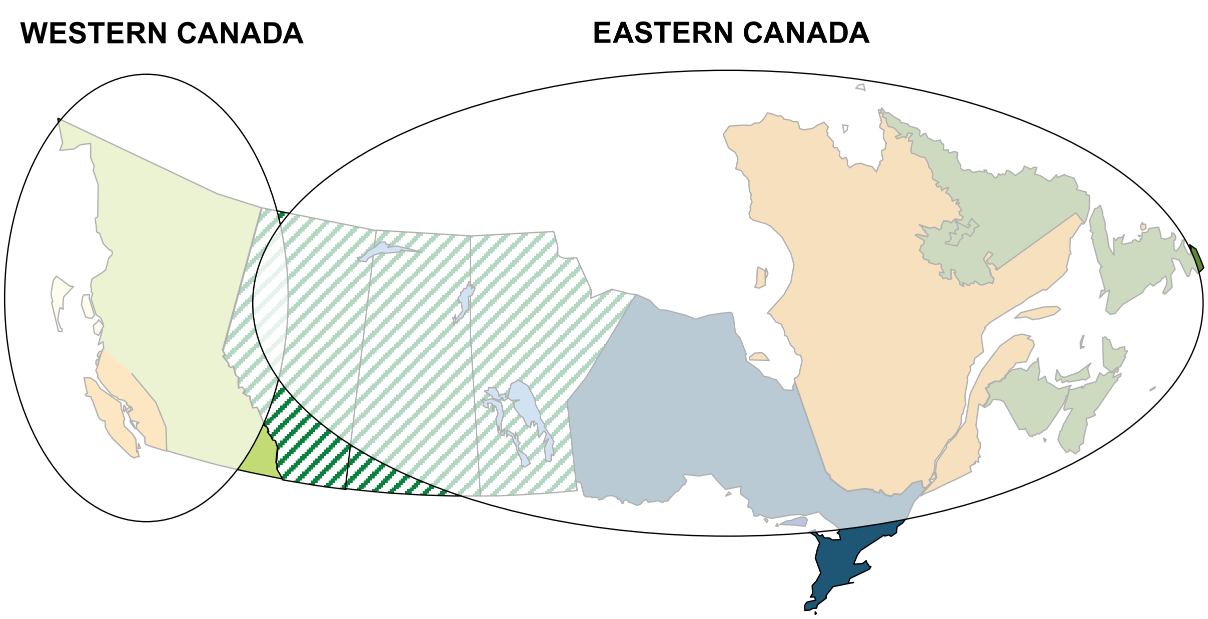


FIGURE 2.5 CANADIAN FOREST REGIONS

REGION	OWNERSHIP TYPE					TOTAL
	Aboriginal	Crown	Federal	Territories	Private	
Western Canada	3.5	115.6	3.3	39.7	4.1	**166.2**
Eastern Canada	13.3	542.7	10.0	71.3	49.4	**686.8**
Total	**16.8**	**658.3**	**13.3**	**111.0**	**53.5**	**853.0**

TABLE 2.5 CANADIAN FORESTLAND OWNERSHIP (MILLIONS OF ACRES)[5]

2.1.2.3 Canadian Standing Timber Inventory by Key Species

As shown in **Table 2.6**, Canadian forests are predominantly softwoods—about 80 percent of all standing timber is a softwood species. While softwoods predominate throughout Canada, the pattern is most pronounced in western Canada, where almost 97 percent of all standing volume is a softwood species, as opposed to 72 percent of all standing volume in eastern Canada. Both the Canadian West and East are dominated by the SPF (spruce-pine-fir) category, which includes Engelmann spruce, black spruce, lodgepole pine, jack pine, balsam fir, subalpine fir, and others. The maritime subregion in coastal British Columbia is dominated by hemlock, Douglas fir, and western red cedar. The species mix in Canada is well suited for use in mass timber products.

REGION	SOFTWOOD	HARDWOOD	TOTAL
Western Canada	533,153	18,996	**552,150**
Eastern Canada	803,201	315,725	**1,118,926**
Total	**1,336,355**	**334,722**	**1,671,076**

TABLE 2.6 CANADIAN STANDING TIMBER VOLUME BY REGION AND BY SPECIES TYPE (MILLIONS OF CUBIC FEET)

5 Source: Canadian Statistical Service – Varies from Table 2.4 due to differences in data sources

2.2 FOREST SUSTAINABILITY

This section discusses the quantity of wood grown each year (growth) compared to the quantity harvested and/or killed by insects, diseases, storms, and wildfires (drain). Additionally, the certification systems that monitor and critique forest management are reviewed. Finally, there is an analysis of the quantity of timber harvested from public lands: local, state, and federal acreages.

2.2.1 ENVIRONMENTAL FOREST CERTIFICATION

In forest management, sustainability is achieved when managers provide a long-term, continuing supply of goods from a forest. They include wood; wildlife habitat; places to recreate; clean water for cities, agriculture, fish, and other aquatic species; and a wide range of plants, insects, fungi, and other species that support the web of life in a forest ecosystem. Sustainability is evaluated over a large geographic area.

The concern for sustainability and the protection of myriad values began in the United States and Canada in the 1960s, '70s and '80s with the passage of laws such as the National Environmental Policy Act, Endangered Species Act, Clean Water and Clean Air acts, National Forest Management Act, and others. In the 1990s, concern about the sources of wood from private lands and imported wood became a focus.

Increasingly, buyers wanted wood from sustainably managed lands that did not contribute to deforestation or the harvest of rare species. They wanted assurance that other, non-commercial values were protected in the source forests. This public concern spurred the development of certification systems at the World Summit in Rio De Janeiro and the Montreal Process meetings. There, forest health and management criteria and indicators were developed, to be monitored by independent third-party verification groups. The intent: to reward good forest management through market forces.

Decades later, just 11 percent of the world's forests are environmentally certified; however, they provide 29 percent of global timber production. According to the Yale Forest Global Atlas, 92 percent of all certified forests are in the northern hemisphere, with Canada and the United States accounting for 51 percent of the total. The acreage of certified land in tropical forests is approximately 2 percent. So even though the idea of certification was to help stop deforestation, which is primarily a tropical forest issue, very little has been certified in that region of the world.

2.2.1.1 North American Forest Certification Programs

In the 25 years since environmental forest certification began, a number of certification systems have been developed around the world. There are four main certification systems in North America:

- **Forest Stewardship Council:** FSC was initiated in 1993 and is used worldwide, with 169 million acres (or 68 million hectares) in the United States and Canada.
- **Sustainable Forestry Initiative:** SFI was initiated in 1994 and primarily serves large industrial forest landowners. It is endorsed by the Programme for Endorsement of Forest Certification (PEFC), a system widely used in Europe and other parts of the world. In 2017, SFI certified about 305 million acres (or 123 million hectares) in Canada and the United States.
- **Canadian Standards Association:** CSA is the Canadian standards system established in 1996. CSA is also a PEFC-endorsed certification system.
- **American Tree Farm System:** ATFS is managed by the American Forest Foundation and is designed for family forest ownerships that are relatively small. ATFS is also endorsed by PEFC and, therefore, is part of the global certification system.

All of these systems have principles, criteria, and indicators for evaluating forestlands. There are differences from one system to the next, but also significant commonalities. This report does not evaluate the certification systems, but online sites do provide comparisons. For some buyers, the differences between certification systems are important; they may need to closely evaluate the differences before making a choice. For others, knowing that the wood is responsibly sourced from certified lands or public lands is adequate.

2.2.1.2 Certification of Public Lands: United States

Most federal forests in the United States—national parks, national forests, Bureau of Land Management, and wildlife refuges—are not certified. Federal environmental laws guide management on public lands, rather than the principles, criteria, and indicators used by certification systems. Some federal lands (wilderness, parks, inventoried roadless areas) are reserved from timber harvest. These forests, such as the giant sequoia grove pictured below, serve as an important part of sustainable ecosystems by providing habitat conditions not found on forestlands managed for timber production, such as old-growth forests and the species they support, and as awe-inspiring, spiritually renewing refuges for visitors to experience in their natural state.

GIANT SEQUOIA SENATOR GROVE
Source: Treesource; Photo Credit: Bethany Atkins

A number of states have forestlands that are managed for a variety of goals, including reserved parks and wildlife areas and other lands. These lands are managed to generate sustained revenues 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. The state lands are thus managed for grazing, timber production, farm leases, mining, etc. Each state has laws and Best Management Practices (BMPs) that govern their forest management, and all state forestlands require sustainable production. There is considerable variation across the United States in the extent and details of their requirements. The basic state laws and BMPs are designed to protect water quality because clean water is one of the main societal benefits provided by forests. Thus, BMPs guide how logging and forest road building are conducted. Additional requirements for soil productivity, wildlife habitat, etc. may be included. Some states have pursued environmental forest certification (FSC, SFI) while others have not, believing their laws and BMPs achieve sustainability goals without the need for certification. Some states have gone through the ASTM 7612 audit process that verifies wood from their lands is responsibly sourced. Finally, local governments (county, municipal) frequently own and manage forestlands governed by their own laws and regulations. Some of these lands are managed as parks, while others allow timber harvest.

Source: Oregon Forest Resource Institute (OFRI), www.oregonforests.org

2.2.1.3 Certification of Public Lands: Canada

Most Canadian forestland is publicly owned, but as previously described, a tenure system allows private companies to carry out sustainable forest management on public ground. Provincial governments have established forest management standards that guide corporate leaseholders. In addition to those standards, 420 million acres (170 million hectares) have been certified by third parties, including FSC, SFI and CSA. Canada also has 59 million acres (24 million hectares) reserved from harvest in the form of parks and other protective designations. These represent 7 percent of Canada's forests.

2.2.2 ARE NORTH AMERICAN FORESTS OVERHARVESTED?

A key component of forest sustainability is the rate of harvest compared to growth of the forest, factoring in mortality from insects, diseases, and wildfires. The goal is to keep the ratio of growth to harvest/death greater than or equal to 1. A ratio greater than 1 indicates annual forest growth is greater than removals, so the forest (as measured by wood volume) holds steady over the long term.

This section presents information related to these figures, often referred to as the *"growth and drain."* Timber harvest plans are recalculated periodically, based on the inventory and monitoring, to remain in balance with mortality. For example, British Columbia reduced its allowable timber harvest because of the mountain pine beetle epidemic of the 2000s. During the epidemic and for a subsequent period of time, the provincial government aggressively pursued the salvage of as much dead timber as possible while it was still usable for milling. Now, much of the dead timber is not valuable for lumber production, so allowable timber harvest levels are being reduced to reflect the reduced acreage of live timber. The beetle-killed forests will regenerate over time.

2.2.2.1 United States Timber Harvest Rate

Figure 2.6 traces the net annual growth of timber, the annual harvest of timber, and annual timber mortality from 1952 to 2012. These values (green, blue, and orange lines) correspond to the left axis of the chart. Between 1952 and 2012, the net annual growth of timber (green line) in the United States doubled, from 13 billion cubic feet per year to over 26 billion cubic feet per year. During the same time, annual harvest (blue line) initially trended up, starting at about 11.5 billion cubic feet in 1952, peaking at 16.5 billion cubic feet in 1986, then declining to 12.8 billion cubic feet in 2012. Finally, mortality (orange line), which is trees dying due to wildfire, insects, and drought, steadily increased, from 5 billion cubic feet per year in 1952 to more than 11 billion cubic feet per year in 2011.

The ratio of net annual growth to the combination of harvest and mortality (drain) is plotted on the chart for the same time period (dotted blue line). These values correspond to the right axis of the chart. As the data show, the ratio of annual growth to annual drain was less than 1 during the 1950s and 1960s. However, since the 1970s, the ratio has been greater than 1, which means that each year, the United States is growing more timber than it loses to timber harvest and natural mortality. **These findings show that increased demand for lumber and other forest products arising from the development of mass timber can be met without overharvesting forests in the United States.**

This conclusion is strengthened by the fact that the analysis applies only to timberland acres, which comprise about 64 percent of all forestland in the United States. If the annual growth occurring on non-timberland acres (where timber harvest is not allowed or not a priority) were added to the analysis, annual growth would further exceed harvest and mortality.

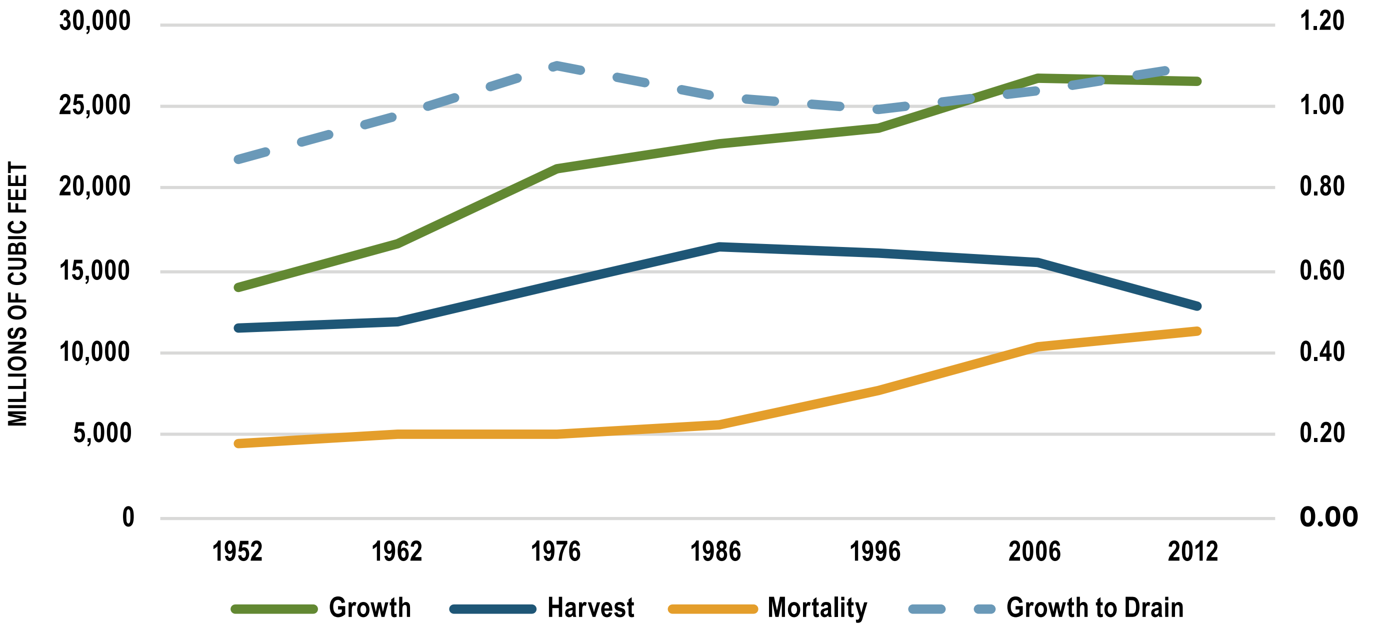


FIGURE 2.6 UNITED STATES NET ANNUAL GROWTH, HARVEST REMOVALS, & MORTALITY FROM 1952 TO 2012[6]

These results are interesting for several reasons. First, the amount of timber grown per year has almost doubled since the 1950s. That's good news, likely attributable to improvements in forest management practices and a change in forest composition. Younger, more vigorously growing trees dominated a larger part of the forests in recent decades.

Second, mortality was essentially flat for four decades. Then, beginning in the mid-1980s, it began a steady upward trajectory. A number of factors contributed to the increase, including more high-intensity wildfires (discussed in more detail in section 2.4 of this report), the mountain pine beetle outbreak in the Inland West (related to the epidemic in western Canada, though on a much smaller scale), drought conditions leading to mortality in older, less vigorous trees (most notably in California), and reduced timber harvests on public lands in the West (leading to overcrowding and higher mortality in those forests). Some natural mortality can be salvaged and utilized, but only a limited amount of standing dead trees are viable for use in most forest products.

Going forward, there may be opportunities to increase harvest levels from publicly owned lands. However, such decisions are socio-political. Federal land management agencies (Forest Service, BLM) have made the case that more thinning and planned burning are needed to reduce wildfire, insect, and disease risks. In parts of the West, a lack of milling infrastructure and logging contractors limit the amount of harvest. Private businesses, nonprofit groups, and government agencies are working together to expand the milling capacity, with limited success. In areas where mills remain, many are underutilized (operating one shift instead of two). Expanded timber sales are easily accomplished in these areas, potentially providing additional lumber for the mass timber market.

6 Data from 2012 USFS FIA (most recent available). Because much of the data was collected just before the Great Recession, dramatically reduced timber harvests for several years during the Great Recession have likely caused current G:D ratios to increase above those shown in the table.

2.2.2.2 Canadian Timber Harvest Rate

Natural Resources Canada, the government ministry responsible for Canada's forests and other natural resources, tracks the sustainability of timber harvests in much the same way that growth-to-drain ratios are used in the United States. In Canada, however, an annual allowable cut (AAC) is determined based on models of forest growth and mortality. In **Table 2.8**, the annual supply (or AAC) is compared to the annual harvest of softwoods, hardwoods, and both species combined for the period 1990 through 2016. As shown, the annual supply is well above harvests for all years and all species. Canadian forests are growing significantly more wood fiber than is harvested each year. A harvest-to-supply ratio specific to eastern and western Canada was not readily available.

It should be noted, however, that in the Inland Region of British Columbia, harvest levels related to growth were recently adjusted downward, reflecting the massive mountain pine beetle epidemic of the early 2000s. The epidemic was aggravated by milder winter temperatures that allowed beetle populations to explode. A great deal of effort was made to salvage as many beetle-killed trees as possible while the wood was still useable. However, extensive areas died without salvage. As a result, land managers adjusted harvest levels down to reflect the reduced growing stock. Western Canada is also experiencing more and larger wildfires as a result of warmer temperatures and longer wildfire seasons. The need for active forest management to make the forests more resilient is vital as the globe adapts to a changing climate.

YEAR	SOFTWOOD			HARDWOOD			TOTAL (SOFTWOOD AND HARDWOOD)		
	Annual Supply	Annual Harvest	Ratio Supply to Harvest	Annual Supply	Annual Harvest	Ratio of Supply to Harvest	Annual Wood Supply	Annual Wood Harvest	Ratio of Supply to Harvest
1990	6,472	4,985	1.3	2,247	538	4.2	8,985	5,523	1.6
1991	6,465	4,891	1.3	2,181	554	3.9	8,915	5,445	1.6
1992	6,354	5,184	1.2	2,135	598	3.6	8,759	5,782	1.5
1993	6,243	5,314	1.2	2,102	674	3.1	8,614	5,988	1.4
1994	6,234	5,444	1.1	2,130	820	2.6	8,633	6,264	1.4
1995	6,127	5,560	1.1	2,096	908	2.3	8,492	6,468	1.3
1996	6,121	5,344	1.1	2,122	941	2.3	8,512	6,284	1.4
1997	6,168	5,431	1.1	2,160	1,051	2.1	8,597	6,482	1.3
1998	6,096	5,042	1.2	2,177	1,100	2.0	8,462	6,142	1.4
1999	6,209	5,749	1.1	2,186	1,196	1.8	8,596	6,945	1.2
2000	6,137	5,766	1.1	2,142	1,278	1.7	8,360	7,044	1.2
2001	6,248	5,294	1.2	2,149	1,218	1.8	8,413	6,512	1.3
2002	6,290	5,637	1.1	2,164	1,261	1.7	8,456	6,899	1.2
2003	6,326	5,079	1.2	2,179	1,329	1.6	8,523	6,408	1.3
2004	6,577	5,950	1.1	2,184	1,398	1.6	8,780	7,349	1.2
2005	6,472	5,833	1.1	2,207	1,276	1.7	8,697	7,110	1.2
2006	6,580	5,253	1.3	2,182	1,190	1.8	8,780	6,443	1.4
2007	6,739	4,754	1.4	2,187	966	2.3	8,927	5,724	1.6
2008	6,734	4,033	1.7	2,140	843	2.5	8,892	4,882	1.8
2009	6,413	3,332	1.9	2,090	754	2.8	8,520	4,090	2.1
2010	6,314	4,145	1.5	2,043	829	2.5	8,368	4,978	1.7
2011	6,163	4,270	1.4	2,017	911	2.2	8,192	5,183	1.6
2012	6117	4401	1.4	1991	869	2.3	8120	5270	1.5
2013	6053	4448	1.4	1969	883	2.2	8022	5331	1.5
2014	6060	4405	1.4	2052	901	2.3	8113	5308	1.5
2015	5991	4528	1.3	2059	965	2.1	8052	5497	1.5
2016	5792	4457	1.3	2086	1005	2.1	7879	5463	1.4

TABLE 2.8 CANADIAN RATIO OF ANNUAL HARVEST TO ANNUAL SUPPLY 1990 TO 2016 (MILLIONS OF CUBIC FEET)

Source: Canadian National Forestry Database, http://nfdp.ccfm.org/en/index.php

2.3 FOREST DIVERSITY

2.3.1 UNITED STATES FOREST DIVERSITY

Almost all U.S. 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 warned that some forest types (and the plant and animal species associated with them) are in decline. Coalitions 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 coalitions of federal and state agencies, nongovernmental organizations, universities, private landowners, and foundations 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 U.S. Department of Agriculture.

2.3.2 CANADIAN FOREST DIVERSITY

The vast majority of Canadian forests are 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. **Figure 2.7.** The largest group is the boreal forest.

FIGURE 2.7 CANADIAN FOREST REGIONS[7]

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

2.4 FOREST HEALTH AND FIRE RESILIENCE

What is a healthy forest? The answer 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 non-corporate 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. Few people are interested in beetle epidemics or forest fires across hundreds of thousands or millions of acres. Maintaining a balance is an important part of managing the forest.

2.4.1 WILDFIRE

Forest fires and the smoke they generate filled the news in recent years across the West, and sometimes nationally. 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 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.

Many land managers, scientists, and wildfire managers 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 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 burning these overgrown forests can seem expensive. That's because the cost of removing smaller trees is almost always greater than their commercial value. However, when thinning and burning costs are weighed against the immense cost of firefighting and the associated losses of lives, property, and resources, the forest restoration projects make sense economically. There are many examples around the country where proactively treating forests saved property, lives, and even communities.

The following photo 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 seen in the foreground of the photo.

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

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 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.

2.4.2 HOW CAN MASS TIMBER IMPROVE FOREST RESILIENCY?

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, which leads 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 a viable economy.

2.5 FOREST CARBON

The world's forests play a critical role in the capture and storage of atmospheric carbon. This subject, and the carbon capture implications of turning timber into durable building products, is explored in Chapter 5.

2.6 SUMMARY

This chapter addressed questions about how the utilization of mass timber could impact forests in Canada and the United States.

- **Will North American forests be decimated by the increased demand?** The data show that forests in Canada and the United States are growing far more wood than is being harvested. An increased demand for timber will not lead to deforestation.
- **How will wildlife habitat and watersheds be protected as timber harvests increase?** Extensive forestlands reserved from timber harvest provide wildlife habitat and preserve watersheds. Timberlands managed for production also provide a number of these values.
- **If deforestation is a problem, why even consider a new use of wood in construction?** In North America, the quantity of forestland has been stable for decades. The use of wood products provides an economic incentive to protect those forests from conversion to non-forested uses.

CHAPTER 3: MASS TIMBER RAW MATERIALS

IMPACTS OF THE MARSHALL EFFECT ON RAW MATERIALS:

- 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.
- Each cubic foot of mass timber raw material is estimated to require 22.5 board feet (nominal) of lumber to produce.
- Doubling the number of buildings made from mass timber every 2 years between 2020 and 2034 equates to an estimated increase in lumber demand of 12.9 billion board feet by 2034*.
- As perspective, 2019 North American softwood lumber demand (the primary raw material used for producing mass timber) was estimated to be about 60 billion board feet. Thus, new softwood lumber demand arising directly from mass timber buildings in 2034 is estimated to be about a 21.5% increase over 2019 demand.

** Assumes average building size of 25,000 square feet.*

It's a fact: the manufacturing of mass timber requires raw materials. This chapter includes a technical analysis of raw material properties, related to their use in mass timber; a look at the production capacity for raw materials needed in mass timber; and an estimation of the demand that mass timber's development could create for raw material suppliers.

3.1 RAW MATERIAL SPECIFICATIONS FOR MASS TIMBER

3.1.0.1 Lumber Specification and Usage in Mass Timber

The following sections briefly summarize the specifications required for lumber used in various mass timber products. Additional, more-detailed information is available in the design standard reference provided for each product.

3.1.0.2 Cross Laminated Timber (CLT)

ANSI/APA PRG-320 – 2018: Standard for Performance-Rated Cross Laminated Timber (PRG 320) is a standard covering the manufacturing, qualification, and quality assurance requirements for CLT. It was developed by APA—the Engineered Wood Association—and the most recent edition was approved by the American National Standards Institute (ANSI) on February 6, 2018.

Section 6, Subsection 6.1 of PRG-320 includes specifications for the lumber allowed for use in approved CLT panels. The full version of the document[1] describes all CLT lumber specifications, but the following list provides a brief summary.

- **Species:** Any softwood species may be utilized that has a specific gravity of at least 0.35 as published in the National Design Specification for Wood Construction. This specification level means that most commercially available softwood species used in structural applications can be used to manufacture CLT. Also specified is that each layer of lumber in a CLT panel must only use a single species. Adjacent layers of lumber within a CLT panel can be made from different species.
- **Grade:** In CLT panels, the lumber layers are referred to as either *parallel* (the major strength direction in a panel) or *perpendicular* (the minor strength direction in a panel). Lumber is graded in two ways: 1) visually: where strength/grade is estimated from a visual inspection, or 2) Machine Stress Rated (MSR): where lumber pieces are measured for resistance to bending and assigned an according strength rating. Therefore, regarding lumber grade, parallel layers must be at least visual grade #2 or 1200f-1.2E for MSR. Perpendicular layers must be at least visual grade #3 or equivalent.

1 See: https://www.apawood.org/ansi-apa-prg-320

- **Thickness:** The minimum thickness of any lumber layer is 5/8 inch (16 mm) at the time of gluing. Maximum thickness is 2 inches (51 mm). Thickness must be consistent across each individual layer. Thickness consistency is defined at the time of bonding as plus or minus 0.008 inch (0.2 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 lumber "shall not be so great that they will not be straightened out by pressure in bonding."
- **Width:** In the parallel layers, the width of a piece of lumber must be at least 1.75 times its thickness. In the perpendicular layers, the width must be at least 3.5 times its thickness.
- **Moisture content:** For lumber used in CLT panels, the moisture must be 12 percent, plus or minus 3 percent, when the panel is manufactured. For structural composite lumber used in CLT panels, the moisture must be 8 percent, plus or minus 3 percent, at the time of manufacture.
- **Surfacing:** Any lumber used must be planed, at least on any surfaces to be bonded, and the planed surface must not have any imperfections that might adversely affect the bonding process (i.e. raised grain, skip, burns, glazing, dust). ANSI and the APA also include a note important to understanding the intricacies of bonding the layers within a CLT panel. It states: for some species, it may be necessary to plane the bonding surfaces within 48 hours of the actual bonding process.

3.1.0.3 Nail Laminated Timber (NLT)

The International Building Code recognizes NLT as a structural material and provides guidance for structural and fire design. No product-specific ANSI standard has been developed, but design guides are available for both the U.S. and Canada.[2] In practice, NLT can be made from virtually any properly graded softwood dimension lumber, with most production utilizing #2 grade dimension lumber in 2-by-4, 2-by-6, and 2-by-8 sizes.

3.1.0.4 Dowel Laminated Timber (DLT)

As of 2019, there was no prescriptive code for using DLT under the International Building Code. Similarly, the National Design Specification for Wood Construction does not provide published design values or equations for calculating capacities of wood dowel joints. However, StructureCraft, a North American mass timber manufacturer of DLT, has developed a design guide.[3] It includes this information:

- **Species & Grade:** For SPF lumber, acceptable grades are J-Grade, Hiline, No. 2 and Better, 2100f-1.8E MSR. For Douglas fir and Hem-fir, acceptable grades are Select Structural, No. 1, No. 2 and Better, 2400f-2.0E MSR. Other species can be used, but grades for those species are not listed in the StructureCraft design guide.
- **Moisture:** Moisture content should be 12 percent, plus or minus 3 percent, at the time of manufacture.
- **Appearance:** The StructureCraft design guide provides guidance on lumber appearance, should DLT panels be used in applications where appearance is a consideration. There are three DLT appearance grades and guidance is provided for a variety of lumber appearance characteristics, including wane, knots, checking, resin pockets, pitch streaks, shake, discoloration, pith, compression wood, decay, sapwood, and surfacing quality.

2 https://www.thinkwood.com/products-and-systems/mass-timber/nltguide

3 Dowel Laminated Timber the All Wood Panel, Mass Timber Design Guide. StructureCraft. Accessed at: https://structurecraft.com/materials/mass-timber/dlt-dowel-laminated-timber

3.1.0.5 Glulam

ANSI A190.1-2017 Standard for Wood Products—Structural Glued Laminated Timber[4] describes the specifications for lumber to be used in glulam timbers. Key specifications include:

- **Species:** 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.
- **Moisture Content:** The moisture content of lumber shall not exceed 16 percent at the time of bonding.
- **Grade:** Lumber used in glulam timbers can be visually graded, mechanically graded, or proof graded. Regardless of the grading method, all lumber shall be identified by grade prior to bonding. Visually graded lumber shall be graded according to standard grading rules approved by the Board of Review of the American Lumber Standard Committee or written laminating grading rules. Mechanically graded lumber shall be graded according to standard grading rules approved by the Board of Review of the American Lumber Standard Committee 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.
- **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.
- **Wane:** For dry-service conditions, wane up to 1/6 the width at each edge of interior laminations is permitted in certain grade combinations. Wane in wet-service conditions is only permitted when moisture accumulation in the wane areas will not occur.
- **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 the lamination shall not exceed plus or minus 0.012 inches.

4 See here: https://www.apawood.org/ansi-a190-1

3.1.0.6 Post and Beam

Traditionally, post and beam construction utilizes large timbers of nominal width and thickness 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, there are several documents that provide some guidance.[5] 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.

In many mass timber projects, glulam members are used in place of solid sawn heavy timbers. Lumber specifications for glulam are listed in the preceding section.

3.1.0.7 Heavy Timber Decking

Like post and beam, specifications for heavy timber decking are less prescriptive than other mass timber products. Some guidance is provided by a document titled Heavy Timber Construction[6] published by the American Wood Council.

- **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, California Redwood Inspection Service, Southern Pine Inspection Bureau, West Coast Lumber Inspection Bureau, Western Wood Products Association, 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 tongued-and-grooved 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 tongued-and-grooved plank not less than 2 inches, nominal, in thickness or of planks not less than 3 inches, nominal, in width set on edge.

3.1.1 VENEER SPECIFICATION AND USAGE IN MASS TIMBER

At the time of printing, Freres Lumber Company in Oregon is the only manufacturer in the world making mass timber panels using wood veneer. Freres has achieved certification for mass plywood panels (MPP) under ANSI/APA PRG 320. The certification is specific to mass plywood panels, which use veneer as a raw material rather than solid sawn lumber. Because veneer is used in MPP, certification falls under the classification of Structural Composite Lumber (SCL), which includes laminated veneer lumber and is covered under ASTM D5456.

5 Timber Framing Master Spec. April 19, 2018. & TFEC 2-2018, Code of Standard Practice for Timber Frame Structures. Accessed at: https://www.tfguild.org/publications/view/173

6 Heavy Timber Construction. American Wood Council. Accessed at: https://www.awc.org/pdf/codes-standards/publications/wcd/AWC-WCD5-HeavyTimber-ViewOnly-0402.pdf

MASS TIMBER PRODUCT	COMPONENT MATERIAL DESCRIPTION	Component Nominal Thickness	Component Nominal Width
CLT	Softwood Dimension Lumber	1” – 2”	4” +
NLT	Softwood Dimension Lumber	2”	4” +
DLT	Softwood Dimension Lumber with Hardwood Dowels	2”	4” +
Glulam	Softwood Dimension Lumber	2”	4” +
Heavy Timber Decking	Softwood Dimension Lumber and Small Timbers	2” – 6”	6”, 8”
Post and Beam	Large Timbers (and Softwood Dimension Lumber Composites)	6” +	6” +

TABLE 3.1 SUMMARY OF KEY LUMBER SPECIFICATIONS FOR MASS TIMBER PRODUCTS

3.1.2 MASS TIMBER RAW MATERIALS SPECIFICATIONS SUMMARY

Table 3.1 provides a summary of mass timber products and key specifications for the lumber used in their manufacture.

3.2 NORTH AMERICAN LUMBER SUPPLY

Given the rapid growth in mass timber construction projects, an obvious concern is whether capacity exists to supply mass timber manufacturers with the necessary raw materials. This section focuses on the softwood dimension lumber supply because it is currently the most widely used raw material in mass timber manufacturing.

North American Lumber Production
The following section describes the historical production of softwood lumber in the United States, Canada, and the nations combined.

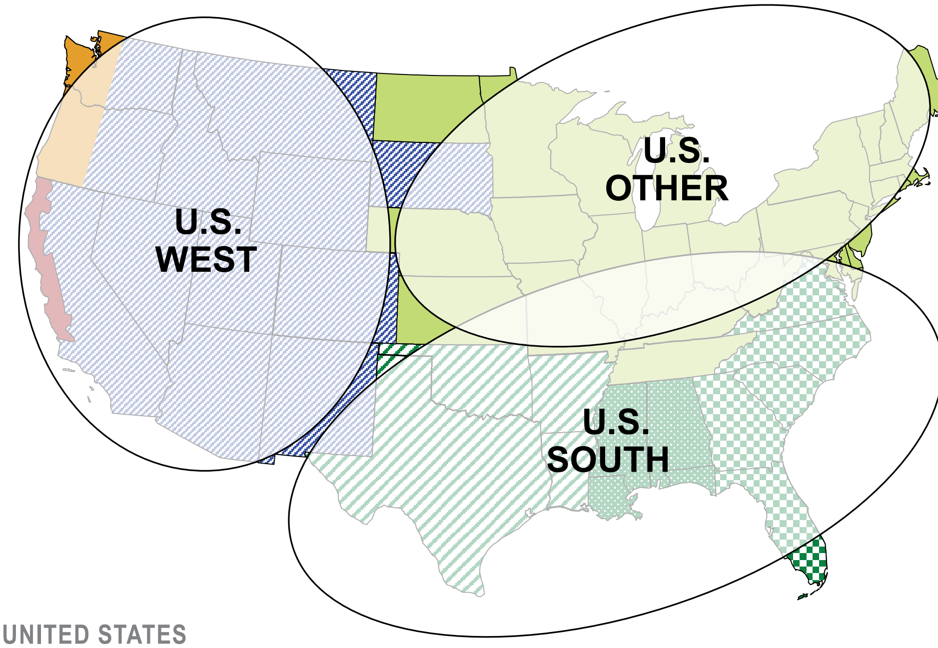


FIGURE 3.1 MAJOR UNITED STATES LUMBER-PRODUCING REGIONS

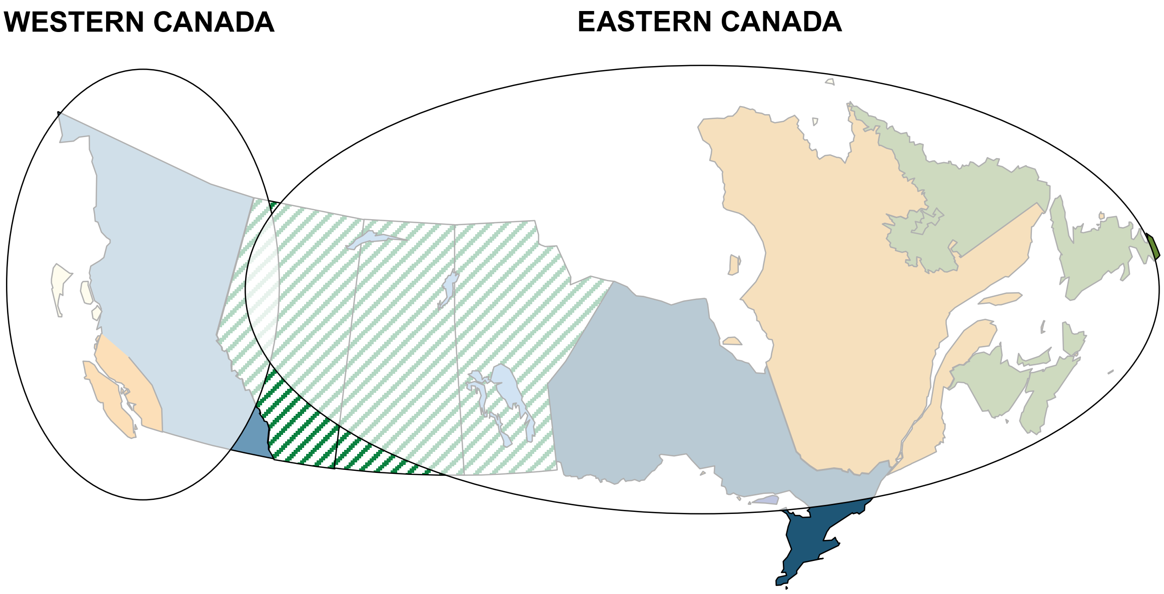


FIGURE 3.2 MAJOR CANADIAN LUMBER-PRODUCING REGIONS

3.2.1 UNITED STATES AND CANADIAN LUMBER-PRODUCING REGIONS

Figure 3.1 shows the three major lumber-producing regions in the United States: the U.S. West, U.S. South, and U.S. Other.

Figure 3.2 shows the two major Canadian lumber-producing regions of Western Canada and Eastern Canada.

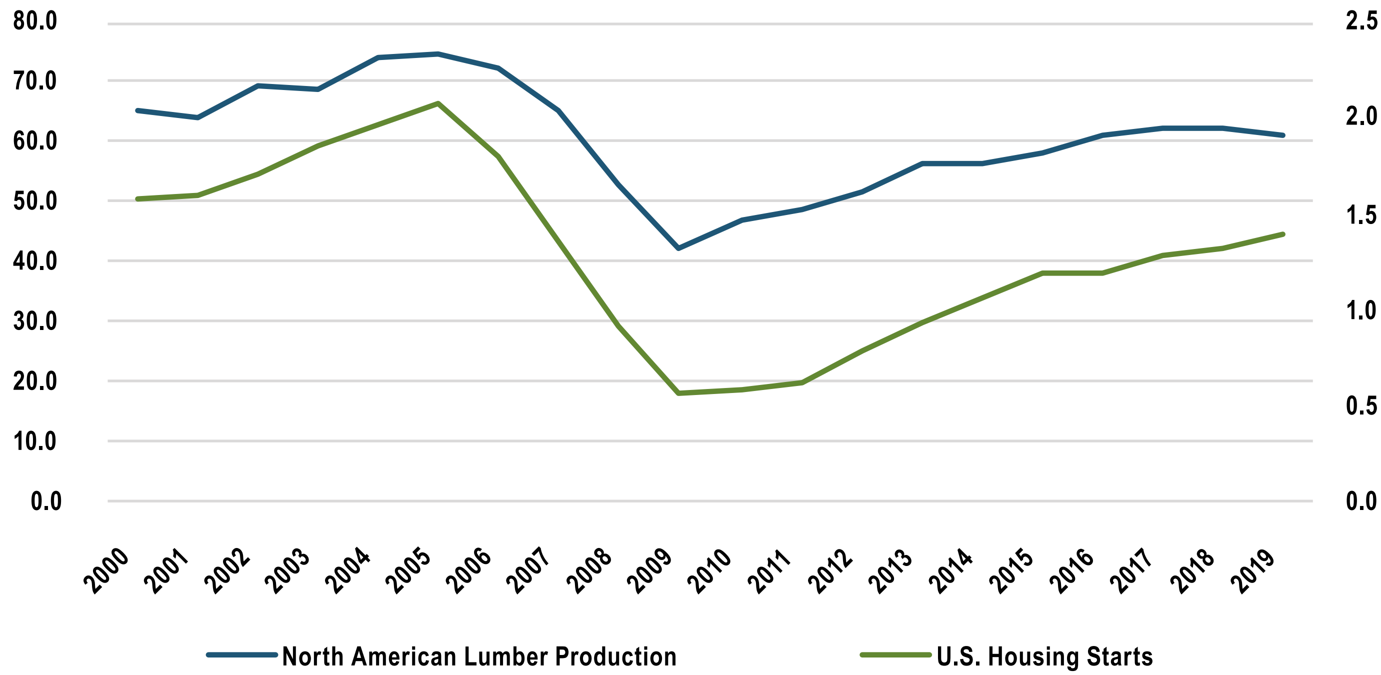


FIGURE 3.3 HIGH CORRELATION BETWEEN NORTH AMERICAN LUMBER PRODUCTION & U.S. HOUSING STARTS[7] (BOARD FEET IN BILLIONS, LEFT AXIS AND HOUSING STARTS IN MILLIONS, RIGHT AXIS.)

3.2.2 HOUSING STARTS: KEY DRIVER OF NORTH AMERICAN SOFTWOOD LUMBER PRODUCTION

Historically, the level of North American softwood lumber production is highly correlated with the level of residential housing starts in the United States, **Figure 3.3.** That's because traditionally about 70 to 75 percent of all softwood lumber produced in North America is used for either new home construction or for home repairs and remodeling. About 20 to 25 percent is used for industrial applications, with 5 percent used in non-residential construction. The proportion of softwood going to various end uses is likely to change as the mass timber sector continues growing.

7 Source: Western Wood Products Association and U.S. Census Bureau

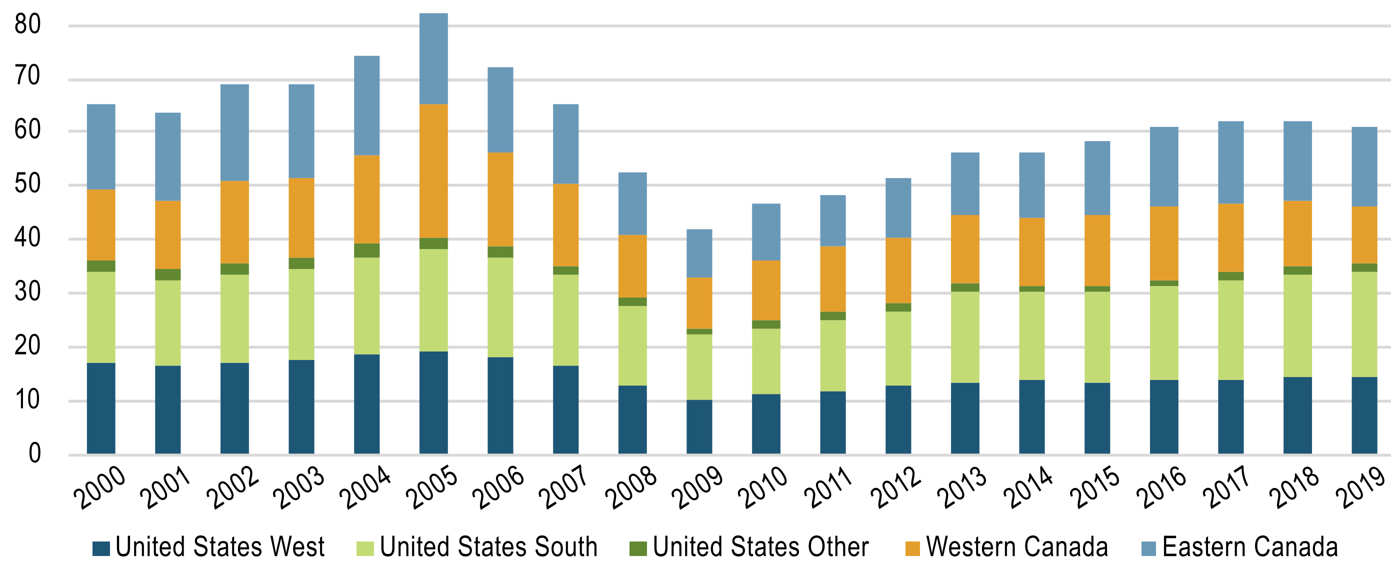


FIGURE 3.4 HISTORICAL UNITED STATES AND CANADIAN SOFTWOOD LUMBER PRODUCTION BY REGION (BOARD FEET IN BILLIONS)[8]

3.2.3 HISTORICAL SOFTWOOD LUMBER PRODUCTION: UNITED STATES AND CANADA

Figure 3.4 shows the historical production of softwood lumber in the United States and Canada.

United States production is shown for three major lumber-producing regions between 2000 and 2019 (note full 2019 data was not available at press time, so 2019 values are projected), as reported by the Western Wood Products Association. United States lumber production peaked in 2005 at more than 40.5 billion board feet. During the Great Recession, U.S. lumber production fell dramatically, reaching a low of 23.4 billion board feet in 2009. Since that time, lumber production has steadily increased, but it has not returned to pre-recession levels. Production in the South recently exceeded pre-recession levels, while production in the West has been mostly flat since 2014.

Canadian lumber production peaked in 2004 at more than 35.1 billion board feet. Production in Canada also dropped precipitously during the Great Recession, reaching a low of 18.8 billion board feet in 2009. Since that time, lumber production has steadily increased, but has not returned to pre-recession levels. Production in Western Canada, especially in Inland British Columbia, has not bounced back as quickly as production in Eastern Canada. This was especially pronounced in 2019, as numerous mills were permanently closed due to a combination of difficult lumber market conditions and limited log supplies in the region. As described in Chapter 2, the mountain pine beetle epidemic has dramatically decreased Interior British Columbia's supply of logs in recent years.

8 Source: Western Wood Products Association

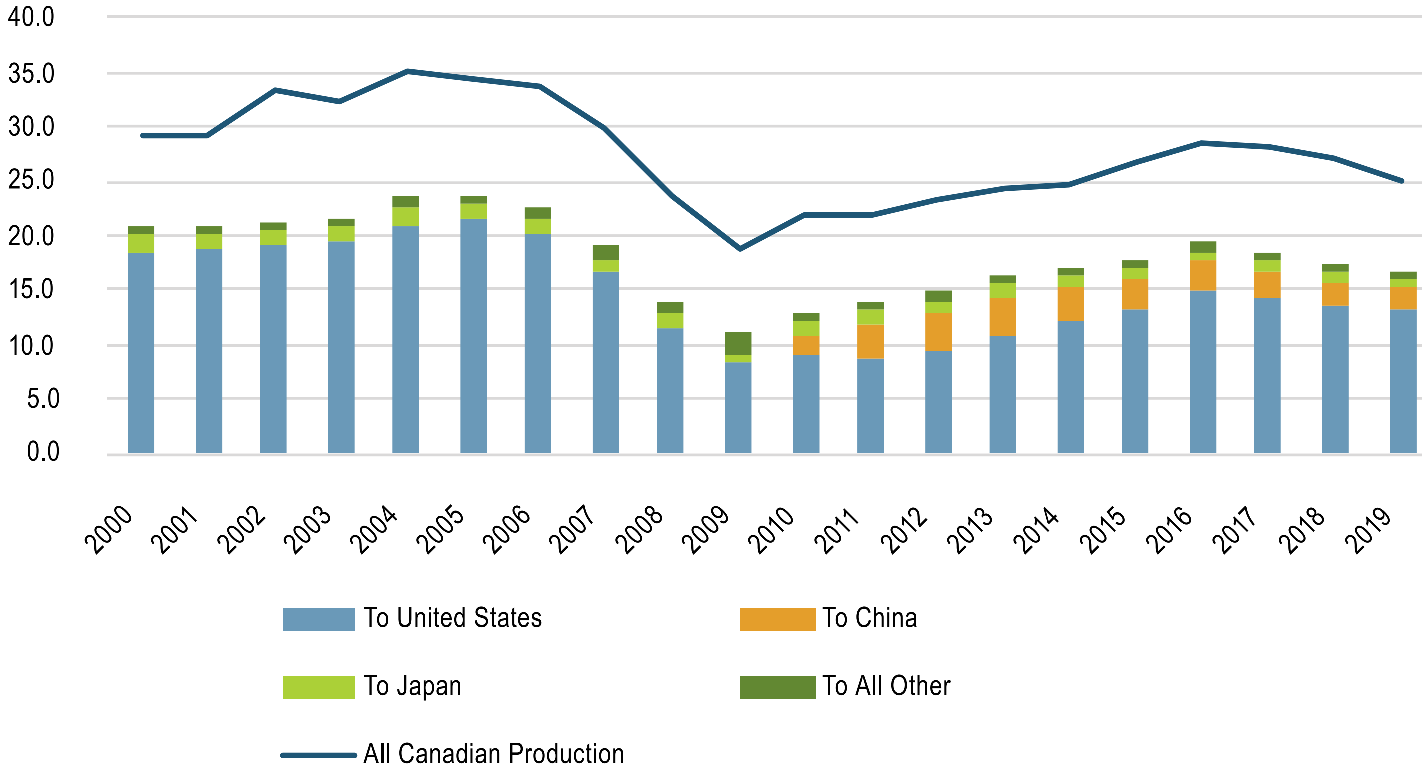


FIGURE 3.5 CANADIAN SOFTWOOD LUMBER EXPORTS AND TOTAL CANADIAN SOFTWOOD LUMBER PRODUCTION (BOARD FEET IN BILLIONS)[9]

Historically, most of Canada's softwood lumber production was exported to foreign countries. For example, during the period shown in **Figure 3.5**, Canada exported 66 percent of its softwood lumber production, on average. Most of the exported volume (about 80 percent) went to the United States. Note, however, the dramatic decline in export volume to the United States during the Great Recession. From a peak of 21.5 billion board feet in 2005, the volume dropped by well over half in just four years, to 8.3 billion board feet. This was driven by sharply lower demand in the United States. As a result, Canada developed new markets for its softwood lumber in China. As U.S. demand recovered following the recession, Canada's exports to China declined, but remain a significant volume. The United States' softwood lumber exports are much smaller than Canada's. During the same time shown in **Figure 3.5**, the United States exported about 4 percent (about 1.3 BBF per year) of its softwood lumber.

9 Source: Western Wood Products Association

Region	2019 Production (BBF)	% Dimension (2"nominal)	Estimated BBF Dimension	% Small Timbers (3"– 5" Nominal)	Estimated BBF Small Timbers	% Large Timbers (6"+ Nominal)	BBF Large Timbers	% Other	Estimated BBF
U.S. West	14.5	55%	8.0	5%	0.7	5%	0.7	35%	5.1
U.S. South	19.7	80%	15.7	10%	2.0	<5%	1.0	5%	1.0
U.S. Other	1.7	20%	0.3	n/a	n/a	n/a	n/a	80%	1.4
Western CA	10.2	75%	7.6	n/a	n/a	n/a	n/a	25%	2.5
Eastern CA	14.8	50%	7.4	n/a	n/a	n/a	n/a	50%	7.4
North America Total	**60.8**		**39.1**		**2.7**		**1.7**		**17.4**

TABLE 3.2 ESTIMATED NORTH AMERICAN SOFTWOOD LUMBER TYPE MIX IN 2019 (BOARD FEET IN BILLIONS)

3.2.4 NORTH AMERICAN SOFTWOOD LUMBER TYPE, GRADE, AND SIZE MIX

As described earlier in this chapter, 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 3.2** shows lumber by lumber type (dimension, timbers, etc.). The values presented use estimated North American softwood lumber production volumes for 2019 (based on Western Wood Products Association reports through October 2019). The percent by size values are estimates from sawmill industry benchmarking data collected by The Beck Group. Of the estimated 60.8 billion board feet of lumber produced in North America in 2019, about 65 percent was estimated to be nominal 2-inch-thick dimension lumber (boards 2 inches thick and 8 to 20-plus feet long). Dimension lumber is the key raw material for most mass timber products. The U.S. South is the leading producer of dimension lumber. The "Other" category includes stud lumber (lumber 2-by-4 or 2-by-6, less than 12 feet in length and graded for use as a stud), pine industrial and common boards (non-structural lumber), and miscellaneous other products.

Region	2019 Production (BBF)	% Above #2	Estimated BBF Above #2	% of #2	Estimated BBF of #2	% of #3	Estimated BBF of #3	% Below #3 and Other	Estimated BBF of Below #3 & Other
U.S. West	8.0	35%	2.8	55%	4.4	5%	0.4	5%	0.4
U.S. South	15.7	40%	6.3	40%	6.3	10%	1.6	10%	1.6
U.S. Other	0.3	10%	0.0	55%	0.2	20%	0.1	15%	0.0
U.S. Total	**24.0**		**9.1**		**10.8**		**2.0**		**2.0**

TABLE 3.3 ESTIMATED UNITED STATES SOFTWOOD DIMENSION LUMBER GRADE MIX IN 2019 (BOARD FEET IN BILLIONS)

Region	2019 Production (BBF)	% 2x4	Estimated BBF 2x4	% 2x6	Estimated BBF 2x6	% 2x8	Estimated BBF 2x8	% 2x10	Estimated BBF 2x10	% 2x12	Estimated BBF 2x12
U.S. West	8.0	40%	3.2	30%	2.4	10%	0.8	10%	0.8	10%	0.8
U.S. South	15.7	25%	3.9	30%	4.7	20%	3.1	15%	2.4	10%	1.6
U.S. Other	0.3	40%	0.1	30%	0.1	10%	0.0	10%	0.0	10%	0.0
U.S. Total	**24.0**		**7.2**		**7.2**		**4.0**		**3.2**		**2.4**

TABLE 3.4 ESTIMATED UNITED STATES SOFTWOOD DIMENSION LUMBER SIZE MIX IN 2019 (BOARD FEET IN BILLIONS)

Table 3.3 illustrates the estimated grade mix of United States softwood dimension lumber production, again using Western Wood Products Association estimated 2019 volumes and The Beck Group's sawmill benchmarking data. About 85 percent of the United States production of dimension softwood lumber is estimated to be #2 grade or better. Data for Canada is not included because the information was not readily available.

Finally, **Table 3.4** provides an estimated lumber size mix of U.S. softwood dimension lumber production using the same methodology as the two preceding tables. About 30% 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 U.S. West than in the U.S. South. As will be described in the following section of this chapter, mass timber manufacturers have largely focused on procuring 6- to 8-inch-wide lumber.

LUMBER PRODUCT	LUMBER WIDTH CATEGORY				
	2 x 4	2 x 6	2 x 8	2 x 10	2 x 12
Kiln Dried Douglas fir #2 & Better	($9)	($10)	($31)	$10	$40
Kiln Dried Southern Yellow Pine #2	$12	($29)	($38)	($18)	$74
Kiln Dried Western SPF #2 & Better	($27)	($35)	($29)	$8	$83
Kiln Dried Eastern SPF #1 & #2	($18)	($13)	($14)	$45	n/a
Average	($11)	($22)	($28)	$11	$65

TABLE 3.5 ANALYSIS OF DIMENSION LUMBER PRICE DIFFERENTIAL BY LUMBER WIDTH: VALUES SHOWN IN THE TABLE ARE THE DEVIATION FROM THE AVERAGE PRICE OF ALL WIDTHS ($/MBF)

3.2.5 HISTORICAL SOFTWOOD LUMBER PRICES

One consideration in procuring lumber for mass timber is the cost, so this section presents data on historical lumber prices (2004 to 2019) for key softwood dimension lumber species and grades. Special attention is given to price differences by width. **Table 3.5** shows the deviation in average price for a given species and grade as the width of the lumber changes. Historically, 2-by-8 lumber has been the lowest-price width, averaging $28 less per thousand board feet than the average price for all widths of dimension lumber. The combination of historically low prices for 2-by-8 lumber and its relative width, which increases production efficiency for mass timber, makes it the preferred lumber width for CLT manufacturing.

Another price consideration is that lower grades of lumber (e.g., #3) are less expensive than better grades (e.g. #2 or #1). However, based on interviews with mass timber manufacturers, it appears that most find buying lower grades of lumber and then removing defects reduces the yield of useable lumber so much that it is more cost effective to pay for a higher lumber grade.

PROGRAM	WEBSITE	FOREST RESOURCE CERTIFICATION	CHAIN OF CUSTODY CERTIFICATION
Forest Stewardship Council (FSC)	https://us.fsc.org/en-us	Yes	Yes
Sustainable Forestry Initiative (SFI)	http://www.sfiprogram.org/	Yes	Yes
Canadian Standards Association (CSA)	https://www.csagroup.org/	Yes	Yes
American Tree Farm System (ATFS)	https://www.treefarmsystem.org/	Yes	Yes

TABLE 3.6 NORTH AMERICAN ENVIRONMENTAL CERTIFICATION PROGRAMS

3.2.6 ENVIRONMENTAL CERTIFICATION OF SOFTWOOD LUMBER

Chapter 2, Section 2 of this report explains the certification of forestland and the certification programs that operate in North America. Each of these programs (FSC, SFI, CSA, and ATFS) offers a chain of custody certification to participants in the supply chain for wood products. This fulfills the desire of end-use consumers for assurance that environmentally certified products are sourced from well-managed forestlands. This is especially true for developers seeking to certify a building under Leadership in Energy and Environmental Design (LEED) and other similar programs.

Wood product manufacturers who follow the guidelines for these certifications can stamp their products and market them as certified. Meeting the requirements for chain-of-custody certification generally involves detailed logistics, inventory management, batch processing, filings, and audits. Because there is considerable effort involved with acquiring and maintaining these certifications, some manufacturers decide not to certify their products even though most, if not all, of the raw materials they purchase are environmentally certified. Some producers choose to certify as much of their product as possible, while others choose to provide certified products only when specifically requested by a customer, and yet others choose not to be certified.

Certified lumber sales volumes are not available, but it is likely that the volume of lumber sold as certified does not represent a large proportion of the overall market. This is despite over 300 million acres in North America certified under SFI, about 175 million certified under FSC, about 100 million certified under CSA, and about 25 million certified under ATFS in 2017.[10] What this means for producers of mass timber products is that market demand for environmentally certified materials is relatively low. Nevertheless, if the mass timber producer is chain-of-custody certified, and needs to acquire certified lumber, they can likely find a chain-of-custody certified sawmill that can provide certified lumber of the necessary size, grade, and moisture content.

From interviews conducted by The Beck Group with some mass timber producers, the 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. In Chapter 4, **Table 4.3** lists mass timber producers and their certifications. **Table 3.6** has been included for those who wish to learn more about these certifications.

10 Stats and Facts. Sustainable Forestry Initiative. 2017.
Accessed at: https://www.sfiprogram.org/wp-content/uploads/SFI-ProgressReport-2018_FINAL-Summary.pdf

3.3 MASS TIMBER RAW MATERIAL DEMAND IN 2019

This section provides an estimate of the lumber consumed for mass timber production.

3.3.1 CUBIC VOLUMES OF MASS TIMBER PRODUCTS USED

The estimated demand for mass timber products in 2019 in North America is 20 to 25 million cubic feet. The components of this demand include

- CLT, NLT, and DLT panels used for building projects—this is the largest part of total mass timber demand
- CLT used for industrial matting
- Glulam used as supporting members in many CLT, NLT, and DLT buildings, and in post and beam structures
- Solid sawn lumber used in heavy timber decking and post and beam building projects

For more information about the number and size of mass timber building projects in 2019, see Chapter 6.

3.3.2 LUMBER DEMAND FROM MASS TIMBER

Based on the preceding estimate of mass timber demand in cubic feet, the **estimated 2019 lumber demand is 450 to 500 million board feet.** The estimate considers the relationship between cubic volumes and nominal dimension lumber measurements, and wood utilization rates for various mass timber products

3.4 IMPLICATIONS FOR MASS TIMBER RAW MATERIAL SUPPLY

The estimated 450 million to 500 million board feet of softwood lumber consumed for North American mass timber during 2019 equates to less than one percent of the 2019 North American softwood lumber production. The mass timber industry can expand to several times its current size before it will make a significant impact on the North American lumber industry. Even if the lumber demand expands to 3 billion board feet per year (more than six times the current level), it would represent only a 5 percent share of today's lumber production.

Also, consider that by 2021, approximately 5 billion board feet per year of new softwood lumber production capacity will be online in the U.S. South. That includes a mix of upgrades to existing mills and new greenfield projects at 16 different sites across the region. Nearly all the companies involved are well-established Southern yellow pine industry veterans, so a high percentage of the announced projects likely will be completed. The increased capacity has largely been driven by a combination of limited opportunities to expand production in the Western U.S. and the Inland Region of Western Canada because of tight log supplies, and an ample timber supply in the U.S. South that is privately owned and therefore more readily available for harvest. The expansion in North American lumber production capacity will help absorb new demand expected from increased mass timber construction

3.5 CLT MANUFACTURER EXPERIENCE

Existing North American CLT manufacturers using lumber were surveyed to assess how their experience procuring raw materials fits with the analysis developed in this chapter. Their feedback is summarized below.

- **Lumber Sizes:** 2-by-8 dimension lumber represents the largest volume of lumber used for CLT, with lesser amounts of 2-by-6 used. Consistent with the data in **Table 3.5**, 2-by-8 is typically lower in price than other sizes of dimension lumber, and the relatively large piece size can be a productivity advantage during the manufacturing process.

  Some other sizes of lumber, such as nominal 1-inch thickness, are used from time to time when an appearance grade layer is added to a panel, but the total volume of sizes other than 2-inch thickness appears to be very small.

- **Lumber Grades:** Most of the lumber purchased is #2 grade, with minor amounts of Select Structural or MSR used when the customer specifies those grades.

  Manufacturers reported that although #3 is acceptable for use in certain parts of the panel per PRG-320 specifications, they typically do not use it for multiple reasons. First, #3 lumber is much less available than #2 because it makes up a very small portion of the total lumber supply. Second, most #3 lumber contains areas with defects that prevent a good glue bond and those defective areas have to be trimmed out. So even though the cost is lower than #2 lumber, it creates more waste and is not a better value for CLT producers. Finally, because #3 lumber can only be used in certain parts of a panel, switching back and forth between grades and managing the material separately in inventory creates more problems than any (lumber) cost savings might be worth.

- **Moisture Content:** CLT requires lumber to be at a moisture content of 12 percent (+/-3 percent). Because most dimension lumber is dried to 19 percent moisture, manufacturers must work with sawmill suppliers to ensure that the lumber supplied is sufficiently dried. A variety of experiences were reported, but in general it appears that sawmills are willing to dry to a lower moisture content with little or no added cost to the buyer. But it was also common that a small portion of the supplied lumber arrived at the plant too wet.

  Part of the standard CLT manufacturing process includes testing the moisture content of the lumber, and any boards that are too wet are set aside and stored indoors for further drying. This is a feasible solution, but it adds to handling and inventory costs, so it appears to be an opportunity for sawmills to better serve their CLT-producing customers.

- **Sustainable Certification:** Manufacturers reported that very few panel orders specify the use of lumber that comes from environmentally certified forests. When certified lumber is specified, the FSC standard of certification is most frequently requested.

- **Opportunities for Improvement:** There are a number of ways that sawmills could provide lumber that would be a better fit for CLT manufacturers. These include:

  - **Dry to 12 percent target moisture content**: As mentioned above, supplying lumber that is dried to a moisture content of 12 percent (+/- 3 percent) would bring improved value to CLT manufacturers, and they may be willing to pay a small premium if entire orders are within the allowable range.

  - **Provide rough, dry lumber**: Because CLT lumber must be surfaced within 48 hours of layup (this helps with glue bonding), the current practice of using surfaced dimension lumber means that the lumber is surfaced twice, resulting in diminished wood fiber value (wood shavings are far less valuable than CLT panels). CLT manufacturers might be willing to buy rough, dry lumber that would result in a larger final surfaced size, meaning better use of the wood fiber and a thicker final panel (with improved strength properties).

  - **Random lengths**: Because lumber used in CLT panels is finger-jointed and trimmed to a variety of lengths, there is no reason that the lumber needs to be trimmed to 2-foot increments. Allowing for true random lengths, or at least smaller increments of 1 foot or 6 inches, would reduce lumber waste and increase marketable volumes for the sawmill.

CHAPTER 4: MASS TIMBER PANEL MANUFACTURERS

IMPACTS OF THE MARSHALL EFFECT ON TIMBER PANEL MANUFACTURERS:

- The practical capacity* of the mass timber manufacturers operating in 2019 is 15,494,000 cubic feet of panels allowed for use in structural applications.
- The estimated demand for mass timber used in North American buildings in 2034 will be 576,000,000 cubic feet.
- This means mass timber manufacturing practical capacity will need to increase by a factor of nearly 40 by 2034 to meet the increase in demand for mass timber used in buildings.

**Practical capacity is currently estimated at 65% of nameplate capacity. The gap between practical and nameplate capacity may shrink in the future as mass timber panel production becomes more standardized (i.e., mass timber panels are produced to standard sizes and thicknesses as opposed to the current.*

Mass timber describes a broad category of building materials and methods that utilize large wooden components as the primary structural elements in a building. As described in Chapter 1, mass timber is a family of related, but distinct products. While these products include traditional building materials such as post and beam, panelized products like CLT, NLT, and DLT are the innovations attracting architects, builders, and building occupants to explore wood as the construction material of choice for large buildings. This chapter focuses on mass timber panels (MTP) and describes the manufacturing process for select products. It also provides a comprehensive and up-to-date analysis of the existing and planned panel manufacturing capacity in North America; analyzes manufacturing costs; and finally, discusses several strategic and technical mass timber manufacturing issues.

A description of the primary mass timber products is given in Chapter 1. Throughout this chapter, the following MTP products are discussed:

- CLT – cross laminated timber
- DLT – dowel laminated timber
- NLT – nail laminated timber
- MPP – mass plywood panels

4.1 MTP MANUFACTURING PROCESS

The following sections describe the manufacturing process for various mass timber products.

4.1.1 CROSS LAMINATED TIMBER MANUFACTURING

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 manufacturing process includes:

1. Inspecting lumber feedstock for quality and moisture content, and marking defective areas to be removed.
2. Using a cross-cut/chop saw to remove major defects from lumber feedstock.
3. Finger-jointing the remaining defect-free lumber pieces into long lengths of lumber.
4. Cutting the finger-jointed lumber into specified lengths.
5. Surfacing (planing) the lumber to the desired thickness and, in the process, activating the wood surface for application of adhesive.
6. Panel lay-up forming the panel layers.
7. Applying adhesive to each panel layer.
8. Pressing the panel while adhesive cures.
9. Final panel manufacturing, including edge trimming and cutting of desired openings, such as windows, and channels for utilities, such as electrical and water piping.
10. Panel packaging and shipment.

FIGURE 4.1 CLT LAYUP AND GLUE APPLICATION[1]

The equipment required to produce CLT panels includes:

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.

Grade Scanning: Identifies 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 (8 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 only limits on the length of a CLT panel are highway/truck restrictions when delivering panels from manufacturer to building site.

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 prior to applying the glue.

Panel Layup: 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 layup time.
- **Vacuum press:** Uses a clamshell and plastic sleeve to encapsulate a panel and then sucks out the air to tighten gaps between boards.
- **Computer Numerically Controlled (CNC) machine:** Uses saws and router heads with movement and actions that are computer controlled 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.

1 Source: Ledinek

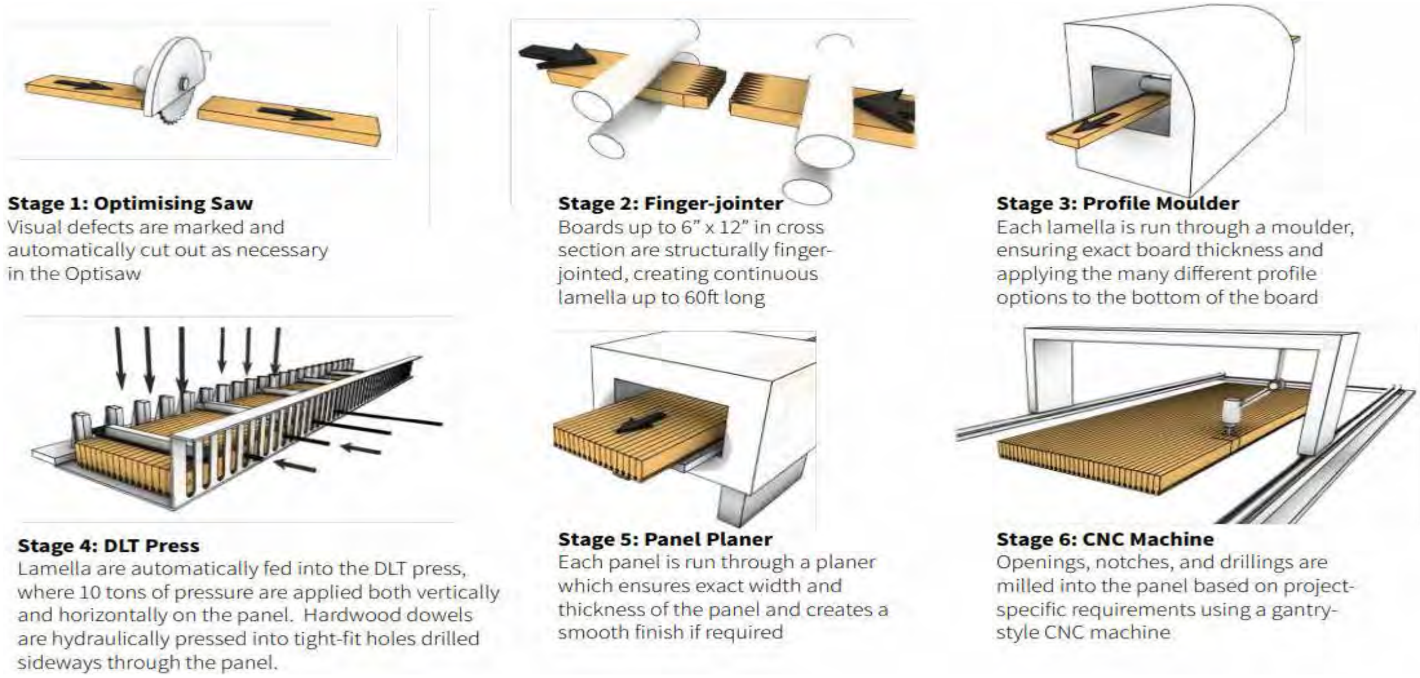


FIGURE 4.2 DRAWING OF DLT MANUFACTURING LINE[2]

4.1.2 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 and dowels are pressed into the panel. 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, so the panels do not have the shear strength properties derived from cross lamination.

StructureCraft's 2018 DLT Design Guide (**Figure 4.2**) provides an illustration of the manufacturing process.

4.1.3 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 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 layup configurations to create a panel.

When making NLT at 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. Similar to 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.

2 Source: StructureCraft

FIGURE 4.3 SCL BILLETS USED IN MPP[3]

4.1.4 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. In the case of Freres Lumber, the only current MPP manufacturer, the company also produces its own veneer. The MPP is created in a two-stage process. First, billets of structural composite lumber (SCL), each 1 inch thick by 4 feet wide and 48.5 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 the requirements of a given project.

Regardless of the mass plywood panel size, however, scarf joints are used to join the SCL billets, and the joints are staggered through the mass plywood panel so that weak points are not created from the joints. 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.

3 Source: Freres Lumber

FIGURE 4.4 MASS TIMBER MANUFACTURER TIMELINE

4.2 MTP MANUFACTURERS

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.

MTP manufacturing is still relatively new in North America, but interest and growth in the technology has spiked in the last several years. The status of manufacturing operations is constantly changing, with several plants recently completed and others under construction. The data and information that follows was current as of December 2019.

Figure 4.4 is a timeline showing the development of mass timber manufacturers over time.

4.2.1 OPERATING MTP PLANTS

The first mass timber manufacturing plants in North America were Nordic Structures in Montreal, Quebec, established in 2007; and Structurlam of Penticton, British Columbia, established in 2010. Both companies are leaders in architectural and industrial grade CLT for building purposes. Also in Canada, StructureCraft of Abbotsford, British Columbia, was established in the late 1990s as a construction firm specializing in timber and hybrid-timber structures. In recent years, the company made inroads with the introduction of NLT and DLT products and completed several high-profile building projects.

SmartLam of Columbia Falls, Montana (2012), and Sterling in Lufkin, Texas (established in 1949, but began producing MTPs in 2012), were the first U.S. manufacturers of CLT panels. Both companies initially focused on producing large volumes of CLT industrial matting, or rig mats, which are used primarily for environmental protection in industrial and construction applications, including oil and gas drilling, pipeline and utility right of way work, and remote construction.

A second wave of companies entered the MTP manufacturing space in recent years. Since 2015, several new entrants focused on producing MTP's, including:

- DR Johnson Wood Innovations in Riddle, Oregon. In September 2015, this company received the first ANSI/APA PRG certification in the United States.
- SmartLam shifted from production of CLT industrial mats and focused on the architectural/building mass timber market. Accordingly, they followed DR Johnson by first receiving SFI/FSC sustainability certification in 2015 and architectural PRG 320 certification in 2016.
- In Ripon, Ontario, Element 5 (2016) opened its project-based design firm and manufacturing company specializing in mass timber project solutions.
- In Lyons, Oregon, Freres Lumber Company (established in 1922) produced, patented, and certified the first mass plywood panel (MPP) in 2017.
- StructureCraft builds NLT structures and transitioned to DLT panel manufacturing at its new manufacturing facility in late 2017.
- Even more recently, International Beam (established in 1995), with manufacturing facilities in Canada that produce wooden I-joists and other engineered wood products, formed IB X-Lam USA LLC and completed installation of its CLT production line in Dothan, Alabama. The plant received APA PRG 320 certification and started producing CLT panels in 2018. The plant was subsequently acquired in 2019 by SmartLam North America.
- Leaf Engineered Wood Products of Devlin, Ontario, started up a glulam, CLT, and joist plant in early 2019. The company previously produced glulam timbers, but has now added CLT manufacturing.
- Texas CLT started up its CLT plant in Magnolia, Arkansas in 2019. The plant is focused on production of industrial matting.
- Katerra, established in 2015, is a vertically integrated company that includes real estate development, design, and construction. Their large scale CLT production facility came online in mid-2019.
- Vaagen Timbers (established in 2017) also started up a CLT plant in mid-2019 in Colville, Washington. Although organized as separate companies, Vaagen Timbers is located next to a Vaagen Brothers Lumber sawmill that produces dimension lumber. Vaagen Timbers is focused on producing specialized CLT, glulam beams and glulam timbers, and long structural finger joint material.
- Sterling has expanded into the Southern mass timber market. Its new Lufkin, Texas, plant began operation in Fall 2019.

4.2.2 MTP PLANTS UNDER CONSTRUCTION

As of December 2019, three CLT production plants have started construction, including:

- Kalesnikoff, a family owned lumber producer, is developing a CLT and glulam plant in South Slocan, British Columbia. The facility should be operational in 2020.
- Element 5 is developing a second CLT plant, with glulam production to complement the panels, in St. Thomas, Ontario. The plant is scheduled to begin operation in late 2020.
- Texas CLT has also announced the construction of a second CLT production facility. The new plant is located in Jasper, Texas, and is expected to be operational in 2020.

STATUS	2019 FACILITY COUNT	DATES (RANGE)
Active	14	2007-2019
Construction	3	2020-2021
Proposed *	3	2021-2026
Total	**20**	
** Publicly Announced. Date range for proposed plants is estimated date of operation.*		

TABLE 4.1 2018 NORTH AMERICAN MTP MANUFACTURING FACILITIES BY STATUS (INCLUDES CLT, DLT, NLT, AND MPP)[4]

4.2.3 PROPOSED MTP PLANTS

There also are three publicly announced mass timber plants in the planning process, two in United States and one in Canada.

1. **SmartLam North America** (currently operating in Montana and Alabama) also has plans for a mass timber facility in the Northeastern U.S.
2. **Sidewalk Labs** has announced plans to develop a CLT manufacturing facility to supply its large-scale mass timber development project in Toronto, Ontario.
3. **Structurlam**, currently operating in British Columbia, has announced plans to develop a new CLT plant in Conway, Arkansas.

In summary, at the time of publication, there are fourteen active MTP production facilities, three under construction, and three proposed or publicly announced in North America. See **Table 4.1.**

4.2.4 MTP MANUFACTURERS BUSINESS SERVICES REVIEW

Mass timber is distinct from most other wood building materials because MTP manufacturers tend to work closely with architects and engineers during building design and specification regarding MTP product specifications (size, thickness, strength). Throughout this process, the manufacturers provide a variety of services to assist building developers and specifiers. As many in the industry have noted, early collaboration between developers, specifiers, and panel manufacturers is essential for efficient and cost-effective design and construction.

North American mass timber panel manufacturers were surveyed to identify the support services offered to customers. Information was collected from a combination of website reviews and direct discussions with manufacturers. Services are grouped into three categories: architectural design, manufacturing and material supply, and construction support.

4 Source: Doug Fir Consulting LLC 2019, The Beck Group

4.2.4.1 Architectural Design and Project Support

- **Design Assist:** MTP manufacturers assist architects with their design and how to best incorporate mass timber into the building.
- **Engineering Services:** Many MTP manufacturers employ engineers who help building designers with the engineering review of structural, mechanical, electrical, seismic, acoustic, fire safety, and other aspects of a building specific to the properties of mass timber products.
- **Modeling CAD Work:** Most MTP manufacturers assist in an array of construction documentation. Most recently, the use of Computer Aid Design services (Solidworks, CATIA, Cadwork, Autocad) has been important for panelizing projects and identifying building assemblies. MTP manufacturers can simply transport engineering documentation into CAD programs and develop robust 3D models of the project using mass timber as part of the building's structure.

4.2.4.2 Manufacturing and Material Supply

- **Panel Manufacturing:** 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:** 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 have also started up, offering secondary manufacturing (CNC milling, finishing) of panels, glulam, and timbers.
- **Supplying Connectors/Hardware/Fasteners:** If MTP manufacturers do not produce connectors and other hardware, they may source them from various manufacturers. They might source products like hardware and fasteners that are required in mass timber buildings. As a service, most MTP manufacturing firms will source needed components.

4.2.4.3 Construction and Installation Support

- **Logistics planning:** Several MTP 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.
- **Construction and Installation Support:** The speed and ease of installation is a hallmark of mass timber panels and a key reason for the industry's success. Because MTP installation and construction are still new to most building contractors, several manufacturers with construction experience provide on-site support.

4.2.4.4 Other Business Services

- **Consulting Services:** Many MTP manufacturers offer consulting services on an hourly basis. If projects require more support on the front end of a project to assess the practicality of CLT, 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 MTP manufacturers offer in-house steel fabrication as a product 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 MTP 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 special requirements of a project.

Company Name (A-Z)	Panel Types Offered	Architectural Design and Project Support	Manufacturing and Material Supply	Construction Support	Other
DR Johnson Wood Innovations	A, I	x	x		
Element5	A, I	x	x		
Freres	A, I	*	x		
Kalesnikoff	A, I, M	*	x	x	
Katerra	A	x	x	x	R,I
LEAF Engineered Wood Products	A, I	x			
Nordic Structures	A, I	x	x	x	
SmartLam North America	A, I, M	x	x		SF
Sterling	A, I	x	x	x	
StructureCraft	A, I, M	x	x	x	
Structurlam	A, I	*	x		
Texas CLT	M				
Vaagen Timbers	A, M	x	x	x	EPS

A — Architectural Grade CLT I- Industrial Grade CLT
M — CLT Matting
EPS — Environmental Protection Services SF- Steel Fabrication
R — Renovation Services I- Interior Design

** Companies noted they work closely with design/engineering partners and outside firms to help and assist in projects. They also have dedicated engineering staff.*

TABLE 4.2 SUMMARY OF SERVICES OFFERED BY MTP MANUFACTURERS[5]

As the North American building market matures, it is likely to more closely resemble the model developed in Europe. With recent mass timber building code changes (see **Section 5.3**), a small number of standardized panel sizes will likely be developed. This may include standard sizes (thickness, width, length), and associated strength and other engineering characteristics. It may also include standard levels of finishing. This would lead to improved efficiencies for manufacturing plants, reducing costs and simplifying the design process (as is the case with some European panel manufacturers). It would also open the door for specialized intermediate manufacturers that would machine and modify standard panels. This transition to a higher level of panel standardization in North America will likely take a decade. In the meantime, MTP manufacturers will continue offering an array of support services.

5 Source: Doug Fir Consulting LLC 2019, The Beck Group

4.2.5 MTP MANUFACTURERS: COMPANY AND FACILITY DETAILS

The level of experience and strategic orientation of companies entering the MTP 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 MTP manufacturers by illustrating the various products offered by known manufacturers and the status of design guides, ANSI/PRG 320 certification, and sustainability certification.

Company Name	Company Status	Date Established	Products Offered	Design Guide Available	PRG 320 Certified	Certification Type	PRG 320 Certification Date	Sustainability Certification
DR Johnson Wood Innovations	Active	1967	CLT, GLT, Lmbr, Tmbrs, EWP	Yes, by request	Yes	APA	2015	FSC, Green Gold
Element 5*	Active	2016	CLT, GLT, NLT	No	Yes	APA	2019	Unknown
Freres	Active	1922	MPP, Lmbr, Plywood/ Veneer	In Process	Yes	APA	2018	No
Kalesnikoff	Construction	1940	CLT, GLT, Timbers, Lumber	In Process	In Process	APA	In Process	FSC, PEFC
Katerra	Active	2015	CLT	Yes	Yes	PFS TECO	2018	SFI, PEFC, FSC
LEAF Engineered Wood Products	Active	2018	CLT, GLT, EWP	No	Yes	APA	2019	Unknown
Nordic Structures	Active	2007	CLT, GLT, I-Joist, Lmbr, CLT	Yes	Yes	APA	2012	Yes
SmartLam North America*	Active	2012	CLT, Glulam	Yes	Yes	APA	2016	SFI, FSC
Sterling Solutions	Active	1949	CLT, Lmbr	No	No	None	-	No
StructureCraft	Active	1998 / DLT 2017	DLT	Yes	N/A	N/A	-	FSC, PEFC
Structurlam	Active	2007	CLT, GLT	Yes	Yes	APA	2012	Yes
Texas CLT*	Active	2018	CLT	No	Unkown	-	-	Unknown
Vaagen Timbers	Active	2016	CLT, GLT, FJ Lmbr, Lmbr	Yes	Yes	APA	2019	In Process

** Companies with construction and proposed additional facilities*

TABLE 4.3 MTP MANUFACTURER DETAILS[6]

6 Source: Doug Fir Consulting 2019, The Beck Group

FIGURE 4.5 MTP PANELS FOR BUILDINGS[7]

4.2.6 MASS TIMBER PANEL TYPES

The following sections describe types of MTP currently utilized in North America.

4.2.6.1 Building Products and Grades

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**, which will either be covered or does not need to meet an appearance requirement. Either grade can be PRG 320 certified if needed. Each manufacturer offers an array of MTP finishes; in most cases, the finish can be customized. Each is described in greater detail below:

- *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 knot holes. 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.

7 Source: Structurlam, Building: First Tech

- *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 knot holes 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 type 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 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. MTPs used in roofs and elevator shafts are typically industrial grade.

4.2.6.2 Industrial Matting

Industrial matting is not intended for use in buildings, but rather in environmental protection applications. 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.

The production of industrial matting is less labor intensive and may involve a lower grade of lumber, so the mats are typically lower in cost than panels used for building projects.

Traditionally, mats are made of lower-value hardwood timbers that are nailed or bolted together. CLT mats offer superior value because of 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, which reduces the set-up time compared to traditional industrial mats. **Figure 4.6** illustrates mass timber industrial mats in use.

While SmartLam and Structurlam produce some industrial mats alongside their CLT building products, Sterling focuses exclusively on industrial matting. Sterling has expanded production rapidly, and when their Lufkin, Texas, plant came online in 2019, they became the largest CLT producer in the world in terms of annual capacity.

4.2.6.3 2019 Facility Overview by Panel Product

Table 4.4 summarizes the types, sizes, and species of MTP products offered by the existing, under construction, and planned MTP manufacturers in North America. Not surprisingly, certifications and species correspond to the region in which the plants are located. Ply and panel dimension maximums describe the press limitations in the production of each panel.

FIGURE 4.6 CLT PANELS IN INDUSTRIAL MAT APPLICATIONS[8]

8 Source: Sterling Solutions

Company	Facility Status	Panel Product Name	PRG 320 Layup Certification	Species	Panel Thickness or Ply Offered	Panel Dimensions
PANELS FOR BUILDING						
DR Johnson Wood Innovations	Active		V1, E2 & E2M1	DF	3, 5, 7 Ply	Thickness- 4 1/8" to 9 3/8"+G4:G28 Width- 1' to 10' Length- Up to 42'
Element5	Active	Macro.CLT / Nano.CLT /	Unknown		2" to 16"	Thickness- 2" to 16" Width- 1' to 9 1/2' Length- 35' 5
Freres	Active	Mass Plywood Panel (MPP)	F16	DF	2" to 12"	Thickness- 2" to 1' Width- 2" to 12' Length- Up to 48'
Kalesnikoff	Construction		E1, E2, E3, V1, V2	DF/L, SPF, Hem Fir	3, 5 Ply (7,9 in Process)	Thickness- 1.75" to 16" Width- 12" to 11'6" Length- 8' to 60'
Katerra	Active		V2, E1 more in process	SPF, DF	N/A	Thickness- 3.4" to 12.4" Width- Up to 12' Length- Up to 60'
LEAF Engineered Wood Products	Active		Unknown	N/A	3, 5, 7, 9 Ply	Thickness- 3 1/2" to 10 1/2" Width- 6' to 10' Length- up to 90'
Nordic Structures	Active	NORDIC X-LAM	E1	SPF	3, 5, 7, 9 Ply	Thickness- 3" to 15" Width- 1' to 8' Length Up to 64'
SmartLam North America	Active		V1-V4, more in process	SPF-S, Hem Fir	3-9 Ply	Thickness- 4 1/8" to 12 3/8" Width- 1' to 11.5" Length- Up to 54'
StructureCraft	Active	DowelLam™	N/A	SPF, DF, HF, SS, WRC, YC	3-9 Ply	Thickness: up to 12in (0.3m) Width: up to 12 ft (3.75m) or wider, governed by shipping Length: up to 60.5ft (18.5m)
Structurlam	Active	CrossLam CLT®	V2, E1	SPF, DF/L	2x6 up to 2x12	Thickness- 3" to 12 3/8" Width- 1' to 10 Length- Up to 40'
Vaagen Timbers	Active		V1, more in process	DF/L, SPF, White Fir	3.43" to 12.42"	Thickness- 4 1/8" to 11 1/2" Width- 1' to 4' Length- Up to 60'
PANELS FOR INDUSTRIAL MATTING						
Sterling Solutions	Active	TERRALAM®	N/A	SYP	3,5,7	3 Ply- 8x14' / 8x16' 5 Ply- 4x16' / 4x18' / 8x16' 7 Ply- 8x16' / 8x18'
Texas CLT	Active		N/A	SYP	Unknown	Unknown

TABLE 4.4 MTP PRODUCTS OFFERED[9]

9 Source: Doug Fir Consulting LLC 2019, The Beck Group

UNIT OF MEASURE	MASS TIMBER FACILITY COUNT	BUILDING CAPACITY		INDUSTRIAL MATTING		TOTAL PANEL CAPACITY	
		Max	Practical	Max	Practical	Max	Practical
Thousand Cubic Meters (mcm)	14	675	439	725	471	1,400	910
Thousand Cubic Feet (mcf)		23,837	15,494	25,603	16,642	49,440	32,136

TABLE 4.5 ESTIMATED ANNUAL NORTH AMERICAN MTP MANUFACTURING CAPACITY (AS OF LATE 2019)

4.2.7 MTP MANUFACTURING CAPACITY AND PRODUCTION ESTIMATES

Annual production capacities are estimated as of the end of 2019 for North American MTP manufacturers. Maximum plant capacity as described in this report is based on projected maximum press production at each plant, given the assumption of a two-shift operating schedule and full utilization of the press.

Additionally, a *practical capacity* was estimated, recognizing that manufacturing plants rarely run at 100 percent of capacity and press volume is not always fully utilized (i.e. panels produced are smaller in dimension than the press itself). A 0.65 factor was used to arrive at an estimate of practical capacity. Finally, capacity estimates are split between end-product uses (building or industrial matting).

Table 4.5 shows the 14 active North American manufacturing facilities with an estimated annual practical panel capacity of 910 MCM (thousand cubic meters), which equates to 32 MMCF (million cubic feet). Of this total annual panel capacity, 48 percent is for building products, with the balance dedicated to industrial matting.

4.2.8 PROJECTED ANNUAL NORTH AMERICAN MTP MANUFACTURING CAPACITY

What will be the mass timber panel manufacturing capacity beyond 2019? Three new facilities are under construction and due to come online sometime in 2020, and they are spread out geographically. The total projected practical capacity for these facilities is 78 MCM, or 2.8 MMCF.

As of January 2020, three proposed facilities have been publicly announced. Combined, these plants have an estimated maximum annual capacity of 182 MCM. **Table 4.6** summarizes the estimated annual capacity of the under-construction and proposed MTP manufacturers.

UNDER CONSTRUCTION AS OF JANUARY 2020

UNIT OF MEASURE	MASS TIMBER FACILITY COUNT	BUILDING CAPACITY		INDUSTRIAL MATTING		TOTAL PANEL CAPACITY	
		Max	Practical	Max	Practical	Max	Practical
Thousand Cubic Meters (mcm)	3	95	62	25	16	120	78
Thousand Cubic Feet (mcf)		3,355	2,181	883	574	4,238	2,754

PROPOSED AS OF JANUARY 2020

UNIT OF MEASURE	MASS TIMBER FACILITY COUNT	BUILDING CAPACITY		INDUSTRIAL MATTING		TOTAL PANEL CAPACITY	
		Max	Practical	Max	Practical	Max	Practical
Thousand Cubic Meters (mcm)	3	280	182	0	0	280	182
Thousand Cubic Feet (mcf)		9,888	6,427	0	0	9,888	6,427

TABLE 4.6 NORTH AMERICAN MTP MANUFACTURING CAPACITY

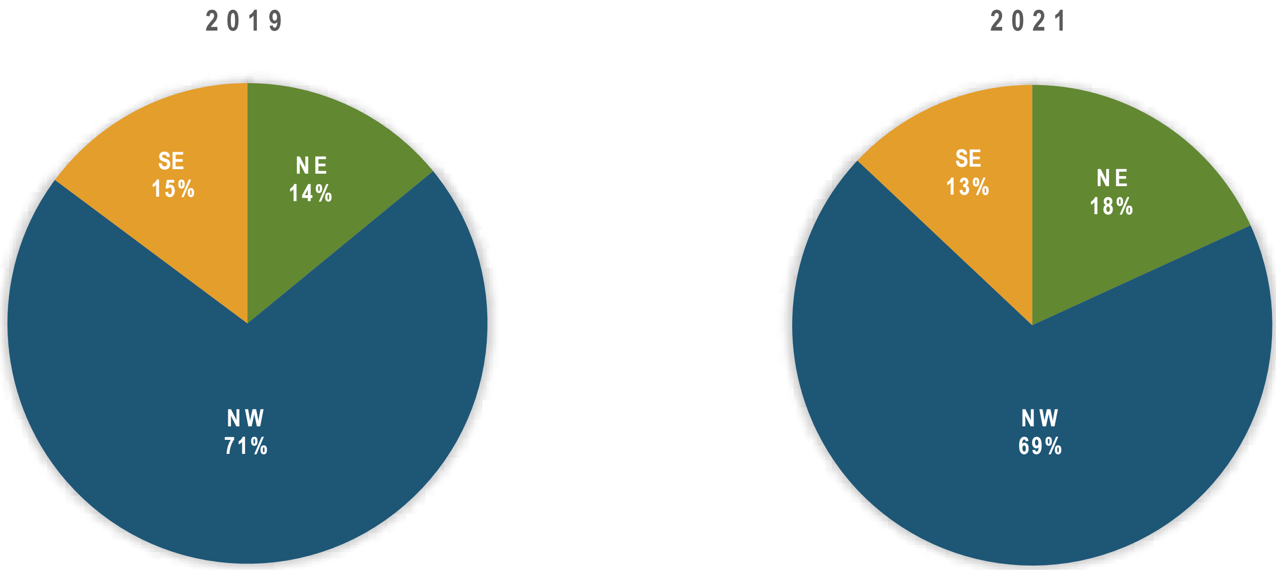


FIGURE 4.7 MASS TIMBER BUILDING PANEL CAPACITIES BY REGION IN YEARS 2019/2021

Figure 4.7 shows how North American building panel capacity will shift regionally from 2019 to 2021, based on plants that are under construction as of January 2020.[10]

4.2.9 NORTH AMERICAN MTP PRODUCTION

Accounting for plants currently under construction, **North American MTP manufacturing capacity will have increased more than 1,000 percent over the 11-year period from 2010-2020** (see **Figure 4.8**). This equates to the addition of more than one new production facility every year, on average. Although the mass timber market is relatively new, this steady and dramatic increase in production capacity signals the industry's and market's readiness for continued growth. Many MTP manufacturers have learned lessons from their European counterparts and have implemented large-scale high-tech and fully automated production lines to help drive down operating costs. (See **Section 4.2.10** for more discussion of global capacity.)

10 Industrial matting capacity excluded

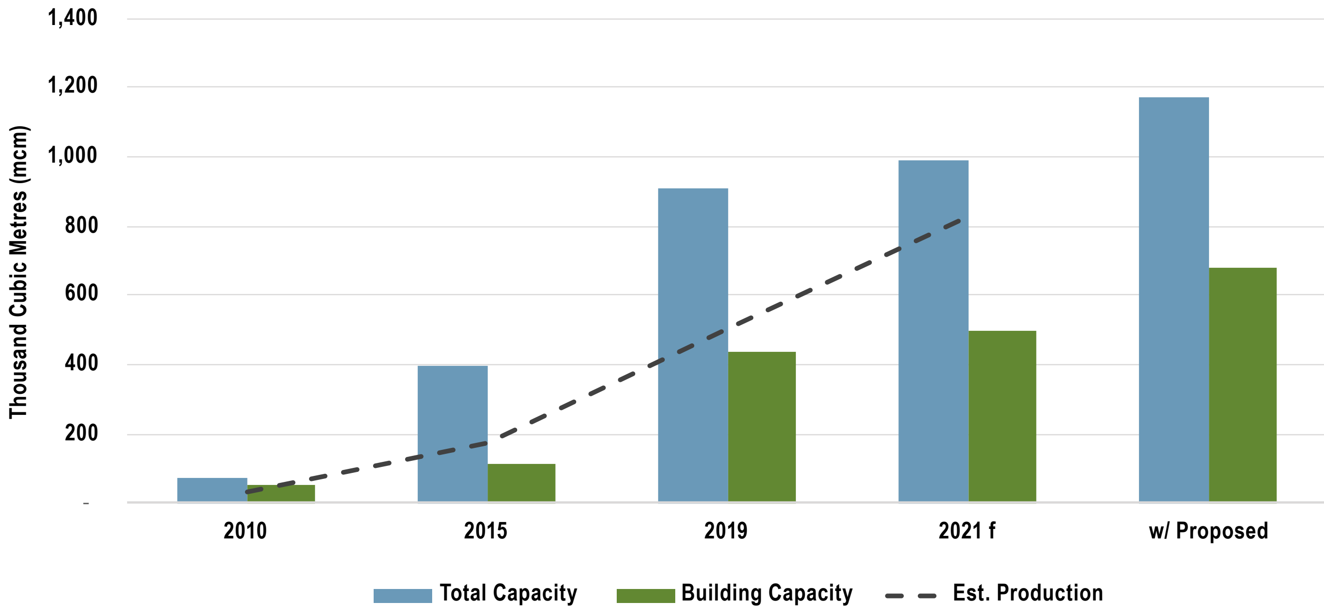


FIGURE 4.8 NORTH AMERICAN MTP PRACTICAL CAPACITY AND ESTIMATED PRODUCTION[11]

CONTINENT	2020 CAPACITY (MCM)		% OF 2020 BUILDING	% OF ALL CLT CAPACITY
	Building	Total [12]		
Europe	1,727		61%	48%
North America	770	1,520	27%	43%
Oceania	200		7%	6%
Asia	95		3%	3%
South America	10		0%	0%
Africa	10		0%	0%
Total	2,812	3,562	100%	100%

TABLE 4.7 GLOBAL MTP CAPACITY BY CONTINENT [13]

4.2.10 GLOBAL CLT MANUFACTURING CAPACITY

Although the focus of this report is on the North American industry, it should be noted that CLT panels from overseas are imported into North America, primarily from Europe. **Table 4.7** lists estimated global MTP production capacity by continent for 2020. North American capacity is expected to represent more than 40 percent of global MTP production by 2020 (all figures based on maximum press capacity).

11 Total includes Industrial Matting Capacity

12 Doug Fir Consulting LLC 2019, The Beck Group

13 Sources: VDMA, Timber Online, Doug Fir Consulting LLC 2019, The Beck Group

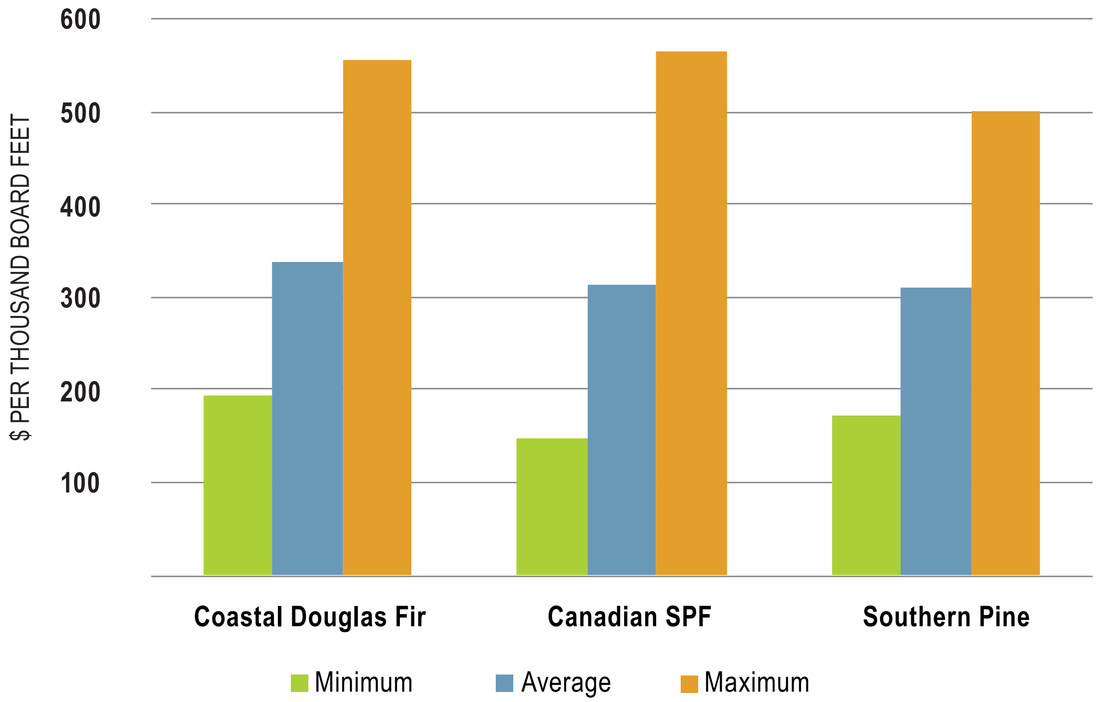


FIGURE 4.9 LUMBER PRICE VARIABILITY FOR CLT

4.3 CLT MANUFACTURING ECONOMICS

The following section provides an analysis of the costs associated with production of MTPs.

4.3.1 LUMBER COST

Lumber supply is the largest cost for CLT manufacturers, typically representing at least 50 percent of the total production cost. Volatility in lumber prices represents a challenge for CLT (and other MTP) producers because, while lumber market prices can change on a weekly basis, the panel manufacturer may be bidding on a project many months in the future. 2018 was particularly volatile for North American softwood lumber values, with prices spiking midyear, then dropping by nearly half.

Figure 4.9 illustrates the minimum, average, and maximum prices for #2 2-by-8 dimension lumber in key producing regions of North America over a 10-year period from 2009 to 2018. Peak prices were over $500 per thousand board feet in all regions, then dropped below $200 per thousand board feet at the market's lowest point.

	MEASUREMENT UNITS	LUMBER COST LEVEL		
Delivered Lumber Price	$ per MBF	$500	$325	$200
	CF per MBF	44.4	44.4	44.4
Lumber Cost, Panel Basis	$ per CF	$11.25	$7.31	$4.50
	CF per CM	35.3	35.3	35.3
Lumber Cost, Panel Basis	$ per CM	$397	$258	$159

TABLE 4.8 LUMBER COST CALCULATIONS FOR CLT

To understand lumber prices on the basis of CLT panel output volume, one must consider the difference between nominal sales sizes and actual cubic volume. (A nominal 2-by-8 is actually 1.5 inches by 7.25 inches, and there are similar differences for other sizes of dimension lumber.) In addition, lumber volume is lost during the panel manufacturing process (surfacing lumber, trimming lumber for defects, trimming panels to final size). **Table 4.8** illustrates lumber cost on a net panel output basis (shown in both $/cubic foot (CF) and $/cubic meter (CM)) at varying delivered lumber prices. Because manufacturing losses, and therefore conversion factors, will vary by plant and panel specification, this data should be considered as an estimate.

4.3.2 MANUFACTURING COST

Aside from lumber, other operating costs at CLT plants vary depending on scale, level of automation, and the amount and type of finishing required for a specific panel. (Architectural grade panels require more labor and material costs than industrial grades.) Cash operating costs commonly range from $5 to $7 per cubic foot.[14] **Figure 4.10** shows a typical breakdown of cash manufacturing costs as a percent of total, excluding lumber.

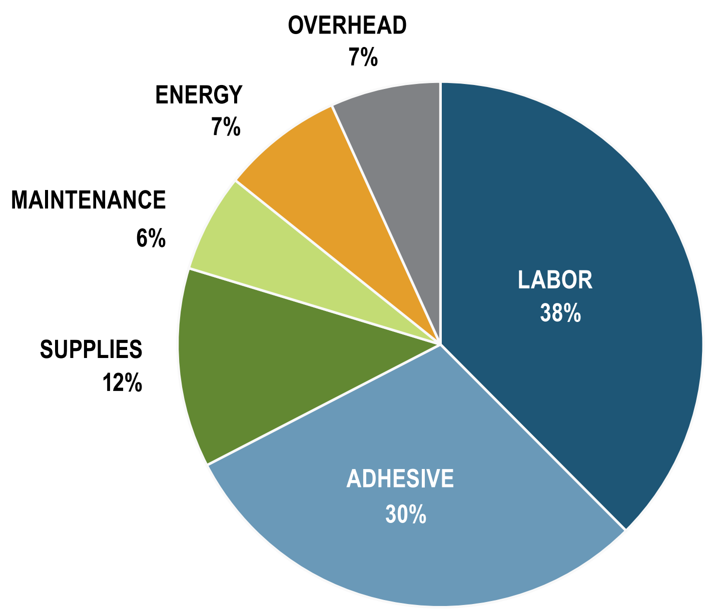


FIGURE 4.10
CLT MANUFACTURING COST BREAKDOWN (EXCLUDES LUMBER)

14 Excludes depreciation, interest, and taxes

4.4 OUTLOOK FOR MTP MANUFACTURERS

The mass timber industry has experienced very rapid growth in North America, with continued expansion expected for the foreseeable future. This section outlines a variety of headwinds and opportunities for MTP manufacturers.

4.4.1 LIMITATIONS IN MANUFACTURING GROWTH IN NORTH AMERICA

Both demand and production capacity for MTPs are growing rapidly in North America. Continued expansion faces some potential limitations, primarily on the supply side.

- **Understanding of building market and design phase:** While some companies in North America have provided a suite of business services focused on the architectural building uses of mass timber, some MTP-producing 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 12-month lead times to deliver equipment.
- **Manufacturing learning curve:** Several MTP 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, which may negatively affect broader mass timber market growth.
- **Product standardization:** Currently, 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 MTP manufacturers (additional, highly trained staff), planning and logistical challenges, and can lengthen the design phase, 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.

4.4.2 OPPORTUNITIES FOR MANUFACTURING IN NORTH AMERICA

- **Local, state, and national building code changes:** As described in **Section 5.3**, building code changes that allow wood's use in taller buildings continue 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:** Currently a limitation in the growth of panel manufacturing, this 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 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 Thinkwood, among others. Additionally, the International Mass Timber Conference has played a vital role as a venue for sharing information in 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 2018 Farm Bill, passed by Congress in December 2018, included the Timber Innovation Act, which provides grants and enhances research, development, and technical assistance in support of mass timber construction.
  - Seeking to enhance mass timber design and engineering, Oregon State University and the University of Oregon have partnered to establish the Tallwood Design Institute. The organization combines expertise from both schools in wood science, engineering, and architecture.
  - In 2019 the State of California offered a $500,000 grant program to stimulate the development of viable and repeatable mass timber designs for commercial and multifamily buildings
  - The U.S. Forest Service has supported mass timber market development and growth, including funding the Wood Innovations Grant Program, the Tall Wood Building Competition, and mass timber research through the Forest Products Laboratory, the Mass Timber University Grant Program, and other partners.

CHAPTER 5: MASS TIMBER DESIGNERS & SPECIFIERS

"All important ideas must include the trees, the mountains, and the rivers." — Mary Oliver

IMPACTS OF THE MARSHALL EFFECT ON MASS TIMBER DESIGNERS AND SPECIFIERS:

- Carbon neutrality is an important goal, but the building industry can and should go further, and by 2034 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.[a,b]
- Quantifying the embodied carbon of wood products is complex, and it's currently in a nascent and rapidly developing research phase.
- Forestry practices matter greatly in the carbon storage potential of wood, but it is not yet clear how to accurately measure or regulate carbon objectives.
- The Life Cycle Analysis (LCA) of a given building may choose to exclude wood decomposition in the carbon profile to better understand short-term (2050) impacts. Reuse potential is generally not factored in LCA models, nor is the global goal of reducing atmospheric carbon in the short term.

a. There is an estimated 0.023 tons of carbon offset for every square foot of mass timber building instead of using steel and/or concrete.
b. There is an estimated 0.0047 net tons of carbon sequestered by mass timber for every square foot of mass timber building.

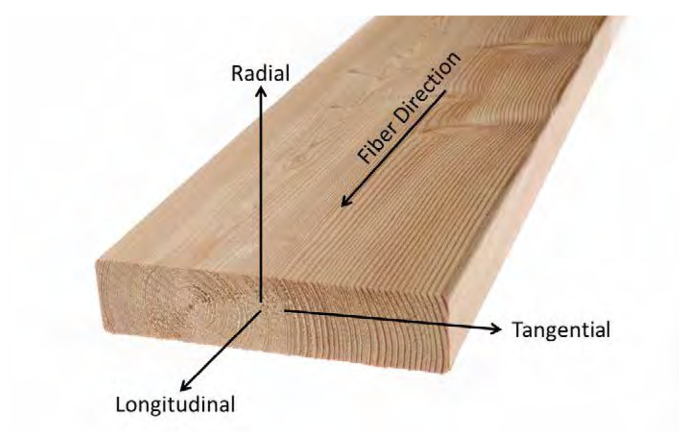
5.1 MASS TIMBER DESIGN CONSIDERATIONS

5.1.1 PANEL STRENGTH

Wood is one of the oldest building materials. As far back as 6000 BCE, humans made dwellings using wood. Wooden longhouses sheltering more than 20 people date to at least 4000 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 (MTP) systems.

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 strength 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.

FIGURE 5.1 LUMBER STRENGTH ILLUSTRATION



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 innumerable 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.**

5.1.2 ADHESIVES

Adhesives play an important role in many engineered wood products. The selection of the proper adhesive for a given application, and the process and conditions under which the adhesive is applied, are critical. Adhesives are used in most engineered wood products, including plywood, LVL, glulam, CLT, and MPP. Standards have been established to ensure that the adhesives are reliable and safe, and many products have Environmental Product Declarations (EPD) available.

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 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.

5.1.3 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 glued-in, or dry insert, wooden or steel rods. Some of these systems are proprietary, while others are traditional and widely available.

There are two families of connections for wood construction: traditional joinery (or carpentry) and mechanical. Joinery uses specialized cutting techniques to form joints between wood components (mortise and tenon, dovetail, etc.). Mechanical fasteners include nails, screws, and bolts. Joinery can create impressive results, both in beauty and strength; however, it is a time-consuming manual process that requires a significant amount of skill. By comparison, mechanical fasteners, connectors, and connector systems can be installed quickly and easily. This measurable difference in labor costs, between mechanical and jointed connections, may be minimized by the further development of sophisticated and affordable CNC machining.

Figure 5.2 shows examples of connectors used in mass timber construction.

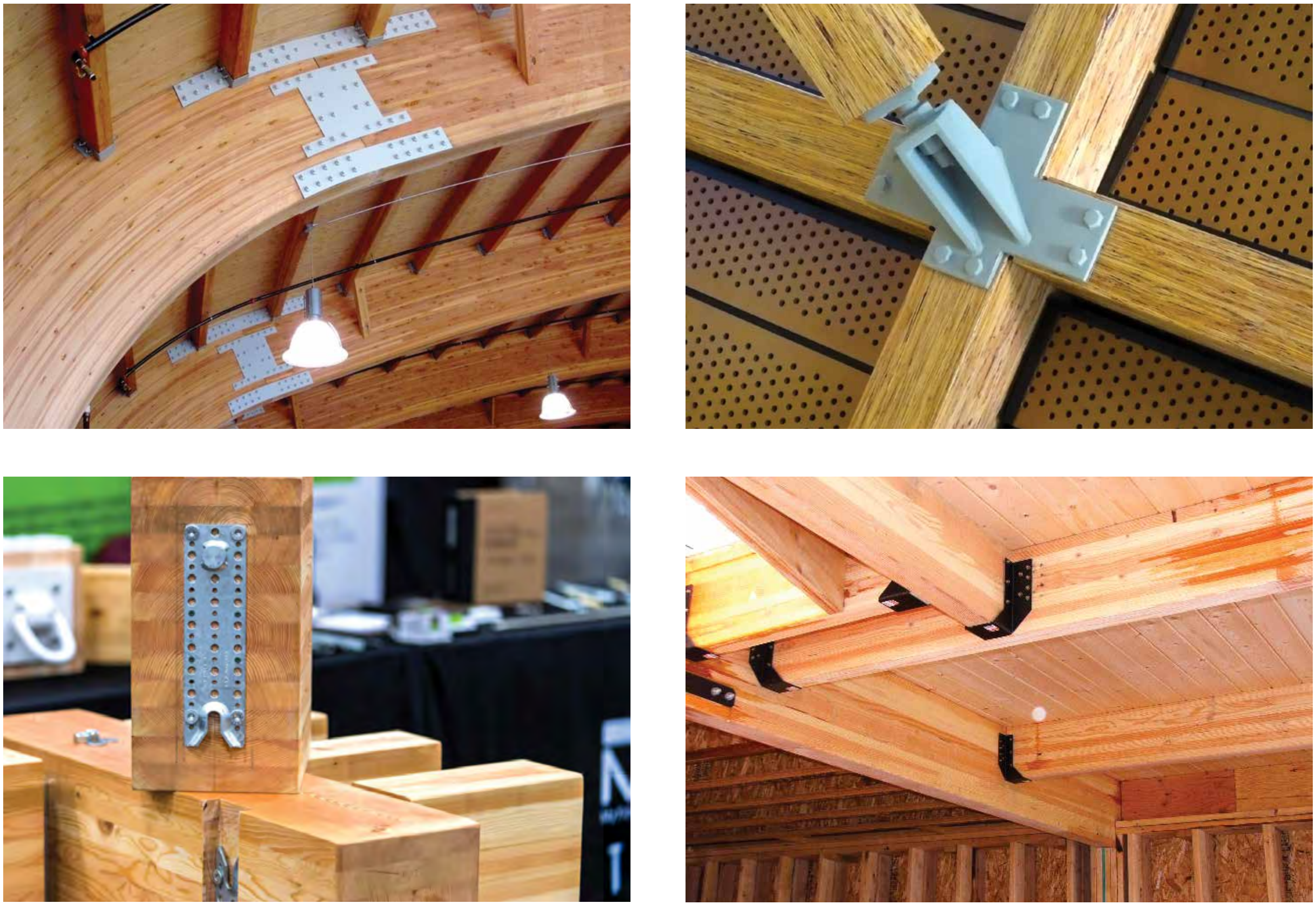


FIGURE 5.2 MASS TIMBER CONNECTOR EXAMPLES[1]

Mechanical fasteners or connectors fall into three main categories: dowel connectors, connector plates, and shear (or bearing) connectors. Many proprietary systems also are available.

Dowel connectors are the most common type of mechanical fastener. These include staples, nails, screws, and bolts. Dowel connectors perform well at transferring loads. They are generally easy to install and cost effective. The National Design Specification (NDS) for Wood Construction allows designers and engineers to calculate the strength properties for dowel connectors.

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, or bearing connectors, include shear plates, toothed shear plates, and split rings. These connectors are designed to help wooden components handle heavier loads. Shear plates, or timber washers, are iron discs with a shallow rim on one side and 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.

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

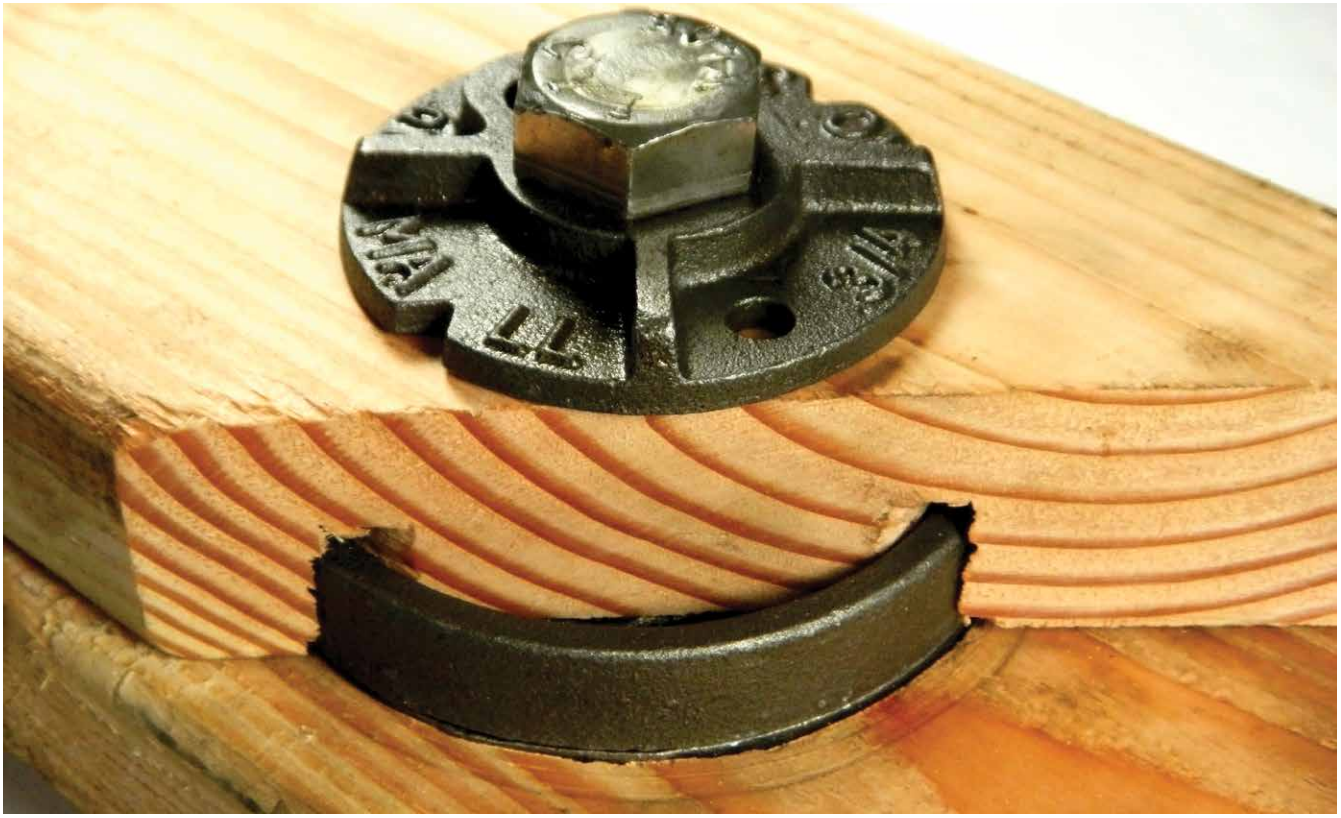


FIGURE 5.3 SHEAR PLATE CONNECTOR[2]

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 wooden 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.

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 for Wood Construction (NDS) 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 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 International Building Code (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. Section 2304.10.1 through 2304.10.7 of the IBC defines the requirements for connectors and fasteners of wood components: which types of fasteners are to be used in which situations, how many, and where they should be placed.

2 Source: Portland Bolt & Manufacturing Co.

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

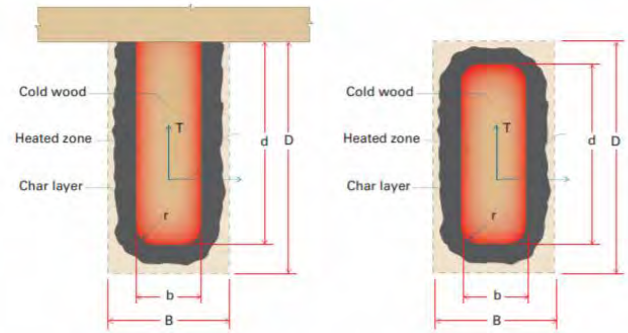


Figure 1-1 Reduction in member breadth and depth over time, t

FIGURE 5.4 REFERENCES FOR FIRE RESISTANCE[3]

5.1.4 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 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. While opponents of mass timber buildings imply that they are unsafe because wood is flammable, tests done around the world show that properly designed mass timber structures retain their required strength and provide valuable time for occupants to evacuate in the event of a fire.

The IBC references the National Design Specification for Wood Construction (NDS), 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 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.

For projects seeking approval through alternate means and methods, smoke spread may govern 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 straight-forward protective material. Concepts for improving fire resistance and reducing smoke or flame spread through the addition of coatings or treatments show promise for future enhancements, but are not currently proven options.

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

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. 1. 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. 2. 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: 1. Fire retardant-treated wood sheathing complying with Section 2303.2 and not less than 15/32 inch thick, 2. Gypsum board not less than 1/2 inch thick, or 3. A noncombustible material. 3. 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. 1. Fire resistance rated construction. 2. Non-fire resistance rated construction.

TABLE 5.1 CONSTRUCTION TYPE CLASSIFICATION OF BUILDINGS

Table 5.1 lists the classification types for buildings and describes their construction elements, including the allowable use of wood in Type IV buildings. See **Section 5.3** for 2021 IBC code changes for Type IV buildings. These changes take effect on different schedules depending on local IBC adoption timelines.

5.1.5 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 also improves the ability to build over contaminated soils with minimum disruption. Using less concrete is desirable for lowering a building's carbon footprint.

GRID LAYOUT/STRUCTURAL BAY

Mass Timber Panel (MTP) dimensions, thicknesses, and strength and stiffness properties 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.

Manufacturing dimensions of various MTP systems should be considered to optimize material use in plan layouts for cost efficiency. It is advisable to bring a 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 establishing this relationship.

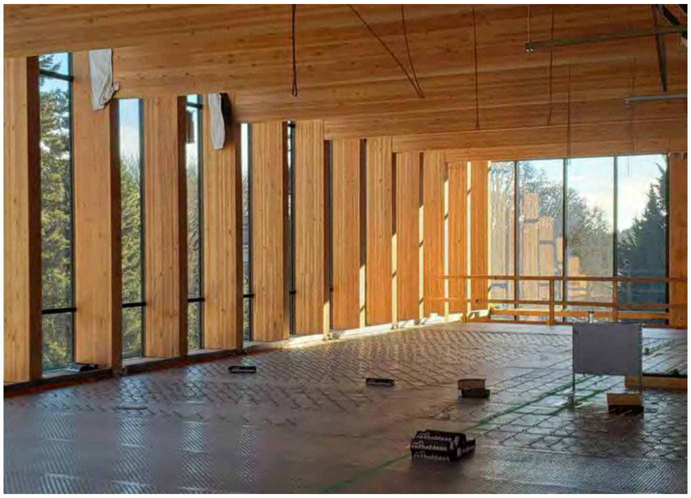


FIGURE 5.5 PEAVY HALL EXAMPLE OF COMPOSITE CONCRETE-TIMBER SLABS[4]

FIGURE 5.6 COMPOSITE CONCRETE-TIMBER SLABS WITH FLANGES[5]

HYBRID SYSTEMS

Most timber structures use steel-reinforced concrete for foundations, and steel components for connections. A hybrid structural design, 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 approach. While wood is very strong by weight in both tension and compression, selectively incorporating concrete, 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 currently a hybrid design, component approaches, such as hybrid slabs and lateral systems, are also developing in research and in practice.

HYBRID SLABS

Some building programs require spans that are difficult to accomplish with MTPs alone. For example, an efficient classroom building with an ideal 30-foot grid would call for solid timber floors with a cost-prohibitively thick section. Such projects could instead consider adding beams, tension cords, or composite slabs. Standard design values are developing, but at this point in time, a performance-based approach may be required for permit approval. Options for hybrid slabs includes:

Composite concrete-timber slabs are comprised of concrete and timber connected via steel components to create composite action. A thin 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 may be fasteners driven into the timber at an angle before the concrete is poured, see **Figure 5.5**, perforated steel flanges added during the timber manufacturing or glued in on-site, see **Figure 5.6**, or two-way rebar. Several research projects are in progress to determine performance characteristics of composite slabs. For example, testing will begin in 2020 at the Tallwood Design Institute (TDI) to generate benchmark data to characterize the performance of concrete-composite Mass Plywood Panel (MPP) floors through multi-scale testing of novel shear connectors, MPP floor elements and full-scale floor systems, including MPP-to-glulam connections.

4 Photo Source: Peavy Hall, OSU. Photo Credit: Evan Schmidt.

5 Photo Source: John W. Olver Design Building at UMass Amherst. Photo credit: Alex Schreyer / UMASS.

FIGURE 5.7 POST-TENSIONED TIMBER BEAM[6]

FIGURE 5.8 CATALYST EXAMPLE OF TIMBER-TIMBER COMPOSITE FLOOR PANEL[7]

Post-tensioned timber — Adding steel tension cords to timber beams can reduce overall beam depth or increase structural transparency (see Figure 5.7 Clay Creative).

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, WA, conceived and developed a timber-timber composite floor panel to achieve a 30ft span with CLT floors and shallow CLT beams integrated during panel fabrication (see Figure 5.8 Catalyst).

HYBRID LATERAL SYSTEMS

Because of the stiffness of MTPs (see ductility section below), using other approaches for lateral systems is often cost-effective. Common strategies include:

For mid-rise structures, **light framed wood shear walls** are a straight-forward 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 time-saving advantages of timber framing.

FIGURE 5.9 CLT WITH BUCKLING RESTRAINED BRACED FRAME CORE[8]

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

7 Photo Source: Catalyst, Katerra. Photo Credit: Hans-Erik Blomgren

8 Photo Source: Carbon 12. Photo Credit: Kaiser + Path

FIGURE 5.10 POST-TENSIONED CLT SHEAR WALL INSTALLATION[9]

FIGURE 5.11 LIGHT FRAME AND MASS TIMBER HYBRID[10]

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.

Post-Tensioned CLT "Rocking" shear walls combine strong, rigid wood panels with steel tendons and fuses for added ductility and seismic force dissipation (See also **Section 8.1.9** 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 5.5**.

Ongoing research projects seek to find additional lateral systems solutions. For example, another 2020 TDI project[11] 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. This work will lay the foundation for upcoming six-story and ten-story mass timber seismic shake table tests, part of a multi-organization research initiative, including the Colorado School of Mines.

9 Photo Source: Peavy Hall, Photo Credit: Hannah O'Leary

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

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

FIGURE 5.12 HYBRID STEEL AND CLT STRUCTURE[12]

FIGURE 5.13 CONCRETE CORES AND PRECAST CONCRETE FRAME WITH TIMBER SLAB AND BEAMS.[13]

SEISMIC PERFORMANCE

An earthquake is shaking of the ground resulting from the release of energy in the outermost portion of the Earth's crust. The released energy travels through the ground in seismic waves that transfer motion to buildings. The extent of seismic waves' force on a building depends on the magnitude of the quake, the distance from the quake's epicenter, and soil conditions below the building. Because these factors are largely beyond human control, building designers must create structures that can withstand unpredictable, infrequent seismic forces.

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 a "Snakedance" theory, which enables 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.

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

13 Photo Source: Adidas. Photo Credit: courtesy Lever Architecture.

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

Ductility — 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 cross-laminated timber 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).

Recent research and testing of CLT shear walls have resulted in proposals to use an R value of 3 to 4, depending on the CLT wall aspect ratio. However, this still means designing forces roughly twice that of light frame plywood shear walls.

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 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.

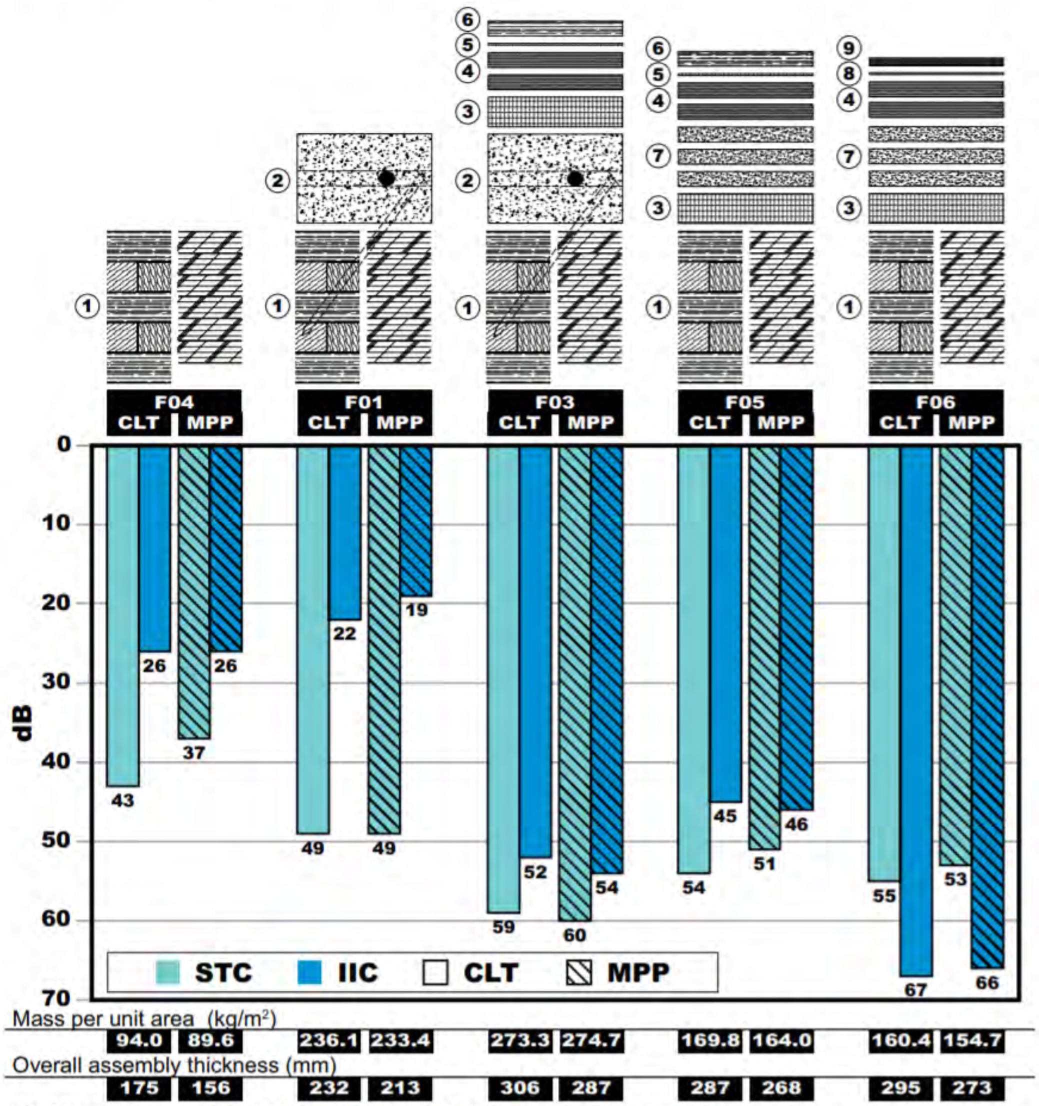
5.1.6 ACOUSTIC PROPERTIES

Acoustics are the properties of a room or building that determine how sound is transmitted. Sound and acoustics are considerations in building design because, regardless of building type or structural materials used, there are two basic sound-related objectives. The first is controlling *sound transmission* from one part of the building to another, or from the outside of the building to the inside of the building. Controlling the transmission of sound is generally achieved in two ways: by using sound insulation to block air pathways through which sound can travel, and with mass to dampen sound wave vibration through a structure. The second is controlling *sound characteristics* within a building, using sound absorption. For example, a building's sound reverberation time is a measure of how long a sound persists in a room or building after the source has stopped. Different sound absorptive materials affect reverberation time.

STC (Sound Transmission Class) is a numerical rating system describing how much sound a wall or floor/ceiling blocks from one unit to the next. Similarly, IIC (Impact Insulation Class) is a numerical rating describing how much noise is created by impact on a floor though a ceiling. The International Building Code specifies that walls, partitions, and floor/ceiling assemblies separating dwelling units and sleeping units from one another or from public or service areas shall have an STC and IIC rating of not less than 50. Designers may choose more or less stringent specifications depending on the intended purpose of a building.

Design standards for acoustical performance in mass timber buildings are still under development. Nevertheless, some guidelines have been developed for floor assemblies. For example, the mass of a timber floor panel helps mitigate transfer of low-frequency sound vibrations. The addition of resilient (rubber membrane) and finish layers (gypsum or concrete) further enhances acoustical performance.

CLT + MPP FLOOR TESTING RESULTS



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

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FIGURE 5.14 CLT + MPP FLOOR TESTING RESULTS[14]

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

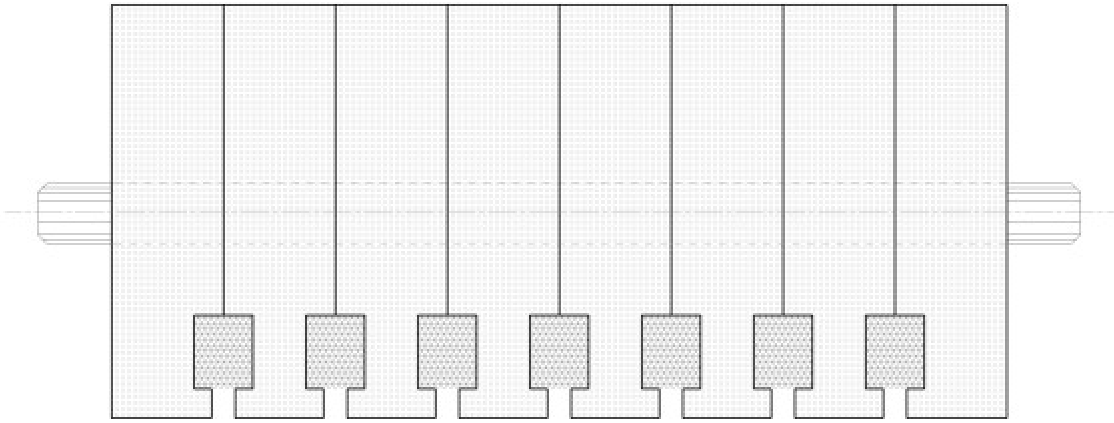


FIGURE 5.15 SIDE VIEW OF ACOUSTICALLY DESIGNED DLT PANEL, *Image provided courtesy of StructureCraft*[15]

A 2019 research project[16] at TDI, an industry survey, resulted in five common floor assemblies to be tested, each with a CLT and MPP iteration. Testing was done at two certified acoustic facilities in Illinois. Testing was completed spring of 2019, see **Figure 5.14**. 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.

Researchers are also investigating the *in situ* performance of mass timber-concrete composite floor assemblies to compile a database of actual performance and compare to laboratory results. Testing was completed in late 2019 and will be available mid-2020.

Though more data is becoming available, certified tested assemblies are limited in number and may have proprietary components. As with other code-required assemblies, the permitting authorities may permit a performance-based approach. An acoustic engineer can review floor and wall assemblies, make performance recommendations, and provide project-specific STC and IIC values.

Through University of Oregon leadership in the College of Design and collaboration with TDI and Business Oregon, plans are underway to build a certified acoustic testing facility in Oregon's Willamette Valley by 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. (**Figure 5.15**) According to StructureCraft, "*The Acoustic Square profile incorporates a dap into the sides of each board which is acoustically engineered to trap sound waves. This dap is filled with non-combustible fibrous insulation strips which act as an absorbing material to shorten the reverberation time and create higher acoustic performance inside rooms.*"

15 Acoustic Field Testing of Mass Timber Buildings," Dr. Kevin Van Den Wymelenberg, University of Oregon (UO)

16 "Acoustic Testing of Typical Multi-Family Residential CLT and MPP Dry and Concrete-Composite Wall and Floor Assemblies," Dr. Kevin Van Den Wymelenberg, UO.

5.1.7 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.

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 temperature 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 temperature more quickly, and thus are generally not useful insulators. Materials with low thermal conductivity transfer temperature more slowly and are more likely found in insulating applications.

The R-value, known as thermal resistance, can be measured for an individual material layer and quantifies the effectiveness of that layer as an insulator, given its thickness. It is calculated by taking the thickness of a layer and dividing 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 environmental footprint.

TABLE 5.2 THERMAL CONDUCTIVITY OF BUILDING MATERIALS[17]

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

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

17 Source: Engineering Toolbox, (2003). Thermal Conductivity of Common Materials and Gases. Accessed at: https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

5.1.8 MOISTURE

Wood is an organic material with 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 environmental 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 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, and roof or plumbing leaks.

At harvest, the moisture content of a log is about 50 percent (i.e., 50% 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 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.

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 5.16 MOISTURE MONITORING WITH A HAMMER-IN PROBE.[18]

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.

MOISTURE MANAGEMENT & 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. 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. The more slowly wood reaches moisture equilibrium, the less problematic shrinkage and checking issues will be, which can be of concern, especially on visible, exposed faces.

18 Photo credit: Kevin Lee

MITIGATION

The most effective and low-cost ways to protect a wood building from moisture are **detailing** to allow for shrinkage, **protecting** wood from direct moisture contact, and allowing wood in-place to **breathe** (release moisture). Mitigation details should protect wood appropriately from exposure and contact with materials like concrete that can transfer moisture. Moisture is absorbed or expelled most readily through the end-grain.

Treatments or coating products may be warranted to protect against various exposure conditions.

Coatings add protection against moisture and UV, both for the completed building and during construction exposure. 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, 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 treated mass timber structural performance and 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 due to moisture and temperature swings than lumber or sawn timber, because adhesives and multiple fiber directions hold overall dimensions stable. CLT and MPP panels therefore have an advantage over Nail Laminated or Dowel Laminated Timber if a building is constructed during wet weather. Potential dimensional changes during construction should be factored in to detailing these systems.

In CLT, a panel is manufactured with little to no gap between each board in a lamination. On some European-sourced panels, even the board edges are glued to each other. Because overall panel width and length dimensions remain stable, added moisture causes each laminated board to swell and push on each other. A significant drop in moisture content of an over-saturated panel creates greater gaps between each board, or splitting of the wood in the case of edge-glued boards. 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.

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.

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 UBC 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 due to a greater number of floors.

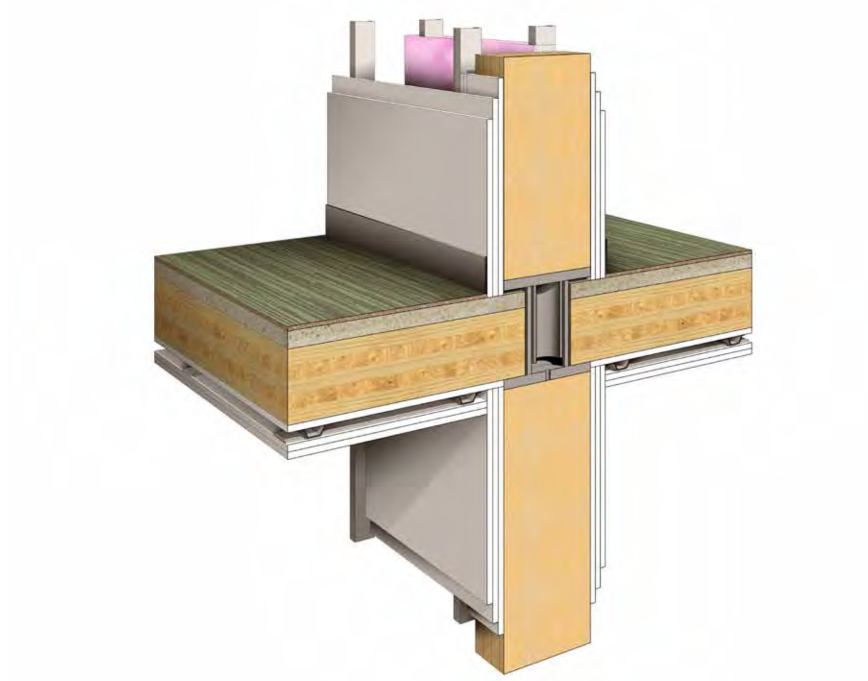


FIGURE 5.17 END-GRAIN TO END-GRAIN COLUMN CONNECTIONS MINIMIZE SHRINKAGE[19]

A "Water in Mass Timber"[20] project is being funded through a $500,000 grant from the United States Department of Agriculture (USDA) and a $250,000 Agricultural Research Service award from TDI. One aspect of this project is exploring the effects of a variety of moisture exposures (ambient exposure through sustained flooding) on timber connection performance and providing benchmark data for engineering models. In early 2020, hundreds of connection samples were being cut by CNC and fabricated at TDI's A.A. "Red" Emmerson Advanced Wood Products Laboratory.

Ongoing research in the industry, will continue to inform best practices for protection and detailing.

5.1.9 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 worth $1.9 billion annually for buildings, housing, and facilities requiring low levels of blast resistance.[21] 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.

19 Brock Commons, Provided Courtesy of Acton Ostry Architects

20 "Water in Mass Timber", PI Arijit Sinha, Oregon State University (OSU)

21 Cross Laminated Timber Blasts its Way into Government Construction. Woodworks. Accessed at: http://www.woodworks.org/wp- content/uploads/Mass-Timber-Government-Construction.pdf

STANDARD	WEBSITE
National Design Specification (NDS) for Wood Construction; National Design Specification (NDS) Supplement; Special Design Provisions for Wind and Seismic; and Manual for Engineered Wood Construction	https://awc.org/codes-standards/publications/nds-2018
Nail Laminated Timber Design and Construction Guide	https://www.thinkwood.com/products-and-systems/mass-timber/nltguide
CLT Handbook-US Edition	https://info.thinkwood.com/clt-handbook
ANSI/APA PRG 320: Standard for Performance-Rated Cross-Laminated Timber; Glulam Product Guide; Engineered Wood Construction Guide; ANSI/APA A190.1: Standard for Wood Products-Structural Glued Laminated Timber; ANSI 405: Standard for Adhesives for Use in Structural Glued Laminated Timber; Many more	https://www.apawood.org/resource-library
American Institute of Timber Construction: Test Methods for Structural Glued Laminated Timber	https://www.aitc-glulam.org
CSA Standard O177-06: Qualification code for manufacturers of structural glued-laminated timber	https://www.csagroup.org
International Building Code	https://www.iccsafe.org

TABLE 5.3 AUTHORITATIVE SOURCES

In addition, efforts are underway to understand how mass timber structures perform when struck by projectiles. Tests were completed by Georgia Tech University in which CLT panels made of spruce-pine-fir 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.[22]

5.1.10 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 are not free resources and 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.

22 Exploring Cross-Laminated Timber Use for Temporary Military Structures. Kathryn P. Sanborn. Ph.D. Thesis. Georgia Tech University. Accessed at: https://ce.gatech.edu/exploring-crosslaminated-timber-use-temporary-military-structures-kathryn-p-sanborn

5.2 COORDINATION CONSIDERATIONS

At these early stages of the introduction of mass timber into North America, design teams need to be well-educated as to 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.

5.2.1 PLANNING AHEAD

DESIGN PARTNERS

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

Early Mechanical, Electrical, and Plumbing (MEP) coordination can have positive aesthetic, cost, and maintenance implications in the final building. MEP designs are typically diagrammatic, intended to be largely field coordinated. The mass timber in a structure is often open to view as much as possible, so it can become desirable to consolidate utilities to carefully planned zones and to thoughtfully expose components as necessary. If penetration locations are determined before timber components are fabricated, reductions in on-site trade conflicts and more off-site fabricated components will improve both schedule and craftsmanship. In the completed building, as-built reference documents will be more accurate, as they will not need to be changed significantly from the design documents. Building operations and management teams working with logical, accurate reference material also will be more efficient and successful.

MANUFACTURING PARTNERS

One of the most interesting and unique opportunities inherent in designing with mass timber is early, project-specific coordination with a mass timber manufacturer. In a typical project where a bidding process occurs at the end of the design phase, manufacturers and suppliers are chosen long after significant design decisions have been made. To produce an efficient and cost-effective mass timber design, the design team must work more closely with the overseers of the building materials and fabrication processes. A building owner should be advised to use collaborative contract models that support effective pre-bid coordination (see also **Section 8.2 in Chapter 8**).

CONSTRUCTION PARTNERS

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

RESEARCH PARTNERS

For novel and performance-based design approaches, it can be very helpful to utilize resources available through research institutions like FPInnovations, TDI, and others.

TALLWOOD DESIGN INSTITUTE — FACILITY NEWS

2019 marked the opening of the A.A. "Red" Emmerson Advanced Wood Products Laboratory at Oregon State University. The facility boasts state-of-the-art advanced fabrication equipment for timber construction, and one of the largest strong walls dedicated to structural timber research in the country. 2020 will mark the first year that large scale structural projects will take place in the lab, including testing of multiple three-story structures.

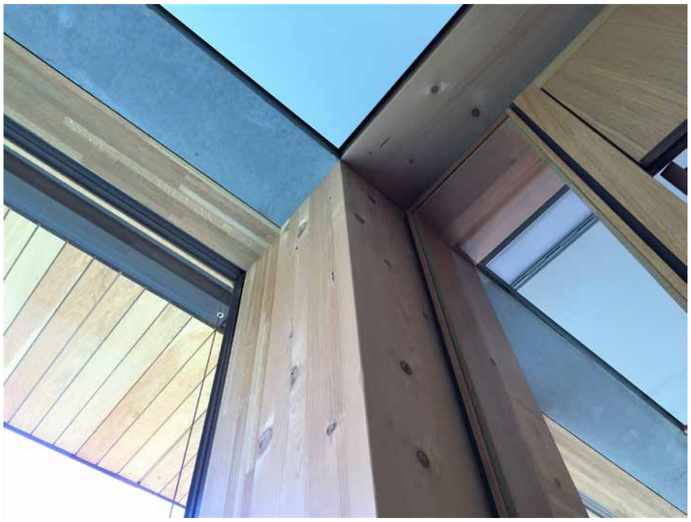
A fire testing facility is slated to open at Oregon State University late 2020. The space will have testing capabilities for structural fire engineering and wildfire research, with space to expose structural components and systems to parametric fires and fires similar to the standard fire curve.

The "Living Lab @ Peavy Hall" project is monitoring environment, moisture, and structural performance of the new mass timber structure, George W. Peavy Hall Forest Science Center, at OSU's College of Forestry. Data from this project is being used to refine a protocol for installing and tensioning of post tensioned timber wall systems.

TDI research news: 2020 marks the formation of the "Consortium for Engineering, Architecture & Construction of Advanced Timber Structures (CEACATS)," a member-based mass timber research coalition of industry and academic partners jointly funding and directing applied R+D activities answering questions of common interest for advancing mass timber construction.

Contact tdi@oregonstate.edu with inquiries.

FIGURE 5.18 HERMANN KAUFMANN, IZM (LCT-TWO) BUILDING[23]



5.2.2 BUILDING INTEGRATED MODELING (BIM)

Building Information Models (BIM) are virtual models used for architecture and engineering built in 3 dimensions, including all of the elements that will make up a building, used for coordination and collaboration across design disciplines. 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 be adapted into shop drawings, which facilitates communication around complex 3-dimensional material intersections. BIM models can be built to a very high level of detail so that 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.

5.2.3 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, discussed in detail in **Chapter 6**, and for the completed project, see **Chapter 8**. Designing with mass timber may lead to further discussions of off site fabrication, which could grow from a focus on structure to systems components or even full wall assemblies and finish materials.

Implications for the design team include planning for more up-front coordination. The extent of prefabricated components will dictate the amount of extra coordination required.

5.3 BUILDING CODES

Historically, common wood structural building materials and methods are included in building codes across North America. For example, Type IV construction 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.

The American Wood Council[24] is the leading resource for code information and standards related to structural wood products in the United States, and offers numerous publications in print and electronic formats. Similarly, the Canadian Wood Council[25] offers code-related information for wood construction in Canada.

Design standards for NLT have been developed and released by the Binational Softwood Lumber Council, and a free design guide is available for download.[26]

23 Image Credit: Emily Dawson

24 https://www.awc.org/codes-standards/publications

25 http://cwc.ca/design-with-wood/building-code/

26 https://www.thinkwood.com/products-and-systems/mass-timber/nltguide

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 convincing the permitting body that the materials and methods are more than adequate 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 the adoption of new building codes.

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.

5.3.1 2009 BRITISH COLUMBIA CODE

In 2009, British Columbia revised building codes to allow the use of wood as the structural frame in residential buildings as tall as six stories. (The previous limit was four stories.)

5.3.2 2021 NATIONAL BUILDING CODE OF CANADA

Updates to the National Building Code of Canada (NBCC), which is developed by the CCBFC are expected to allow buildings similar to the ICC Type IV-B by the end of 2020. The new code increases the maximum allowable height of mass timber structures from 6 to 12-stories. The requirements include encapsulation of structural timber with non-combustible materials, and limited permissions for exposed structures.

5.3.3 2015 INTERNATIONAL BUILDING CODES

In early 2015, the ICC adopted new codes allowing the use of CLT in buildings up to six stories for offices, or five 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.[27]

5.3.4 2021 INTERNATIONAL BUILDING CODES

The ICC is developing new codes for the 2021 edition of the IBC. Specific to mass timber, they include provisions for the use of CLT in buildings up to 18 stories in height (i.e., Tall Wood).

The Tall Wood provisions were debated in public hearings in October 2018 and approved in December 2018, clearing the way for inclusion in the 2021 IBC, scheduled for release in late in 2020.

Construction Type IV will be revised to include three additional types, distinguished by fire resistance, height and area restrictions, see **Figure 5.19**.

27 For more complete information, see the American Wood Council's website: https://www.awc.org/codes-standards/code-adoption-map

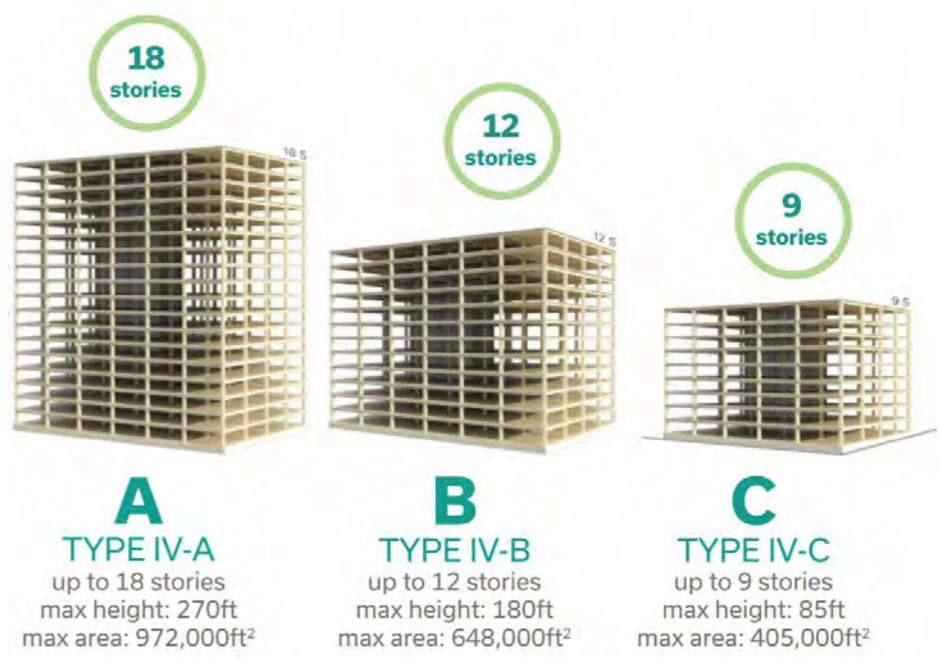


FIGURE 5.19 ADDITIONAL CONSTRUCTION TYPE IV CODES.[28]

- 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 non-combustible (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, 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.

Testing to reduce the encapsulation requirements of the new code provisions is ongoing. A 2019 USDA wood innovations grant was awarded to implement fire testing with the aim to justify more exposed wood in Tall Wood, especially Type IV-B. Test results are expected in 2020.

5.3.5 EARLY CODE ADOPTION

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, with a four month period where either version of the code may be applied. In December 2019, Denver, Colorado also approved the new provisions for adoption immediately. Early adoption proposals in California are ongoing.

In British Columbia, certain jurisdictions can opt in to an initiative to preemptively adopt the draft NBCC code.

28 Think Wood Research Brief Mass Timber 2021 Code updated July 2019

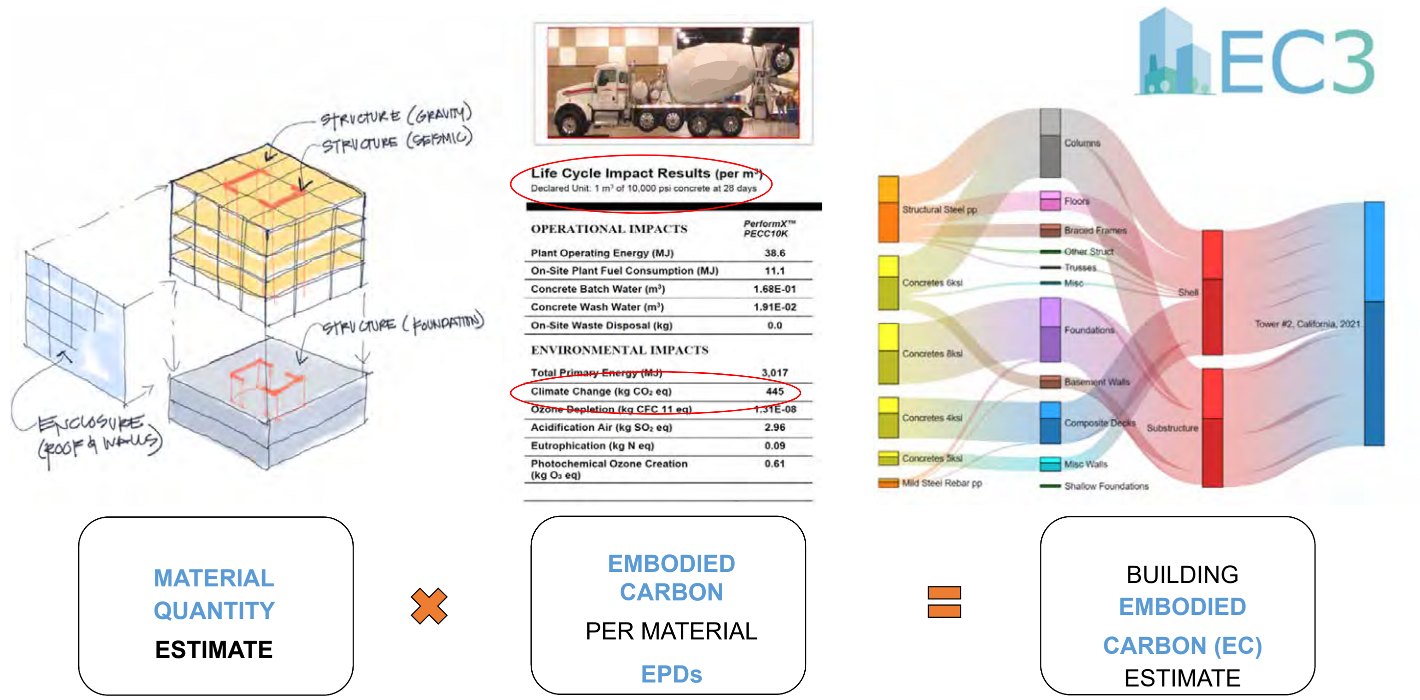


FIGURE 5.20 EMBODIED CARBON IN CONSTRUCTION CALCULATOR (EC3) TOOL[29]

5.4 MASS TIMBER ENVIRONMENTAL PERFORMANCE

What is the construction industry's appetite for innovation? The U.S. Green Building Council considers about 5 percent of the industry as innovators, 20 percent as leaders, 70 percent as followers of current codes, and 5 percent as law breakers (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, it is likely that these industry leaders will pull the entire building construction industry in that direction. As such, the industry is expected to increasingly use systems and materials that reduce a building's environmental footprint.

5.4.1 ENVIRONMENTAL IMPACT OF BUILDING MATERIALS

Analyzing environmental impacts during building material selection is complicated but critical. There are tools that can help with the decision-making process, including life cycle assessments (LCA), environmental product declarations (EPD), and certification programs designed to promote environmentally conscious construction.

LIFE CYCLE ASSESSMENTS

All construction materials carry a variety of consequences in terms of environmental impacts from extraction, manufacturing, construction, demolition, and disposal. LCAs are a process for documenting those effects and comparing similar products. The Consortium for Research on Renewable Industrial Materials (CORRIM) is a leading resource on life cycle assessments for a variety of wood products.

EC3 is a free, open-source LCA tool released in late 2019 and developed by a multidisciplinary team led by the Carbon Leadership Forum. It is the most sophisticated tool to date, but research is ongoing to fully understand and calculate the impact of wood products. See **Section 5.4.2** discussing carbon impacts.

29 Source: Embodied Carbon in Construction Calculator Carbon Leadership Forum.

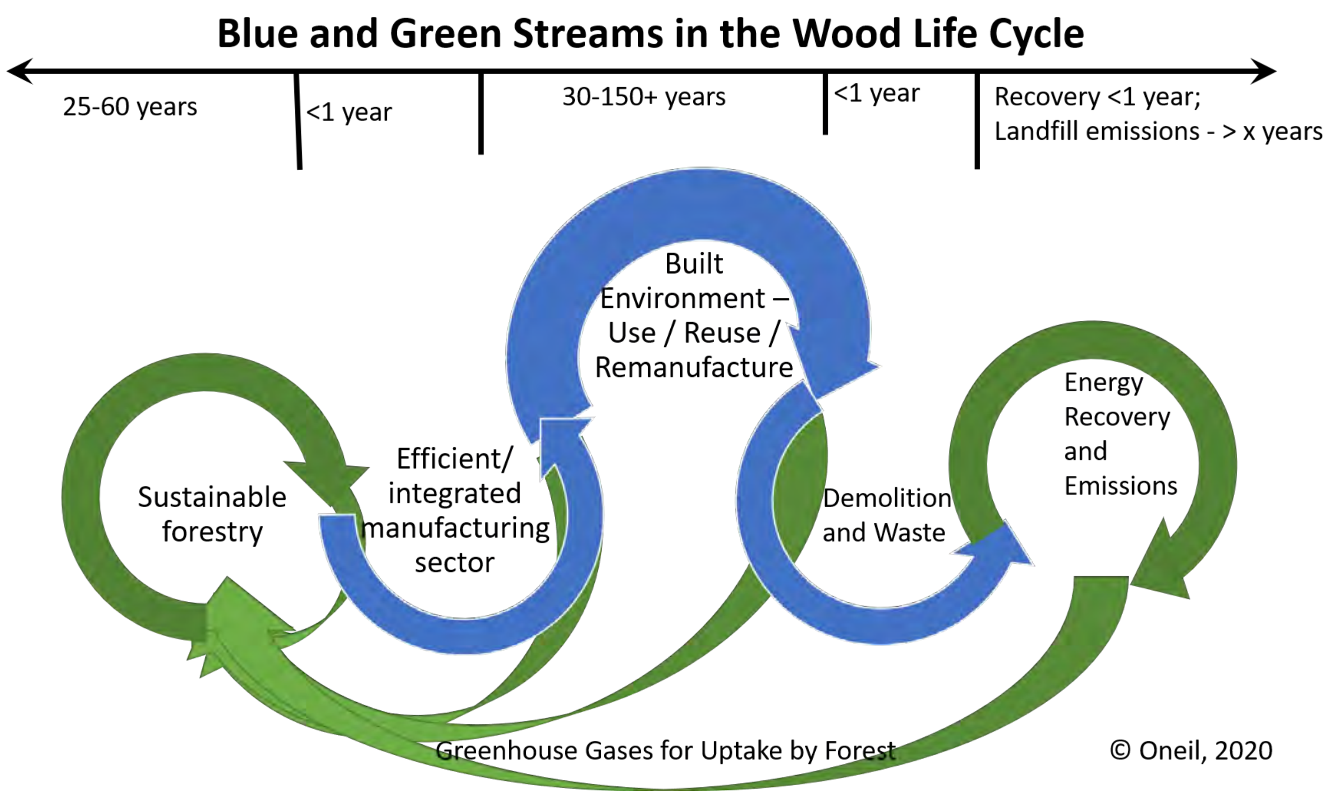


FIGURE 5.21 EXTENDED LIFE CYCLES OF WORKING FORESTS.[30]

While end-of-life considerations are important, most buildings built today will remain standing long after global carbon reduction timelines are passed. Absorbing as much atmospheric carbon as possible in the next 30 years is a global priority to avoid irreversible climate change. It can be argued that embodied carbon stored today is more critical than accounting for the potential deconstruction approach in 50 or 100 years. Markets for reuse will likely develop for mass timber, which would avoid the landfill decomposition assumed in many LCA calculations. Including possible future decomposition obscures the data around immediate benefits of wood construction, skewing the outcome to a longer-term, lower impact.

The World Green Building Council (WorldGBC) stresses the importance of reducing "upfront" or embodied carbon in their 2019 report Bringing Embodied Carbon Upfront. The report states: "To achieve our vision, we must take urgent action to tackle upfront carbon while designing with whole life carbon in mind."

Design teams should take these concepts into consideration when making decisions about building materials. Opportunities to offset calculated carbon impacts should also be considered. For example, it is possible to calculate the approximate number of trees that go into a timber building. If sequestration goals are important to the project, consider a donation to an organization to re-plant that number of trees in an area that has already been identified for reforestation.

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

ENVIRONMENTAL PRODUCT DECLARATIONS
Environmental Product Declarations (EPDs) are documents that allow comparisons among building products in 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. They can also include information on land conversion, toxicity, and other factors.

EPDs are sources of information that allow a specifier to compare different materials that provide the same function in a construction project. FPInnovations has produced two EPDs for CLT products. The American Wood Council has an industry-wide EPD for glulam beams. EPDs specific to wood products are available through the American and Canadian Wood Councils.

One of the most demanding EPD labels is the Declare label, which identifies the most dangerous "red list" ingredients, and clearly states when products are free of them. StructurLam achieved the highest "red list free" label for their CLT product, Crosslam.

GREEN BUILDING CERTIFICATION PROGRAMS
In addition to LCAs and EPDs, there are green building certification programs, including LEED, Green Globes, Passive Haus, and Living Building Challenge. 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.

Pursuing environmental certifications is optional, but these programs and their supporters generally believe there are financial and non-financial benefits. Benefits include recognition/prestige, tax incentives, reduced ongoing operating costs, faster lease-up times, increased property value, increased energy efficiency, reduced waste, and healthier, more enjoyable working/living conditions for tenants.

Where wood building products are concerned, these building certification programs often tie back into forest management certifications, solidifying the connection between sustainably managed forests and the utilization of wood in new and creative construction approaches. These systems continually extend the goal of creating human habitat with an ever-smaller environmental footprint. The use of wood is central to that commitment.

5.4.2 MASS TIMBER AND ATMOSPHERIC CARBON

CARBON CYCLES IN THE FOREST
Forests are key to the Earth's natural carbon capture and storage system. In the United States alone, forests store more than 10 billion metric tons of carbon[31]. As part of the photosynthesis process, trees take in carbon dioxide (along with sunlight and water) to create simple carbohydrates, or sugars, which 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.

If unaltered by human activity, the complete life cycle of a tree is carbon neutral. However, this cycle can take a hundreds of years to complete depending local conditions and the species of trees involved. Some are relatively short-lived (only 80 to 120 years old), 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 fairly 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 wind storm can blow down hundreds or thousands of acres of trees which 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

31 Source: US Forest Service. https://www.fs.fed.us/climatechange/advisor/scorecard/Carbon_Infographic_Final.pdf

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 its remaining carbon back into the atmosphere. 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 can retain much carbon as they slowly decay or it can be released 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 long as humans have wielded fire and tools for cutting, forests have been managed in every region of the globe; pre-historically, there is evidence that human intervention actually improved the health and diversity of forests, while providing a sustainable source of wood for building, weaving, and tool making. 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."[32]

Per a report from University of British Columbia, Department of Forest Sciences, "Due to fire suppression and selective harvesting (for species other than pine) during the latter half of the previous century, there was more than three times the amount of mature pine in western Canada at the start of the current outbreak than 100 years earlier." And, as a 2019 New Yorker article reporting on California's shifting forest management practices pointed out, "Without intervention, the cinder-strewn moonscape that megafires leave behind is unlikely to grow back as forest."

As part of actively managing forests, the carbon cycle is extended. After trees are harvested, they are manufactured into durable, long-lived products which can continue storing carbon while in service. The harvested forests regenerate with vigorous growth. Active forest management decreases natural mortality or captures it while the wood is still usable. The wood products store carbon in building products, furniture, packaging, and paper, thus leading to a more efficient capture and storage of carbon. **Figure 5.22**

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 (see **Chapter 2.2**) 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 also show how building design teams can incorporate wood into their Life Cycle Analyses (LCA).

32 Sprout Lands: Tending the Endless Gift of Trees, William Bryant Logan.

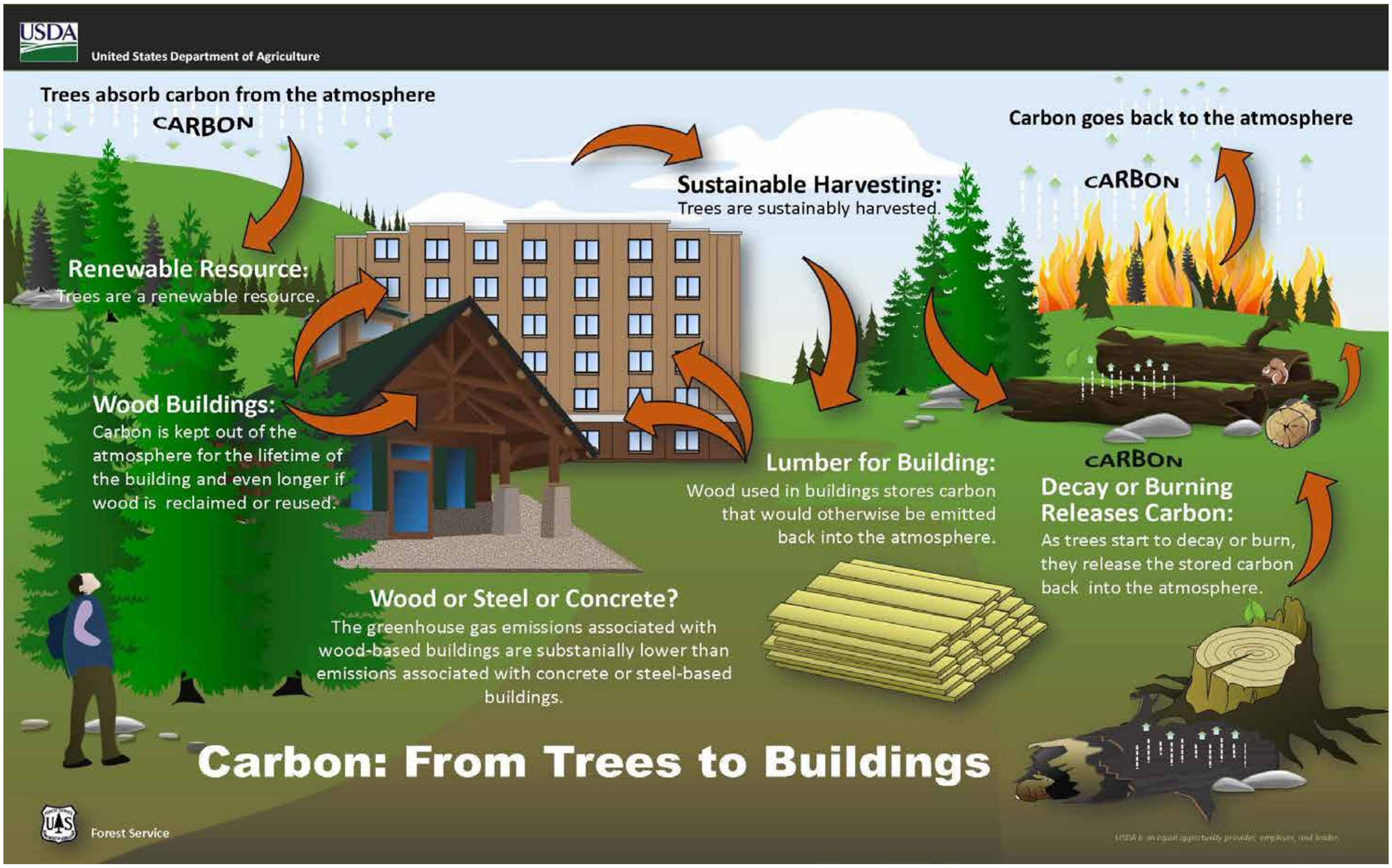


FIGURE 5.22 FOREST CARBON CYCLES[33]

A 2007 report from the Intergovernmental Panel on Climate Change[34] stated: "*[I]n the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit.*"

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.

33 Source: US Department of Agriculture

34 https://www.ipcc.ch/report/ar4/syr/

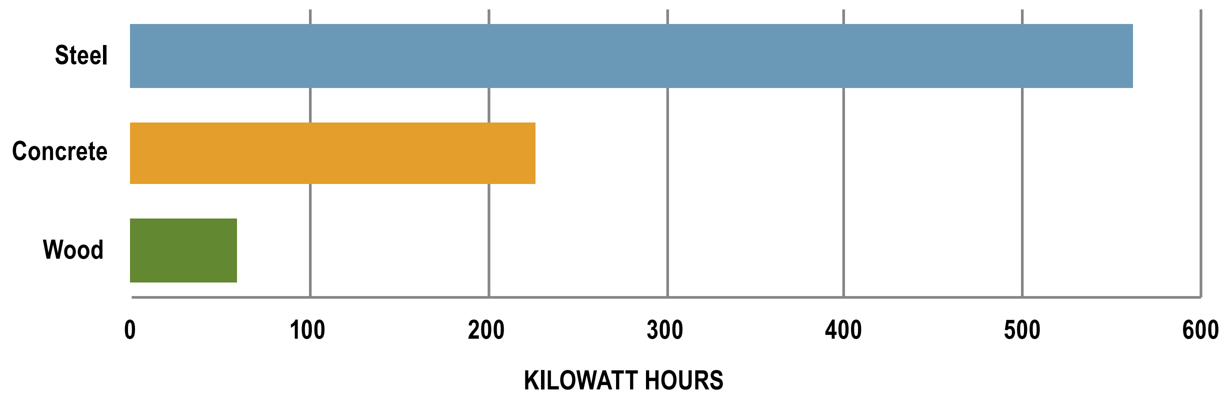


FIGURE 5.23 ENERGY REQUIREMENTS FOR PRODUCING A 3-METER COLUMN CARRYING SAME LOAD[35]

CARBON IMPACTS IN BUILDING MATERIALS: STORAGE AND SUBSTITUTION

In addition to forest benefits, wood as a building material provides long-term carbon storage, lower embodied fossil energy content, and superior energy efficiency through its thermal properties. (See **Section 5.1.7**.)

As illustrated in **Figure 5.22**, 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. One cubic meter of wood stores approximately one ton of carbon dioxide.

Not only do wood products naturally store carbon, they also require less energy to produce than other building materials. Most processes involved in the extraction and manufacturing of building products rely on fossil fuels, so a building material's energy use and carbon footprint are closely related. Wood products have much lower embodied fossil energy content than concrete or steel because they typically require less energy to produce. In fact, they are often produced substantially with renewable energy (including combusting wood residues for drying lumber and veneer). **Figure 5.23** shows the amount of energy required to produce comparable wood, concrete, and steel building materials.

When wood is chosen over steel or concrete building materials, the net effect is a reduction in fossil fuel use. The benefit is immediately achieved when a building is constructed, and significantly slows the increase of atmospheric carbon dioxide. Mass timber, in combination with a variety of other wood products, can replace many products currently derived from sources that are more heavily dependent upon fossil sources. Forest products can be the foundation for a more sustainable, low-carbon society.

35 Systems in Timber Engineering - Josef Kolb, 2008

CHAPTER 6: MASS TIMBER BUILDERS

IMPACTS OF THE MARSHALL EFFECT ON MASS TIMBER BUILDERS:

- Of the main structural material choices for buildings, wood is the only option that can be sustainably sourced and that can also store rather than emit carbon.
- Collaborative design processes bring designers, builders, and manufacturers together in a scenario that can more closely control the 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 equity and social sustainability of communities.
- 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.

This chapter assesses mass timber from the perspective of builders. It's a review of construction styles, so readers understand not only how mass timber fits with other wood construction methods, but also with other building materials. Information has been sourced directly from builders with mass timber construction experience, and data analyzing the total size of the mass timber construction market in the United States provides context for growth potential.

6.1 MASS TIMBER IN CONTEXT OF BUILDING SYSTEMS

Table 6.1 shows the value of all construction in the United States, per U.S. Census Bureau data. The data is categorized by building use as non-residential and residential. The annual value of all construction was over $1 trillion in 2008. It dropped significantly during the Great Recession, but has since climbed back to $1.2 trillion in 2017. While non-residential construction has always accounted for most of the total value, over time residential construction value has increased from about 30 percent of the total to over 40 percent.

Another way of categorizing building activity is by the type of material used. In North America, there are four principal structural building materials: steel, concrete, wood, and masonry. Each of those material types has numerous variations, but for this report the basic categorization of steel, concrete, wood, and masonry is used.

Type of Construction:	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Residential	0.367	0.256	0.252	0.253	0.276	0.329	0.375	0.429	0.474	0.532
Nonresidential	0.711	0.651	0.557	0.536	0.574	0.577	0.631	0.685	0.718	0.714
Total Construction	1.078	0.907	0.809	0.789	0.850	0.906	1.006	1.114	1.192	1.246

TABLE 6.1 ANNUAL VALUE OF ALL CONSTRUCTION, 2008 TO 2017 ($ IN TRILLIONS)

CONSTRUCTION MATERIAL TYPE	2009	2010	2011	2012	2013	2014	2015	2016
Structural Steel	56	58	56	51	47	49	48	49
Concrete	20	21	22	28	31	31	33	32
Wood	7	7	8	8	9	8	8	9
Pre-engineered	7	6	6	6	6	5	5	4
Masonry	10	9	7	7	7	7	6	6

TABLE 6.2 UNITED STATES FRAMING MATERIAL MARKET SHARE BY MATERIAL TYPE (PERCENT)[1]

Table 6.2 illustrates the historical market share of these different building materials in non-residential and multistory buildings between 2009 and 2016 in the United States. Structural steel remains the most commonly used framing material. Concrete, however, has gained significant market share. Wood has also slightly increased in market share, while pre-engineered steel and masonry have lost market share. Pre-engineered steel is included as a separate category in this table, but is essentially a subcategory of structural steel. Pre-engineered refers to structural steel buildings where the steel beams and columns are fabricated in a factory and then shipped to a construction site for quick assembly. The end uses for this type of construction are often warehouses or industrial facilities.

6.2 STRUCTURAL BUILDING MATERIAL TYPES

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 types is that buildings typically contain horizontal components called *beams* and vertical components called *columns, studs,* or *posts* depending on the material and construction type.

6.2.1 CONCRETE

In this type of construction, the horizontal structural beams, vertical structural columns, and slab floors are all made from 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 because the compressive strength of concrete is complemented by the tensile strength of steel reinforcing Thus, a concrete building readily supports its own weight and is resistant to bending and tension forces from wind or seismic activity. Reinforced concrete is considered non-combustible and is dimensionally stable. Another plus: the material can typically be produced at or near the building site because cement, aggregate, and water are readily available and relatively inexpensive. Finally, concrete can be shaped into any size or dimension using forms.

1 Source: Dodge Analytics via American Institute of Steel Construction. Structural Steel an Industry Overview. A White Paper by the American Institute of Steel Construction August 2018. Accessed at: https://www.aisc.org/globalassets/aisc/publications/white-papers/structural_steel_industry_overview_2018.pdf

The main disadvantage of concrete is the significant consumed energy embedded in the production of cement and steel, lowering its attractiveness from an environmental perspective. Also, repeated cycles of drying and wetting can lead to cracking in concrete over time. While concrete buildings can be durable for centuries, cracks in concrete can allow water to reach the steel 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 the deterioration of both steel and concrete. Also, 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. Concrete begins curing almost immediately upon being poured into forms. However, to reach design strength, curing continues for an extended period; in some cases, construction may be delayed until some building components have cured to adequate levels.

6.2.2 STRUCTURAL STEEL

Steel is a mix of carbon and iron, and, depending on the percentage of carbon, steel is more, or less, flexible. Certain mixes, including structural steel, are ideal for building construction.

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 on-site waste. Additionally, steel is fabricated 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 non-combustible 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.

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 building style is still used for smaller residential buildings, it is rarely used today for large buildings.

Masonry is a well-established construction style, and well understood by tradesmen. 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 (or nighttime cold) and releasing it back into the outdoor atmosphere before it reaches the building's 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.

6.2.4 WOOD

Wood is uniquely strong in both tension and compression, and thus has a high potential for resilience, or recovery, under strong gravity loads, as well as seismic and wind loads. Three types of wood construction are reviewed: light wood frame, traditional heavy timber, and mass timber.

FIGURE 6.1 LIGHT WOOD FRAME BUILDING[2]

LIGHT WOOD FRAME

This type of construction, also known as stick frame, is the most common construction method 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. The building walls and roofs are sheathed in wooden panels made of plywood or oriented strand board. **Figure 6.1** provides an illustration of light wood frame construction.

The advantages of this building system are low cost and ease of assembly. Lumber, plywood, oriented strand board, 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 a relative ease of construction compared to other building types.

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 material costs. Of the building styles discussed here, light frame wood carries the highest risk of fire damage. Another disadvantage is that insects, mold, and fungi can negatively impact the strength and appearance of wood.

2 Photo Source: APA – The Engineered Wood Association

FIGURE 6.2 POST AND BEAM BUILDING[3]

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. **Figure 6.2** illustrates a post and beam building design.

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 could provide a means for insects, mold, and fungi to degrade the wood.

3 Photo Source: Nordic Structures

FIGURE 6.3 MASS TIMBER BUILDING[4]

MASS TIMBER

Mass timber refers largely to massive engineered wood members that comprise beams, columns, walls, floors, and roofs with a high level of fire resistance. Up to this point, most mass timber buildings in North America have been low- to mid-rise structures. However, building code changes enacted by the ICC in late 2018 mean three new types of wood construction will be included in the 2021 International Building Code, including buildings that reach a height of 18 stories (270 feet). **Figure 6.3** illustrates a typical mass timber building design. 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

The previous sections briefly described the advantages and disadvantages of other widely used structural building materials. The following sections take a deeper look at the experiences of mass timber builders. Mass timber is a disruptive technology with respect to building construction, with implications for increased off-site fabrication and new construction approaches. When mass timber started making headway as a building material in North America, there were 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.

4 First Tech Building. Photo Source: Structurlam

6.3.1 BIDDING AND PLANNING MASS TIMBER PROJECTS

Educating building contractors in the process of planning and bidding a mass timber building is an identified industry need. For example, a 2017 report[5] 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 of 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 between 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.

All of these barriers indicate a need for training and education of developers and construction companies. In response, WoodWorks is developing a training program for building contractors on how to bid and plan a mass timber project, slated for launch in 2020. A CLT installation training program became available in April 2019, a joint effort by WoodWorks and the Chicago Regional Council of Carpenters Apprentice and Training Program. The workshop includes 56 hours of training focused on CLT. The first courses were offered in the Chicago area, and they are 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.

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 **Chapter 8** for elaboration.

OPTIMIZE DURING DESIGN

A custom mass timber package can save significant field costs, but the benefits are realized only if the manufacturing, design, and build teams work together from early in the design process. Mass timber manufacturers have specific efficiencies and limitations that should be worked into the design and into logistics plans to balance the premium cost of 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. This will push design work into the construction phase, with the inevitable result of otherwise avoidable change orders.

5 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

A high level of coordination during design was an essential part of the construction-phase success of the mass timber building Carbon12, in Portland, Oregon. As described by the project team:

"Like CLT itself, the Mechanical, Electrical, Plumbing and Fire systems (MEPF) require careful up-front coordination. Carbon12 was built using a design-build approach with the subcontractors. During the longer-than-usual permitting process, time was dedicated to MEPF pre-design to ensure that the shaft pre-cut in the CLT manufacturing facility would accommodate all of the building systems. Hours of meetings were held on each shaft, soffit, and ceiling in an effort to reduce the size of ducts and pipes, ensure structural integrity, and to create a sequencing plan to allow subcontractors to install their systems without impeding others' work.

"The meetings and subsequent installation were challenging as each contractor negotiated for the space and location that would be most advantageous for their tasks. The dedicated MEPF teams created workarounds and custom solutions to adapt to the spaces provided. At times this meant less efficiency, either with materials or install time. It helped that the floors were identical so improvements were made as they progressed. In the end, the subcontractors were working together like a well-oiled machine." [6]

AVAILABILITY AND LEAD TIMES

Advantages to securing a timber manufacturing partner early in project planning include insight into availability and more control over lead times. The number of mass timber manufacturing facilities in North America is increasing every year, but available capacity can still vary greatly depending on regional project demands. This supply and demand pressure will continue to shift as the market matures, more facilities come on line, 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 that drive lead time is the detailing work needed at the manufacturer before production begins, and selecting a manufacturer early can help ensure that the team has plenty of time to accomplish this and still meet the construction schedule.

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

BIM AND CNC

Mass Timber and Building Information Modeling (BIM) (see **Chapter 5** for more information) are coming of age together, and that is no coincidence. The pre-planning and coordination required for reducing on-site construction time through prefabrication is well supported by a collaborative virtual building model. The potential of using BIM 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 non-integrated teams, but BIM is also a relatively new technology, and all parties involved are still becoming accustomed to an integrated modelling process. A traditional building contract can also benefit from BIM at all stages.

Currently, the most common and effective ways to utilize BIM for mass timber are for Architectural, Structural, and MEP coordination both in design and in construction. These design models can be shared with the mass timber manufacturer for direct use in creating shop drawings for fabrication.

6 Source: https://buildingcarbon12.com/

FIGURE 6.4 PREFABRICATED TIMBER STRUCTURE AND PANELIZED FACADE COMPONENTS.[7]

Today, using BIM to coordinate a mass timber project can be as basic as the timber manufacturer preparing 3-dimensional panel models that are then presented for approval to the design and build team as traditional 2-dimensional shop drawings. They are then used to guide the CNC (Computer Numerical Control) machine, which will cut each panel to precise specifications. The process can reach higher levels of sophistication and 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 material takeoffs and ordering, clash detection for all building systems, and modeling for prefabrication of any building component.

PREFABRICATION

Successful projects that maximize prefabrication are pushing the building industry to reconsider project delivery. Modularizing the entire structural system has benefits for on-site safety, schedule efficiencies, 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 erection times. Whatever the approach, local jurisdictional inspection requirements should be taken into account when strategizing prefabricated building elements, as well as transportation limitations.

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

When Mechanical, Electrical, Plumbing, and Fire protection (MEPF) penetrations are precisely located, as with a coordinated BIM process, many components can be fabricated off-site and installed directly into place. Planning ahead results in fewer trade conflicts on-site, whether or not additional off-site construction is part of the strategy. But maximizing prefabrication can also lead to 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 on the University of British Columbia Campus in Vancouver, Brock Commons, was erected two floors per week, following the concrete foundation and cores. The CLT and glulam levels were closely followed by a panelized timber facade, which provided immediate weather protection and saved 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.

7 Photo Source: Brock Commons, Photo Credit: Provided Courtesy of Acton Ostry Architects

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 Architectects 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 required for structural erection of 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." [8]
- **Climate Controlled:** 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, which may be in conflict with local noise ordinances. Prolonged exposure to extreme conditions, as on an unshaded or freezing job site, is stressful to human health. Controlled temperature, 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.
- **Predictable 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 the establishment of 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.
- **Diversity:** Due to the reasons cited above, factory environments provide increased accessibility of 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, profit, and reduced turnover.
- **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."[9] Such a range of job opportunities supports diverse communities, which is especially beneficial for rural communities with limited job options.

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

9 Prefab Architecture, Ryan E. Smith, (book, 2010) p. 87

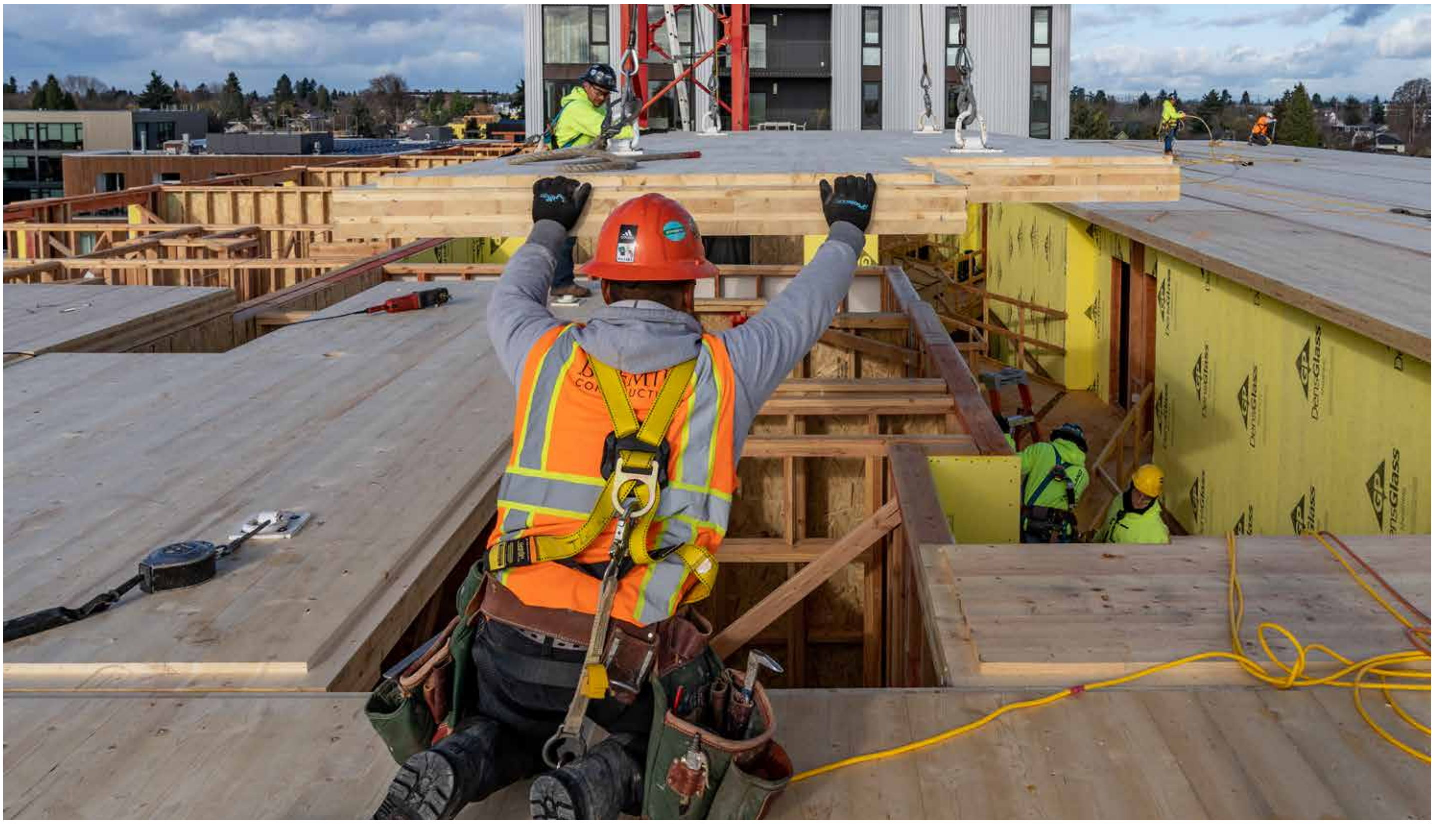


FIGURE 6.5 CONSTRUCTION WORKER GUIDES A PANEL PLACEMENT[10]

PRECISION

Most commodity building products are not as precise as custom, engineered timber components, which are typically precise up to ⅛ inch. If fully coordinated in advance, they should require no field modifications. Tolerances between materials should be identified and allowed for in the design details, and designers should clearly identify where greater levels of precision are most critical. Installation conflicts can be reduced or eliminated by coordinating in advance of fabrication. Common interfaces:

- **Cast-in-place concrete** will commonly incur inconsistencies up to 1 inch. Foundations are not typically approached with precision as a high priority, but a precise foundation will go a long way to setting a timber installation up for success. Concrete shear walls likewise may have variances from floor to floor or across a face that are in conflict with more precise components. A general contractor should impress upon the concrete team where to take special care and help coordinate details that allow room for accurate installation.
- **Pre-cast concrete** will have a higher level of precision than cast-in-place concrete. This prefabricated solution is worth considering for exposed components with a high level of finish quality.

10 Photo Source: The Canyons Photo credit: Marcus Kauffman, Oregon Dept of Forestry

- **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.[11] Coordinating tolerances of **exposed or concealed steel connectors**, especially details that occur frequently, can significantly impact the schedule success of a project. Custom fabricated connections may need to be shimmed depending on the design. As with larger components, greater length brings more potential for variation. Highly accurate proprietary engineered connections may have a higher up-front cost, but contribute to schedule savings by reducing field conflicts and retrofits.
- Options for achieving required **fire resistance ratings** at structural intersections should also be evaluated for aesthetics, cost, and constructability.

With a coordinated design, build, and fabrication team, site conflicts can be minimized.

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."

From the Building Carbon12 website:

As the winter of 2016 approached, all eyes were on Carbon12. The foundations had been poured and a steel frame stood two stories high, waiting for the wood panels that would enable it to climb skyward. The goal was to build the entire eight story structure in just ten weeks. Here is how it happened.

It was essential that the steel and concrete were ready to accept the CLT panels that were ready and waiting in Canada. The wood package required a tolerance of ⅛", yet acceptable tolerances for concrete are ½" to 1" depending on location, and up to ¾" for structural steel. It was imperative that the trades worked together to achieve a tight tolerance across the board. The first floor wood columns were sized to assume for some shimming to occur at their base. This allowed the framers to make up for some of the tolerances in the steel bases across the ground floor before the CLT arrived.

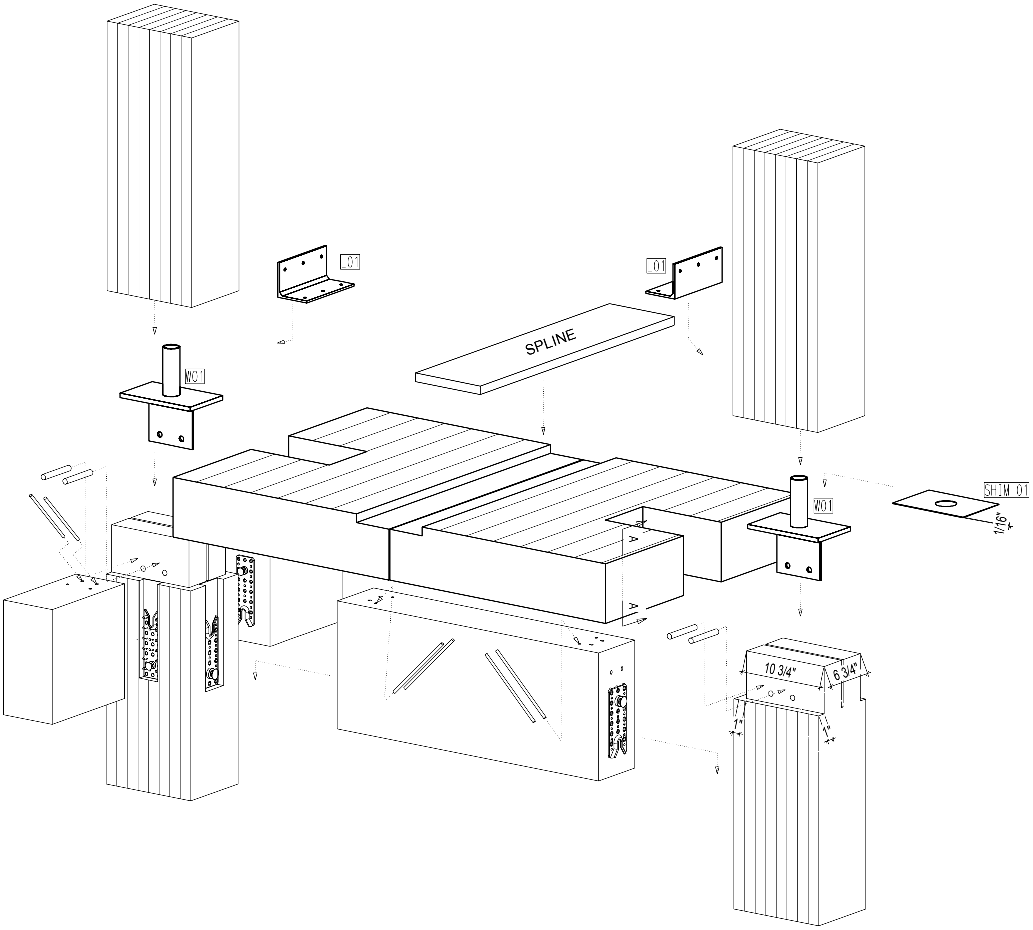
The wood columns and beams were installed on the east side first. Once the columns and beams were plumbed, squared and leveled, they were screwed together with long diagonal screws on the top. The framers then moved to the other side and installed the columns and beams. The CLT panels took roughly two days to install, including installation of the splines, steel straps and screws. The first level took roughly two weeks, but the upper floors were completed with a floor every four days.

After three floors of CLT were installed, the framers had to stop CLT installation to add the next level of the steel core. They then dropped back and installed the interior walls and stairs to keep the project moving forward and make the floors safe for other trades.

The entire wood package arrived as a kit of parts. The building had 234 columns and 336 beams, of which only 4 beams had to be trimmed to fit.

Replacing Carbon12's structural elements (steel core and BRB brace frame, glulam beams and columns plus CLT floor and roof plates) with post tensioned concrete slabs and regular concrete columns would have added an additional 10 weeks to the construction schedule.

11 American Institute of Steel Construction



(LEFT) FIGURE 6.6
KIT OF PARTS ASSEMBLY DIAGRAM FOR TIMBER COLUMN, BEAM, AND CLT FLOOR ATTACHMENTS[12]

(BELOW) FIGURE 6.7 OFF-THE-SHELF COLUMN-TO-BEAM CONNECTIONS, AND CUSTOM STEEL COLUMN-TO-COLUMN CONNECTIONS[13]

12 Source: Carbon 12, Kaiser + Path

13 Source: Carbon 12, Kaiser + Path

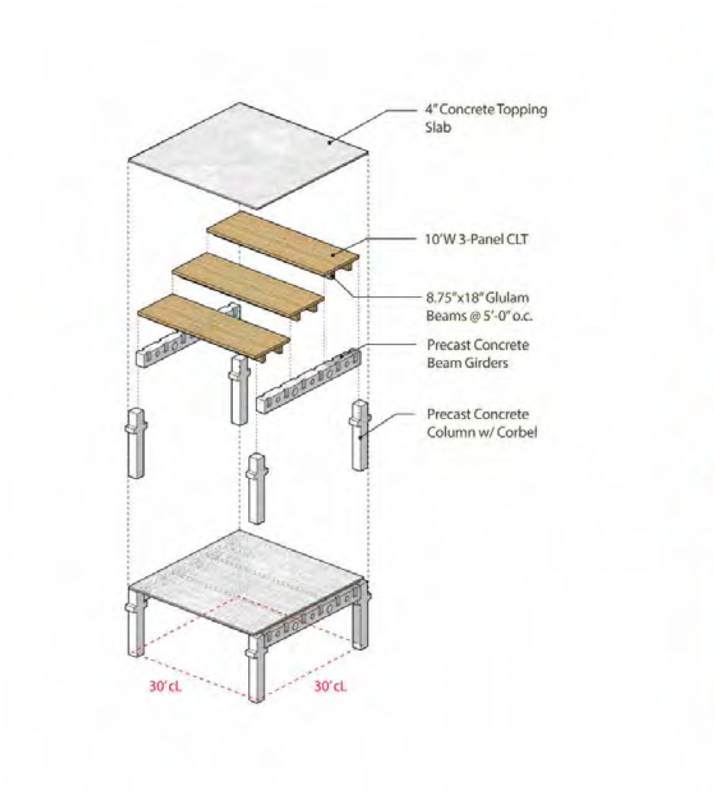


FIGURE 6.8 PRECAST CONCRETE AND TIMBER HYBRID STRUCTURE[14]

14 Adidas North Building, Lever Architecture

(CLOCKWISE FROM ABOVE)

FIGURE 6.9 CLT WALL AND ROOF PANELS IN A STEEL FRAME[15]

FIGURE 6.10 STEEL FRAME WITH CLT FLOORS[16]

FIGURE 6.11 PREPARATION FOR COMPOSITE CLT/CONCRETE SLAB [17]

6.3.2 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, as illustrated in **Figure 6.13**. According to a recent case study[18] published by the DLR Group:

"It is essential when procuring this type of building to have an engineer managing the delivery schedule and plant fabrication schedule. Because of the volume of wood being produced, and the time involved in handling the product, the manufacturers want to produce the project, set it on a truck, and ship it out to the construction site. Manufacturers do not want to sit on inventory or product because it would require a large amount of climate-controlled space. This means that a mass timber building is going to be fabricated within days or weeks of installation and the coordination of the construction schedule to plant fabrication schedule is paramount."

15 Lincoln City Police Department, Photo Credit: Swinerton Builders

16 Brentwood Public Library, Holmes Structures, Photo credit: Blake Marvin Photography

17 Microsoft Mountain View, Source: Holmes structures, Photo credit: Blake Marvin Photography

18 Tall With Timber: A Seattle Mass Timber Tower Case Study. DLR Group. November 2018. Accessed at: http://www.fastepp.com/wp-content/uploads/181109-Seattle-Mass-Timber-Tower-Book.pdf

FIGURE 6.12 MASS TIMBER MATERIALS HANDLING[19]

A GOOD NEIGHBOR

A modular building approach naturally leads to less time on-site, cutting down on local disruptions associated with construction, like increased traffic, lane closures, site disturbance, and noise. Smaller crews require fewer parking spaces, while reduced or eliminated field modifications make for a very quiet site. Large structural components can be offloaded 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.

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 increasing distances between the building site and the mass timber manufacturer, regional restrictions on oversized loads, challenging terrain, or constrained urban sites. The transport team can advise on route strategies and restrictions, and any added costs associated with oversized loads.

19 Source: Nordic Structures

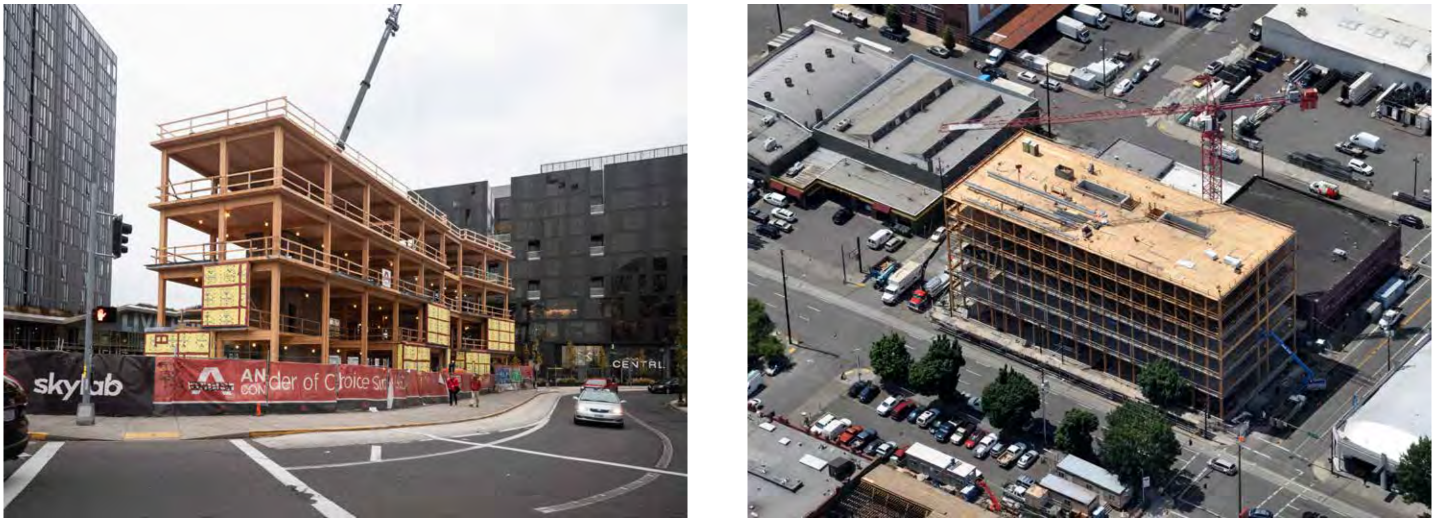


FIGURE 6.13 MODULAR TIMBER CONSTRUCTION ON CONSTRAINED URBAN SITES (LEFT [20]) (RIGHT [21])

When panels are loaded onto the truck, they must be placed from top to bottom in the order that they will be used. This system allows a crane to move a panel or beam from the truck directly into place in the building, without the need for on-site storage.

Managing material within a given space at a building site isn't specific to mass timber. Unique to mass timber is that each prefabricated element has a specific location in the building. Off-load sequencing is critical for smooth installation, but it will also be informed by weight distribution on the truck, as well as by panel size and shape. A building design with many similarly sized panels will be more straightforward to coordinate than one with many unique or unusual shapes. In the latter case, some lay-down space for re-sequencing should be planned for.

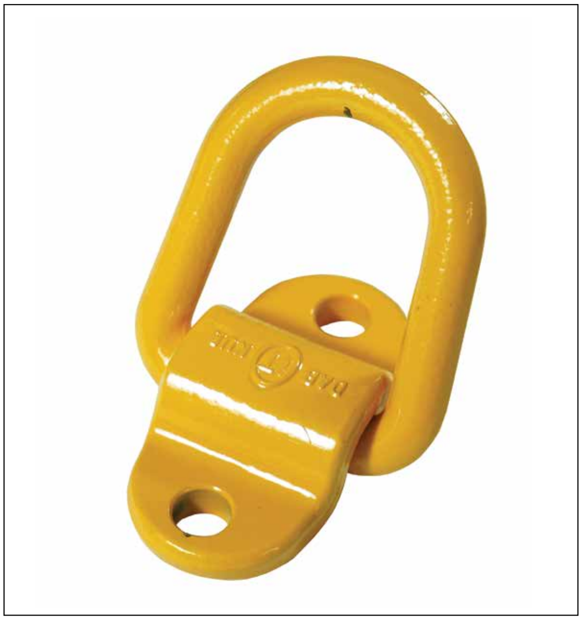
SUPPORT EQUIPMENT

It is important to determine the amount and type of support equipment needed at the site to ensure efficient operation. For example, 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 (as when mass timber is supplied by an overseas manufacturer), 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 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.

20 Sideyard Source: Holmes Structures. Photo credit: Skylab Architecture

21 Source: Project: District Office, Photo Credit: Andersen Construction



(ABOVE) FIGURE 6.14 PANEL LIFTING DEVICE[22]
(RIGHT) FIGURE 6.15 CLT PANEL INSTALLATION ON TIMBER FRAME[23]

Figure 6.14 illustrates a typical lifting device called a Yoke 1T, which 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, which eases installation. The pick points also enhance safety 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 is very little field cutting of material, meaning very little wood waste is created at the job site. Builders report this contributes to enhanced safety because the site stays clean, and storage and removal of waste doesn't require management's attention.

Panels will come wrapped in plastic for protection during transport and on-site storage. While light weight, this currently comprises the bulk of on-site waste volume associated with mass timber. There is potential for this waste to be reduced if the protection is reusable or multifunctional.

22 Source My-Ti-Con

23 District Office, Source: Anderson Construction, Photo Credit Pete Eckert

FIGURE 6.16 TIMBER FRAME AND STEEL CORE PROGRESSING IN COLD, SNOWY WEATHER[24]

METRIC UNITS OF MEASUREMENT

As the capacity of North American mass timber manufacturers is ramping up, some building projects are utilizing mass timber produced in 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 only calibrated in metric units. The crew quickly adapted to metric measurements.

6.3.3 WEATHER

Mass timber has 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 in any weather conditions. This has excellent implications for reducing weather delay contingencies during timelines that expect challenging weather months.

For example, the framing for Carbon12 took place between December 2016 and February 2017, which was one of the wettest, coldest, snowiest winters in the recent history of Portland, Oregon. While most of the construction sites in town were closed for several days at a time, Carbon12 continued to rise.

Once in place, however, wood components will need to be protected against wet weather to prevent moisture uptake.

24 Source: Carbon 12, Kaiser + Path

WEATHER PROTECTION AND MOISTURE MANAGEMENT

One of the most critical considerations when building with mass timber in wet climates is how to protect wood from exposure to water. 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. 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.

Standards for mass timber moisture mitigation have not yet been established. In addition to protection, the basic principles of any approach must allow for wood to release excess moisture at an appropriate rate until the structure has reached equilibrium with ambient environmental moisture during occupancy (see also **Chapter 5.1.8** on moisture). The TDI is currently working on developing recommended approaches for moisture management in mass timber construction, including target moisture content ranges, and dry-out procedures.

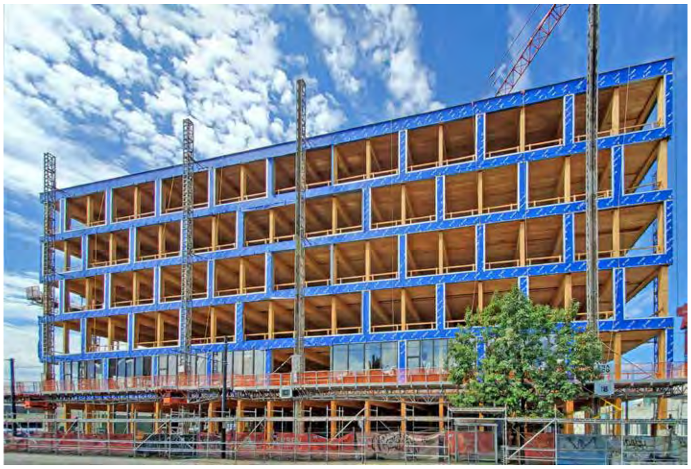
Meanwhile, experienced builders are also developing best practices. While constructing both Peavy Hall and the District Office during Oregon's wet months (both anticipating completion in 2020), Andersen Construction created a four-part Moisture Management Plan for wood structures. Each part is elaborated upon below.

1. **Sealers**
2. **Stain prevention**
3. **Moisture control**
4. **Dry out**

Sealers: Shop-applied sealers can protect against moisture intrusion during construction, and they may come standard with mass timber products. Facility capabilities vary, and they should be fully understood if sealers are to be used for weather protection. Often, a temporary wax coating will be applied by the manufacturer to edges where end-grain is exposed for protection during transport and installation. Moisture uptake is quickest at end-grain conditions, which is where panels are typically joined together and the most vulnerable. 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. All surfaces may benefit from different types of sealers, whether applied before delivery or on-site.

Stain Prevention: If the timber structure will be left exposed, stain prevention will be a primary concern. Some superficial stains can be cleaned or sanded, but proper stain prevention will avoid the risk of permanent marking, as well as reducing clean-up time and expense. Because multi-level buildings often have identical floors, panel seams, and penetrations, if not protected, they will allow water to move from floor to floor at each joint. Water will carry with it any pigments associated with the debris it is contact with, such as rust from metal work shavings or other untreated metals. Managing the construction materials and activities on a mass timber structure intended for finish exposure is critical for preventing stains.

Moisture Control: Two basic concepts are paramount to controlling moisture in structural wood. First, protect wood from prolonged exposure to water. Strategies for protecting panel seams and penetrations may be holistic, as in a tented approach, or local, such as tape. In both cases, 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. Secondly, if wood becomes wet, it must be allowed to breathe. Mass timber above about 14 percent should not be enclosed or encapsulated, but given a controlled opportunity to release moisture. Before panels are encapsulated on any given side, moisture content should be measured and reach a percentage that the team agrees is acceptable.



(LEFT) FIGURE 6.17 DISTRICT OFFICE FOLLOWED A MOISTURE MANAGEMENT PLAN[25]

(RIGHT) FIGURE 6.18 CLT PANELS PROTECTED WITH WRAP FOR TRANSPORT AND STORAGE[26]

Dry-Out: Mass timber naturally dries out more slowly than light framing due to the increased 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 movement created by swelling as the wood takes on water, and shrinking as the wood dries out. This phenomenon creates pressures within a timber element that lead to cracking and checking, which, while typically structurally insignificant, can be aesthetically undesirable or audibly startling to occupants.

6.4 TIME AND LABOR COST SAVINGS

Mass timber buildings can be less costly than other construction types because construction happens much more quickly and with less 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. In addition, developers often begin planning a building by using a parallel design approach using different structural materials for the same project. The resulting analysis compares the construction costs, leading to selection of one material over another. Thus, there may be cost comparisons between structural materials, but they are based on plans and estimates, not on actual construction costs.

The following sections review several studies that analyzed the cost of mass timber versus other building materials.

25 Photo Credit Andersen Construction

26 Hillsboro Community Center, Source: Swinerton Builders, Photo Credit BREWSPHOTO LLC

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 6.3 COMPARISON OF LENDLEASE PAL MASS TIMBER HOTEL; CONSTRUCTION WITH TYPICAL HOTEL CONSTRUCTION

6.4.1 CANDLEWOOD SUITES HOTEL, REDSTONE ARSENAL, ALABAMA[27]

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, four-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 U.S. Army installations, so private sector lodging is available to guests on military bases. So far, Lendlease has hotels at more than 40 U.S. Army installations 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 6.3**.

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, three experienced carpenters, and eight laborers, who were formerly unemployed military 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 was three months quicker (20 percent) for the mass timber building. 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.

27 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

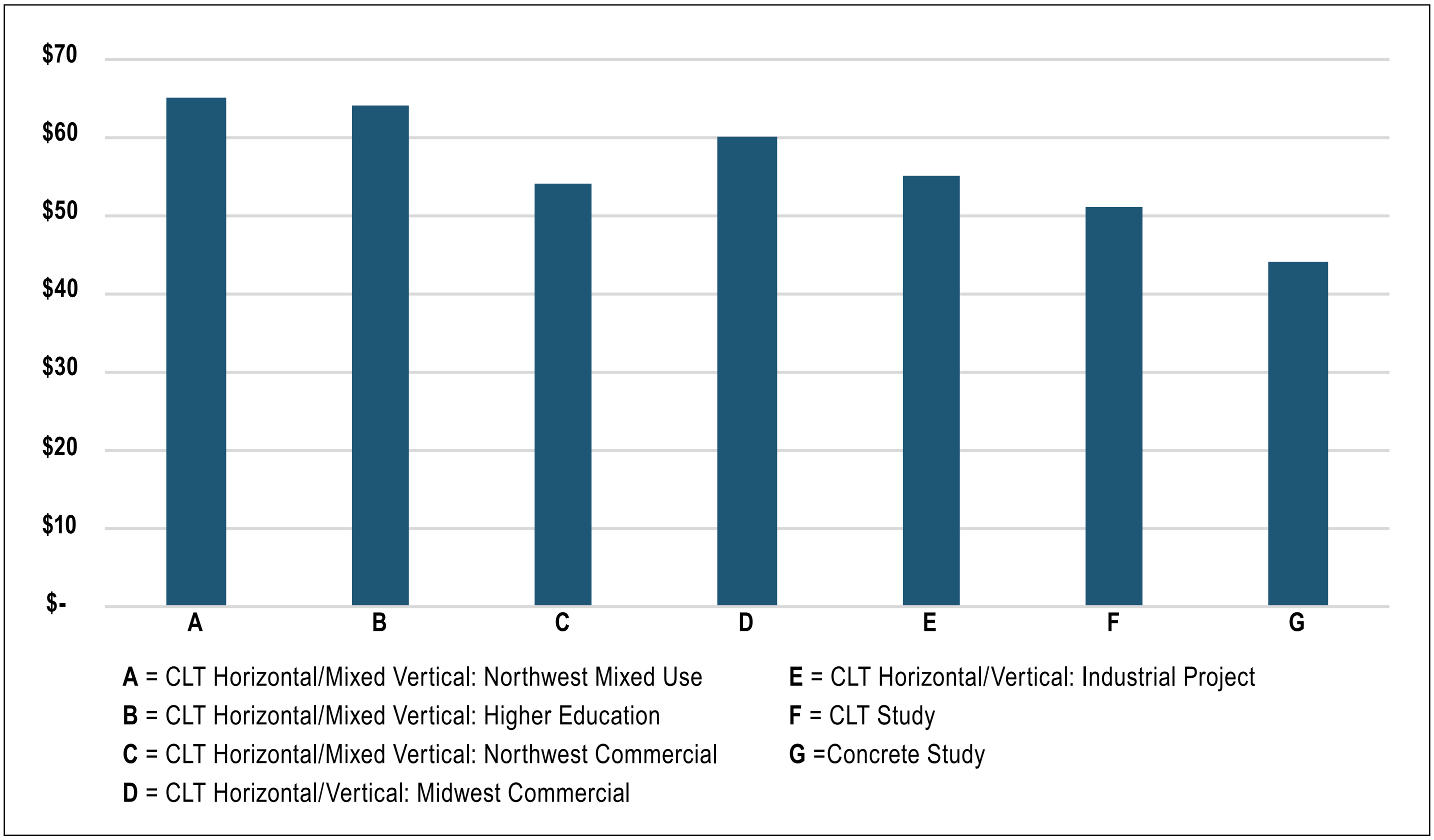


FIGURE 6.19 COST PER GROSS SQUARE FOOT STRUCTURAL FRAME ONLY

6.4.2 CROSS LAMINATED TIMBER FEASIBILITY STUDY[28]

In February 2018, Cary Kopczynski & Company, a structural engineering firm based in Seattle, Washington, completed a study comparing the cost of cross laminated timber 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 6.19**.

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.*"

28 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

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 6.4 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 includes labor cost and connectors for CLT*

6.4.3 CLT VERSUS CONCRETE/STEEL COST COMPARISON CASE STUDY29

In late 2016, researchers at the University of Minnesota's Department of Bioproducts and Biosystems Engineering completed a study comparing the cost of building with CLT versus concrete and steel. The study methodology involved interviewing three representatives from a U.S. 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 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.

29 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

The cost evaluation compared the building as constructed (concrete, structural steel, and light-steel 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 6.4**. Using CLT instead of concrete/steel could have saved up to 22 percent because of reduced labor costs and the 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.

6.5 MASS TIMBER MARKET DEVELOPMENT: U.S. MASS TIMBER PROJECTS

The mass timber industry is growing rapidly in the United States. The following data was provided by WoodWorks, which offers free one-on-one project assistance related to non-residential 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.

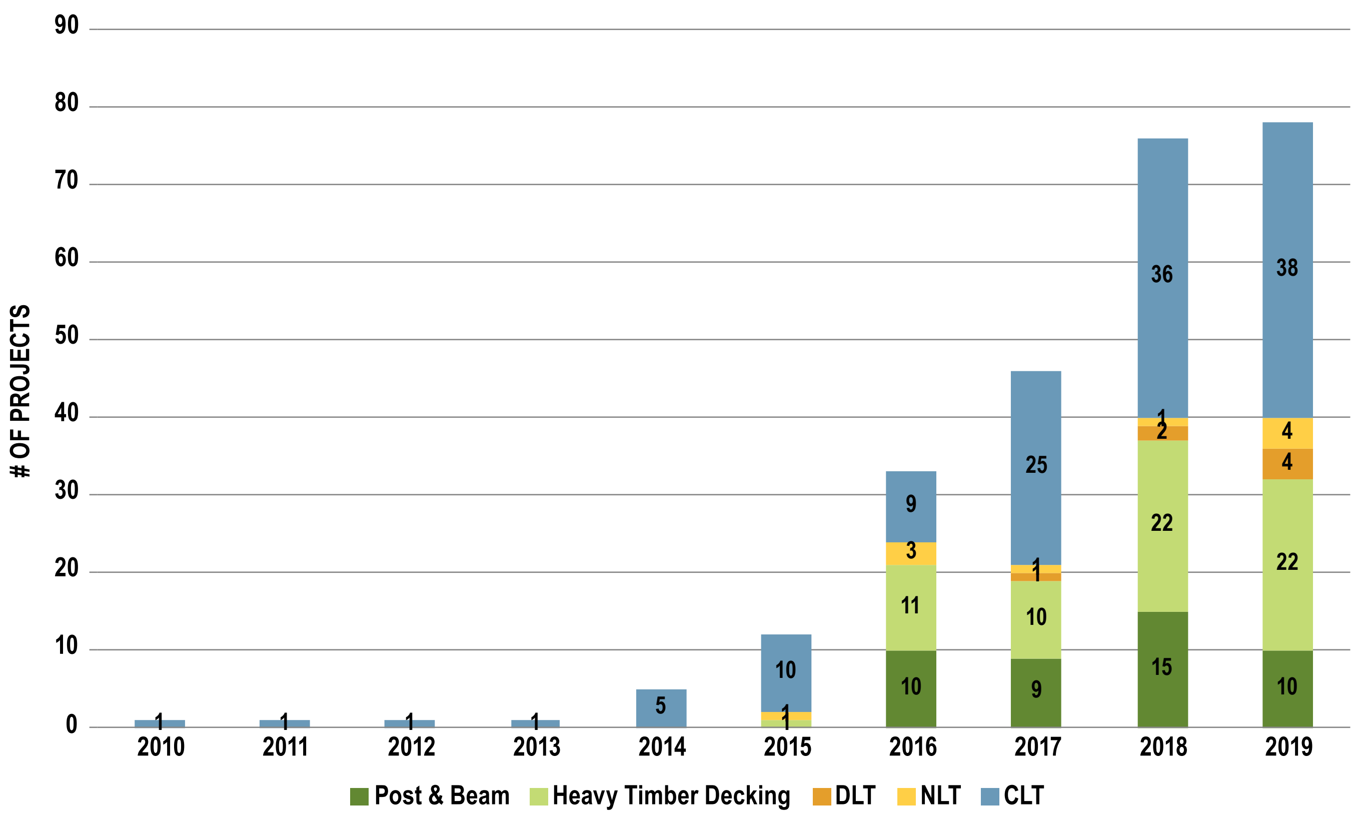


FIGURE 6.20 UNITED STATES PROJECTS BY PRIMARY MASS TIMBER MATERIAL

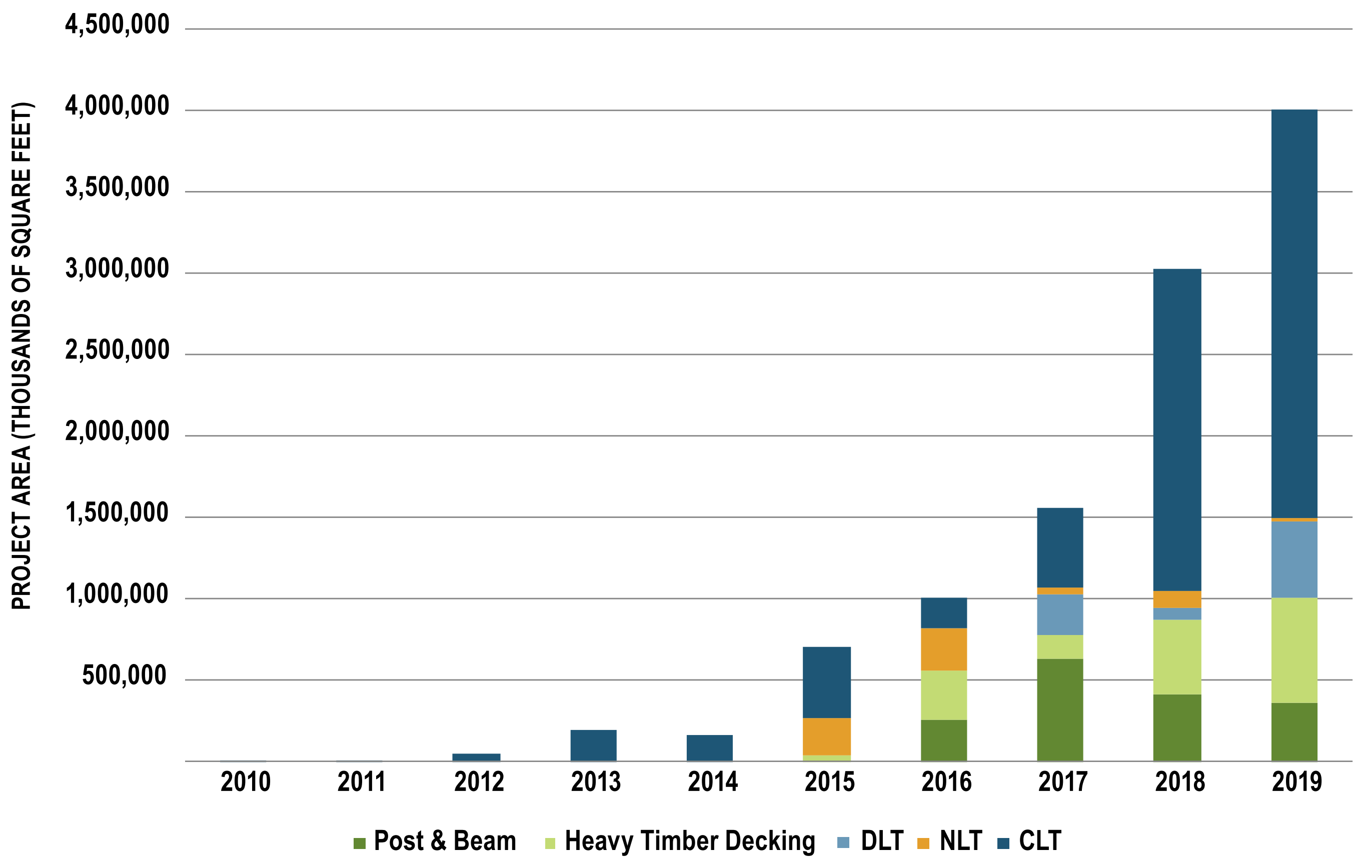


FIGURE 6.21 UNITED STATES BUILDING SQUARE FOOTAGE BY PRIMARY MASS TIMBER MATERIAL

The following figures illustrate the development of the mass timber industry in the United States and provide insights on the popularity of primary materials, regional popularity of mass timber, occupancy types, building sizes, and the total square footage and number of projects constructed from 2010 through 2019. **Figure 6.20** illustrates the rapid growth of mass timber building projects. A breakout shows the number of projects completed by mass timber type. On a project count basis, most of the growth has been in the use of CLT, but post and beam and heavy timber decking have also been popular.

Figure 6.21 shows the same information, but rather than reporting the number of buildings, this chart is based on total constructed square footage. In 2019, mass timber projects totaled 4 million square feet. Combining data from these two figures reveals the average project in 2019 was more than 50,000 square feet. CLT accounts for 62 percent of the square footage, but only about 50 percent of the building projects, indicating that buildings using CLT tended to be larger.

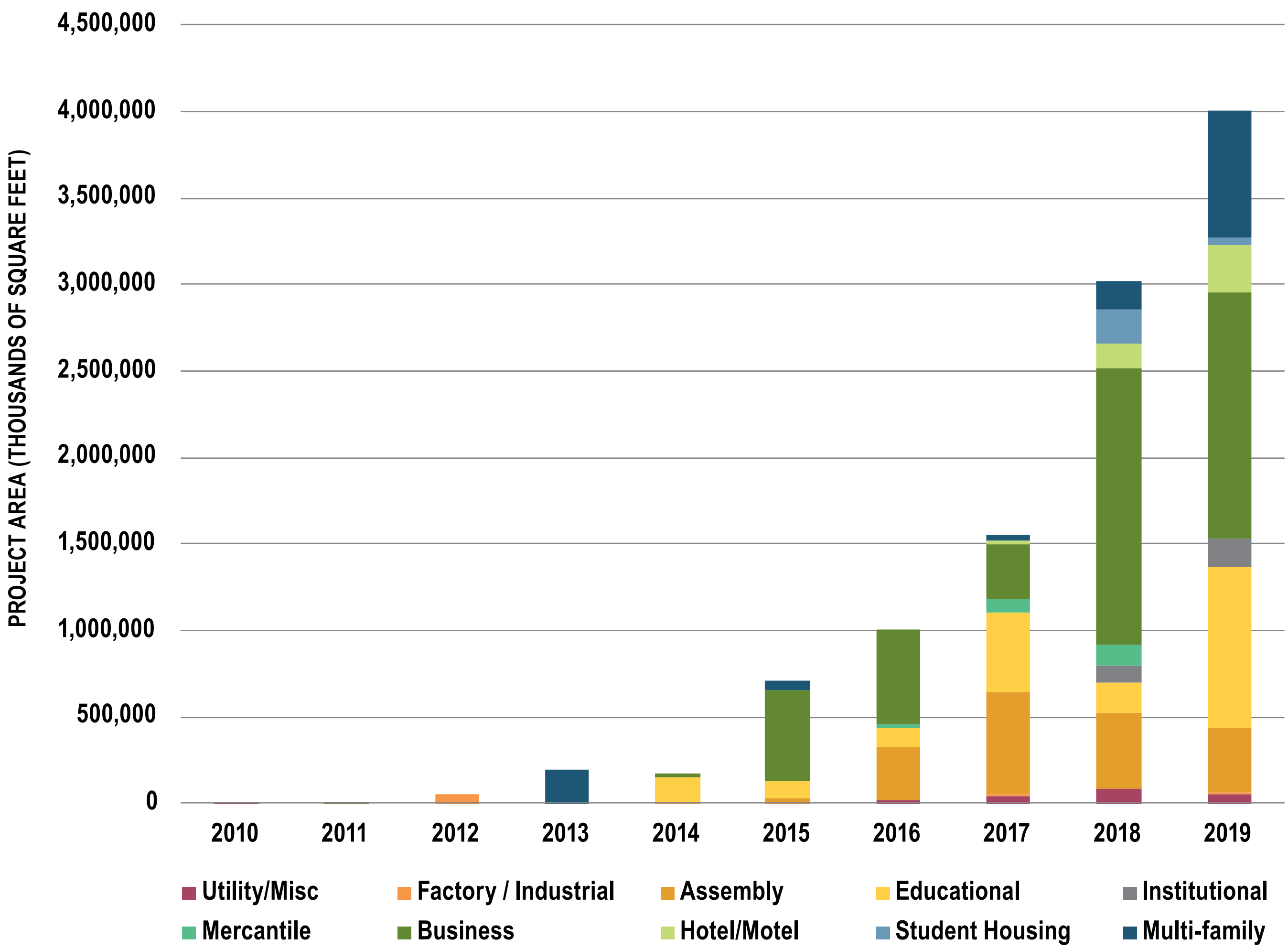


FIGURE 6.22 UNITED STATES MASS TIMBER BUILDING SQUARE FOOTAGE BY OCCUPANCY

Figure 6.22 illustrates the mix of mass timber building occupancy uses in the United States by total constructed square footage over time. In 2019, the most popular application of mass timber was for business buildings (offices, restaurants), followed by buildings used for education, multifamily residential, and public assembly (churches, theaters).

TABLE 6.5 US MASS TIMBER PROJECTS BY STATE ▶

Finally, **Table 6.5** shows the number of mass timber projects in the United States, by state, through 2019. While the previous data in this section represented only projects that have been constructed, this table also includes projects that are still in the design phase. The "in-design" category includes 460 buildings, indicating the rapid growth of mass timber will continue for the foreseeable future.

California, Texas, Washington, and Oregon are the most active states, with more than 40 projects each. Although mass timber construction is a relatively recent phenomenon, projects have been built in most states. As of 2019, only one state has zero mass timber projects (completed or in-design).

	BUILT	IN DESIGN	TOTAL
Alabama	3	8	11
Alaska		1	1
Arizona		3	3
Arkansas	3	5	8
California	32	68	100
Colorado	14	11	25
Connecticut	3	6	9
Delaware		2	2
District of Columbia	2	5	7
Florida	15	18	33
Georgia	4	13	17
Hawaii		3	3
Idaho	3	3	6
Illinois	5	11	16
Indiana	1	1	2
Iowa		1	1
Kansas		2	2
Kentucky	1	2	3
Louisiana		5	5
Maine	1	14	15
Maryland	1	7	8
Massachusetts	13	25	38
Michigan	2	6	8
Minnesota	2	4	6
Mississippi		4	4
Missouri	5	5	10
Montana	6	5	11
Nebraska	1	3	4
Nevada		2	2
New Hampshire	1	1	2
New Jersey	1	6	7
New Mexico		1	1
New York	6	24	30
North Carolina	13	22	35
North Dakota		1	1
Ohio	1	5	6
Oklahoma	1	2	3
Oregon	25	23	48
Pennsylvania	3	5	8
Rhode Island	2	1	3
South Carolina	9	11	20
South Dakota			-
Tennessee	3	4	7
Texas	17	37	54
Utah	3	3	6
Vermont	1	8	9
Virginia	6	7	13
Washington	28	44	72
West Virginia	2		2
Wisconsin	8	12	20
Wyoming	1		1
TOTAL	**248**	**460**	**708**

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CHAPTER 7: MASS TIMBER BUILDING OCCUPANTS

IMPACTS OF THE MARSHALL EFFECT ON MASS TIMBER BUILDING OCCUPANTS:

- Exposed wood surfaces support biophilic responses in building occupants, promoting health and productivity benefits in all building types.
- Demand for comfortable, healthy interior spaces drives a market for sustainably sourced wood buildings.
- 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 study[2] found that in the U.S., respondents spent about 87 percent of their time inside buildings and an additional 6 percent in cars. 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. This chapter shows how mass timber can boost building residents' health, comfort, and productivity.

7.1 MASS TIMBER AND OCCUPANT COMFORT

IEQ's relationship to occupant comfort is multidimensional, including thermal comfort, indoor air quality, acoustics, visual comfort, and safety. In simplest terms, when a person feels comfortable in a built environment, he or she also tends to be more healthy and productive. Mass timber enhances a building's comfort in several ways:

Thermal Comfort—Wood frame buildings perform well thermally because wood is a natural insulator. This gives designers increased flexibility when it comes to the use of insulation to meet energy efficiency codes. Wood also contributes to a perceived sense of thermal comfort, broadening acceptable temperature ranges, which can also save energy.

Indoor Air Quality—Mass timber contributes to indoor air quality because wood is hypoallergenic, 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. And because wood is a hydrophilic material, it can moderate humidity by absorbing moisture during periods of high humidity and releasing moisture during periods of low humidity.

Acoustics—In buildings such as hotels, dormitories, hospitals, offices, and apartments, sound-dampening design features can significantly enhance occupant satisfaction. The sound-dampening qualities of solid wood have long been recognized. While considerations specific to the transfer of sound through wood structures must be accounted for, designers find mass timber offers them great control of acoustic design parameters.

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

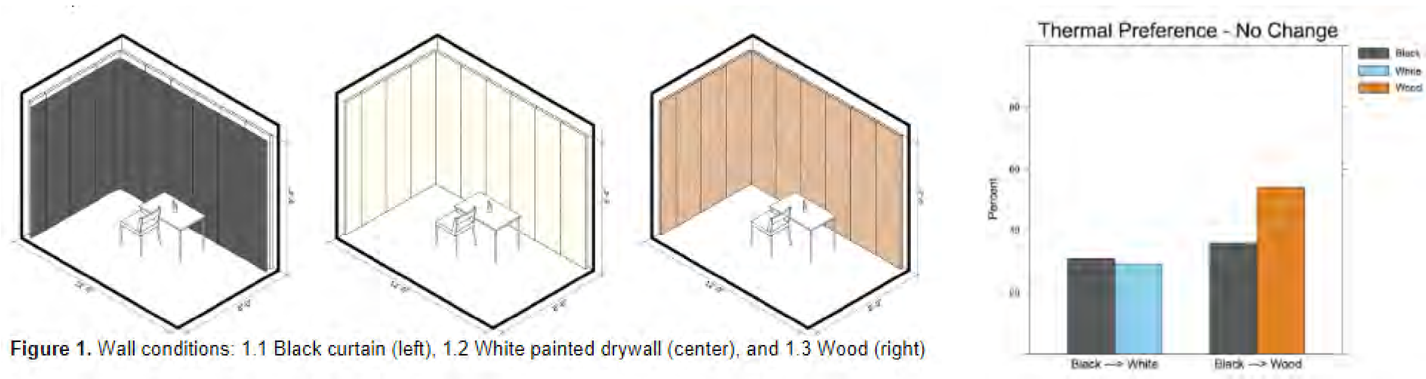

FIGURE 7.1 STUDY FINDINGS ON THERMAL COMFORT[3]

Visual Comfort—Two 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 daylighting and improvements in mood, productivity, and sleep patterns. Views can dramatically affect mood and productivity as well. A well designed building 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 let daylight farther into a building. Mass timber often inspires building designs with open atrium areas that are visually appealing and filled with natural light.

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 it 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 that's made painfully clear every time a large scale disaster displaces a large number of people for long periods of time.

A study performed by The Energy Studies and Building Laboratory (ESBL) at the University of Oregon in 2018 provides evidence that timber buildings support the thermal and visual comfort of occupants. The study found that *"…visually 'pleasant' or 'warm' surroundings can improve perceived thermal comfort, even when the space may call for cooling."* The 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 text subjects answered survey questions related to comfort and perception. With no other variables altered, participants in the wood room were 25 percent more likely to desire no change in thermal environment; 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."*

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

7.2 MASS TIMBER AND OCCUPANT HEALTH

The idea of enhancing human health through building design has been described as the application of biophilia in the built environment. Biophilia, a term created by Harvard professor Edward O. Wilson, is defined as the urge to affiliate with other forms of life. Biophilic design in buildings is an attempt to connect to nature by using natural materials, orienting a building to take advantage of daily and seasonal light patterns, and providing views of 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, "The Economics of Biophilia: why designing with nature in mind makes financial sense."[4] 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.

7.2.1 WOOD IN THE BUILT ENVIRONMENT

A study[5] by FPInnovations[6] connected the use of wood in the built environment and human health. The study documented:

"a link between wood and human health. In the study, the presence of visual wood surfaces in a room lowered sympathetic nervous system (SNS) activation. The SNS is responsible for physiological stress responses in humans. This result opens the door to a myriad of stress-related health benefits that the presence of wood may afford in the built environment. The application of wood to promote health indoors is a new tool for practitioners of evidence-based design."

According to the study, 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. The idea that the health benefits of exposure to nature could be extended to the use of wood were tested as follows:

- Four office environments were created, each identical in all respects except the amount of wood finishings in the furniture and blinds and the number of plants in the office.
- One hundred and nineten students were randomly placed in one of the four offices. The students were told they were taking part in an office performance task, and once in the room they were asked to complete an audio-based mathematics test.
- Heart rate and skin conductivity were monitored while each student was in the office, including an initial baseline, during the test, and after the test.

During all periods, stress as measured by heart rate and skin conductivity were lowest for the group 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.

A Japanese study in 2007 monitored subjects' physiological responses to different ratios of wood surfaces in an environment, discovering that a moderate ratio (45 percent coverage) was subjectively "comfortable" by lowering blood pressure and increasing pulse rate. A large ratio (90%) *"caused significant and large decreases"* in blood pressure in test subjects.[7]

4 https://www.terrapinbrightgreen.com/reports/the-economics-of-biophilia/

5 Wood and Human Health. FP Innovations 2011. Accessed at: http://www.solutionsforwood.com/_docs/reports/Wood_Human_Health_final-single.pdf

6 FP Innovations is a not-for-profit organization specializing in the creation of innovative scientific solutions in support of the Canadian forest sector's global competitiveness with special focus on the priority needs of industry members and government agencies.

7 https://link.springer.com/article/10.1007/s10086-006-0812-5

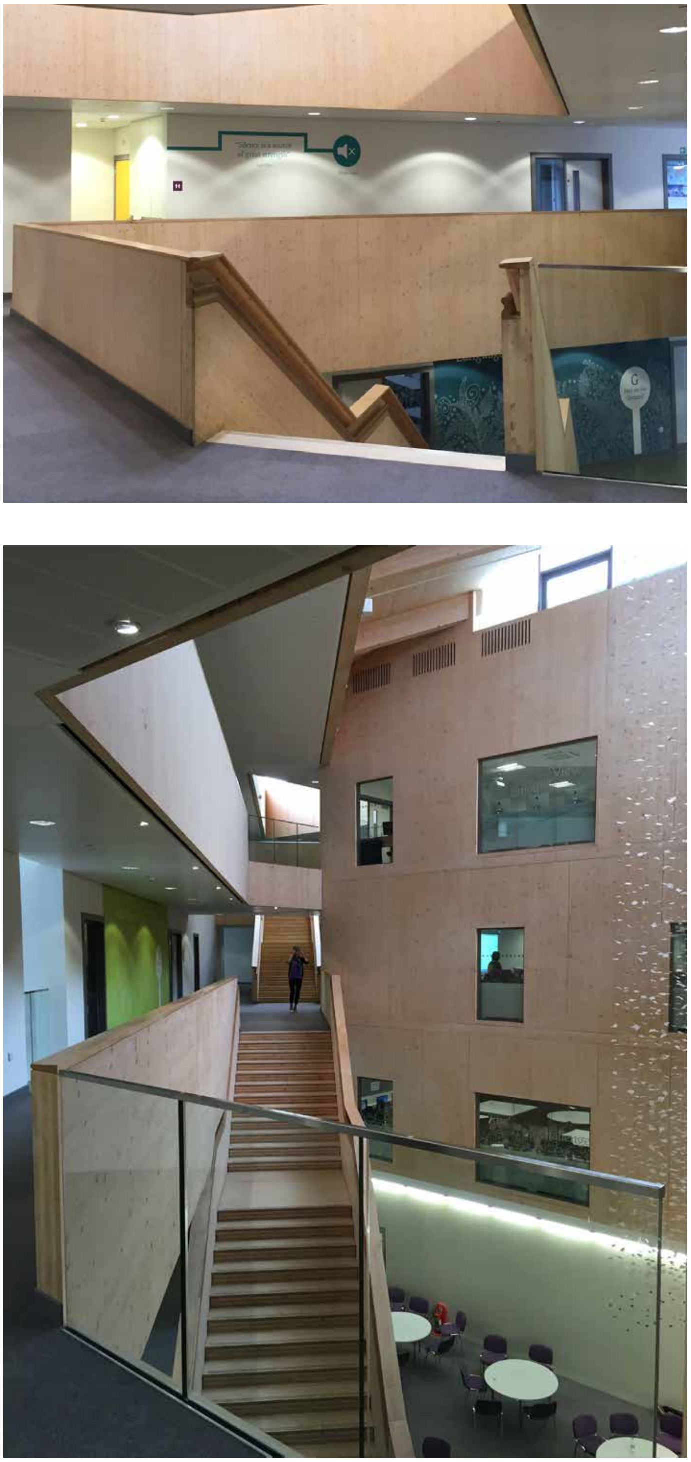

FIGURE 7.2 WILLIAM PERKIN CHURCH OF ENGLAND SCHOOL[8]

7.2.2 WOOD IN HEALTH-CARE ENVIRONMENTS

Another emerging area of occupant health is evidence-based design, which involves analyzing the design of a building to assess how it impacts human health. Already, architects specializing in the design of health-care 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 wood panels in hospital rooms reduced stress as measured by cortisol levels.[9]

Biophilic design in health care environments is linked to shorter hospital stays, faster recovery rates, fewer negative comments from hospital staff, and reduced medications.[10]

8 Photo credit: Emily Dawson.

9 Wood as a Restorative Material in Healthcare Environments. February 2015. FPInnovations. Accessed at: http://www.woodworks.org/wp-content/uploads/Wood-Restorative-Material-Healthcare-Environments.pdf

10 https://www.terrapinbrightgreen.com/reports/the-economics-of-biophilia/#the-economic-advantages-of-biophilia-in-sectors-of-society

7.3 MASS TIMBER AND OCCUPANT BEHAVIOR

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."* It adds, *"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 will be more conducive to spending, contributing to the success of a business.

There are also implications for building maintenance as relates to occupant behavior. 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, which was suggested by the contractor as a 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 for how the new building would be treated, as vandalism may be tempting on the new, exposed wood walls, and be a challenge to remove. Before the new building opened, a behavior strategy of quiet voices was planned for and encouraged in the halls with graphics, words, and quotes, reminding students to be peaceful and wise. To the administration's delight, the students were remarkably calm and respectful in the new space. Behavior issues and subsequent disciplinary actions have decreased significantly. Students report feeling that the space makes them feel valued.[11]

11 William Perkin Church of England School administration interview, 2015, Mass Timber Research Fellowship, SRG Partnership

USDA Forest Service Mass Timber Research and Market Development

T3, Minneapolis, Minnesota

Carbon12, Portland, Oregon

Forest Products Laboratory Research

- Building and fire science
- Durability and wood protection
- Engineering properties
- Life cycle and economic analysis
- Blast and ballistic testing
- Materials and manufacturing processes

Wood Innovations Market Development

- Wood Innovations Grants
- Tall Wood Building Prize competition
- Mass Timber Conference founding partner
- 2021 ICC Building Code adoption
- WoodWorks funding partner
- National Building Museum—*Timber City* exhibit

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CHAPTER 8: MASS TIMBER BUILDING OWNERS

IMPACTS OF THE MARSHALL EFFECT ON MASS TIMBER BUILDING OWNERS:

- In the near future, the carbon impact of any investment will factor into its market value.
- 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 towards maximum carbon storage potential of forest products.

The Life Cycle Analysis (LCA) of a given building may choose to include the 1-to-1 equivalent replanting that occurs in most North American forestry practices, or go further and pledge additional replanting to offset other carbon emitting building elements.

At this stage in the evolution of mass timber, building owners are perhaps assuming the greatest amount of risk in the supply chain. They are the pioneers adopting a relatively new (to North America) building technology, using evolving financing and procurement systems, and relying on contractors, designers, and engineers who may have limited experience with wood structures. This chapter explores the owner's role, the potential benefits of choosing a mass timber system, key development issues, and best practices.

8.1 MASS TIMBER 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[1] 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 timeframe, all while ensuring the safety of construction workers and building occupants.

8.1.1 BUILDING VALUE

The economic, social, and environmental advantages of building with mass timber play into the understanding of a building's market value in unique ways, which a prospective building owner should understand to maximize the advantages of choosing a timber structure.

8.1.2 MASS TIMBER BUILDINGS ARE PREMIUM PRODUCTS

Mass timber market data is limited by a very small number of buildings and the short amount of time those buildings have been on the market. However, mass timber buildings have 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 due to 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.

1 Survey of International Tall Wood Buildings. 2014. Perkins + Will. Accessed at: http://www.woodworks.org/wp-content/uploads/TTWB-2014-Holt-Survey-of-International-Tall-Wood-Buildings.pdf

LEASE UP RATES AND PREMIUMS

Due to increased demand for biophilic buildings as stated above, the leasing period for exposed mass timber buildings can be lower than a typical concrete or steel building with traditional finishes. Securing tenants early allows 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, which allows a building owner and/or investor to begin recuperating 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 return on investment.

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, which translates 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, which will illuminate payback periods. The Canyons, a 6-story apartment building (completion fall 2020) in Portland, Oregon, compared a CLT structure with light framing and painted sheetrock. The team discovered that the payback period for the premium structure was just over 3 years; 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 AND SALES/TIME ON MARKET

A multi-owner mass timber development completed in 2014 in Portland, Oregon, is comprised of three buildings on one block, sharing 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 tongue-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 assumed. Since occupancy, only one office space has been turned over, with a negligible vacancy period.

8.1.3 REDUCED CONSTRUCTION TIME

Taking more time up front in the design phase pays off in construction-phase predictability. Precision of custom components and a highly organized, modular structural package contribute to expedited construction with fewer field modifications, change orders, and delays.

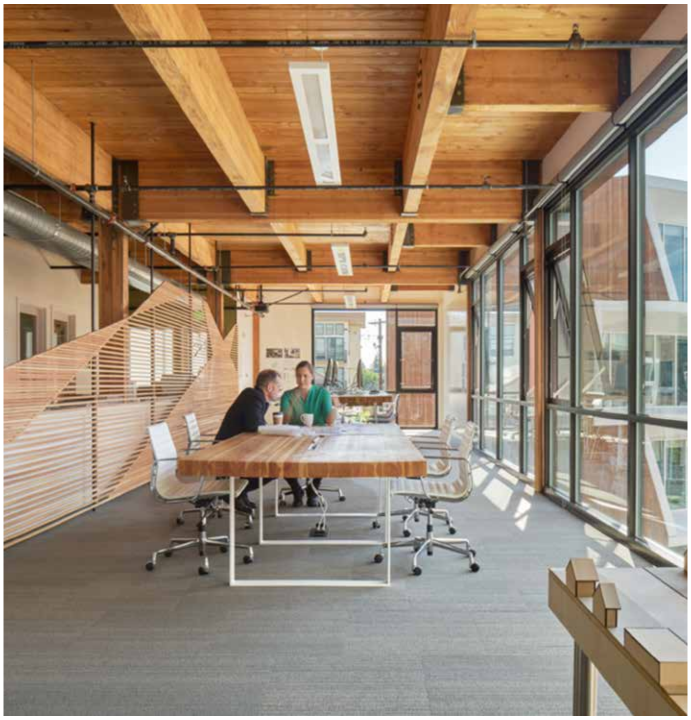
Other associated benefits with schedule reductions include fewer potential weather delays, and lower costs associated with traffic disturbances.

CONTINGENCY

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. 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 by using a highly coordinated approach.

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 tax, and other fees. Reducing carrying costs by even a month or two translates to tangible savings that should be included in comparative cost models.



(Clockwise starting at left)

FIGURE 8.1 RADIATOR BUILDING
Photo credit: Andrew Pogue Photography

FIGURE 8.2 ONE NORTH AND RADIATOR BUILDING
Source: Kaiser + Path

FIGURE 8.3 SIDEYARD
Source: Skylab Architecture

8.1.4 PREFABRICATION

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 ahead and coordinate off-site construction. The resulting building can have a higher level of precision over site-built structures due to the increased quality control afforded by climate controlled interior factory environments.

8.1.5 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 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.

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,[2] Woschitz Group, Vienna, Austria
- 18 stories, 279 feet (85 meters): Mjøstårnet, AB Invest, Brumunddal, Norway

A number of studies and proposals are validating the effectiveness of timber structures up to 40 stories:

- 23 stories: Ascent Residential tower, New Land Enterprises, Milwaukee, WI[3]
- 30 stories: FFTT, Michael Green Architects, Vancouver, BC[4]
- 35 stories: Proto-Model X, Sidewalk Labs, Toronto[5]
- 36 Stories: The Spar, Kaiser + Path, Portland, OR[6]
- 42 stories: SOM timber tower study, Chicago, IL[7]

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.

2 https://vaaju.com/austriaeng/final-track-at-the-wooden-hoho-height-in-vienna-seestadt-aspern/

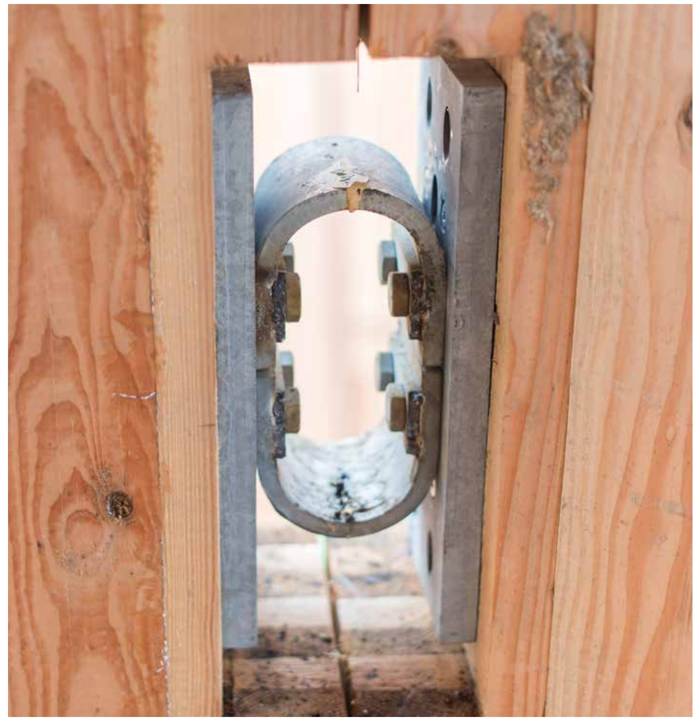
3 Articles: https://www.constructiondive.com/news/nod-given-to-what-could-be-us-tallest-mass-timber-building/547084/ https://www.bizjournals.com/milwaukee/news/2019/08/28/new-land-adds-height-to-timber-apartment-tower.html

4 https://www.archdaily.com/220779/michael-green-presents-the-case-for-tall-wood-buildings

5 https://www.curbed.com/2020/1/29/21110943/sidewalk-labs-mass-timber-gensler-michael-green

6 https://www.kaiserpath.com/the-spar

7 https://www.som.com/ideas/research/timber_tower_research_project



(LEFT) FIGURE 8.4 CLT POST-TENSIONED “ROCKING” SHEAR WALL[8]

(ABOVE) FIGURE 8.5 ROCKING SHEAR WALL FUSE[9]

8.1.6 INCREASE ALLOWABLE BUILDING AREA

A timber building on average weighs only 20 percent of the weight 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 seismic regions. A lighter building can also mean a viable project where foundations to support a heavier building are prohibitively expensive.

Mass timber floor sections can be designed to be thinner than other options, and are inherently fire resistant, requiring no added fireproofing material at certain building heights. Depending on zoning constraints, additional floors may be viable because of reduced floor-to-floor heights.

8.1.7 RESILIENCY

Resiliency is a term used to describe a building's ability to recover from a disaster event like an earthquake, fire, hurricane, or flooding. Mass timber has several resiliency advantages over both steel, concrete, and light frame structures.

Mass timber is both strong and flexible, and therefore well suited for resisting large forces and returning to its original shape. It is also very fire resistant, due to the thickness of each member. Unlike steel and concrete, failures or compromises in wood structural members are visible, so 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 re-occupancy.

8 Source: Project: Oregon State University Peavy Hall Replacement, Photo Credit: Andersen Construction

9 Source: Peavy Hall, Photo credit Hannah O’Leary

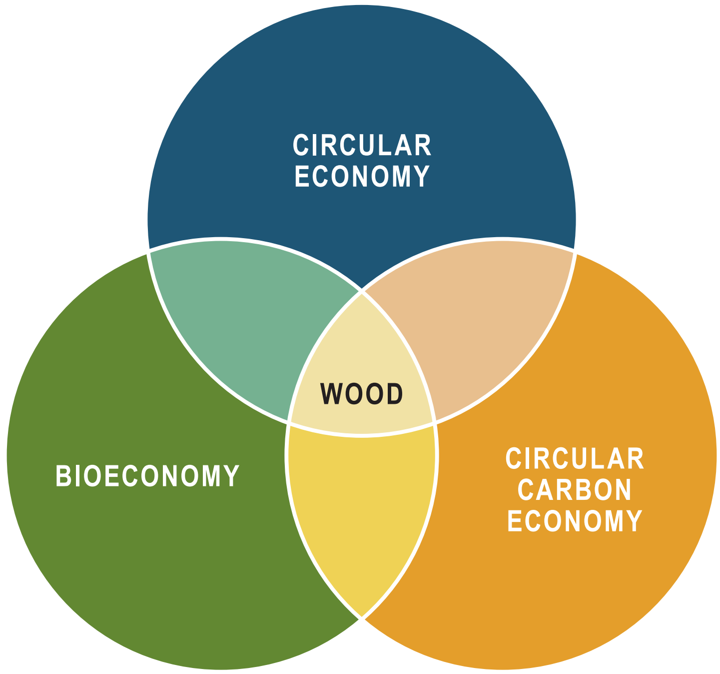


FIGURE 8.6 CIRCULAR ECONOMY

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 retrofitted.

An innovative earthquake-resisting "rocking" shear wall design has been tested and installed in Peavy Hall at OSU. 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.

8.1.8 CIRCULAR CARBON ECONOMY

The Consortium for Research on Renewable Industrial Materials (CORRIM)[10] is a nonprofit research corporation that focuses particularly on the Life Cycle Assessment (LCA) values of forest products, recognizing wood as a material uniquely poised to solve global economic, environmental, and social pressures associated with the building industry. The CORRIM 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 framework concept that offers a systematic strategy for minimizing the loss of materials and value, and the negative externalities associated with economic production-consumption systems. The circular economy is grounded in long-standing research themes, including industrial ecology, regenerative design, performance economy, biomimicry, and cradle-to-cradle design. Fundamentally, circular economy principles focus on designing products and materials in a way that minimizes waste across their entire life-cycle."*

10 https://www.corrim.org/

It is likely that in the near future, the carbon impact of any investment will factor into its value. Carbon taxes or credits or low-carbon incentives are not yet the norm, but they will be increasingly incorporated into the economy. Sustainably sourced mass timber buildings can neutralize or even balance the carbon emissions required to construct a building. This is something to be aware of, and consider for projects that are expected to start a permitting process in the coming years.

CORRIM identifies wood as fitting naturally within the circular economy:

"Wood-products (and other biomaterials) present an interesting opportunity at the nexus of these concepts: within the Circular Economy wood can be designed to be cycled through both technical and biological cycles; and fundamentally, wood and wood products are central to both the bioeconomy and the circular carbon economy."

"[W]ith forests and wood products, that circularity is further extended from the waste stream through the uptake of greenhouse gases during new forest growth. Structural wood products have the potential to act a carbon negative technology that could contribute to the goals of the circular carbon economy without having to develop entirely new engineered systems to remove carbon from the atmosphere."

Recycled material and VOC content data is now commonly provided by materials manufacturers. Disclosing embodied carbon values will soon be expected, with the growing understanding in the building industry that this information is critical to meeting global atmospheric carbon reduction goals.

8.1.9 DEMOLITION AND REUSE

Not often considered early on in the sale value of a property is the ease of demolition of the structure or the reuse value of the building materials at the end of a building's life.

Though it is far too early to have data on the 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. When salvage is possible, reuse is not usually 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.

8.1.10 INCENTIVES

Federal forests are currently an under-utilized source of fiber for the building industry. A developing concept is to combine this supply potential with the demand for affordable housing by subsidizing the extraction and processing of building materials from federally managed forests under the 1947 Materials Act.[11]

The Materials Act, with a subsequent amendment in 1955 for vegetative materials, allows the US government to use public resources for public good. For example, gravel for highways. Timber resources could similarly be utilized to ease the housing crisis facing many of the country's communities.

8.1.11 MAINTENANCE AND BUILDING MANAGEMENT

Exposing wood is often a primary reason to use timber as a structural material. This decision is usually paired with a desire to consolidate **utilities** in deliberately located chases and soffits. Mass timber buildings can and should require more planning in the design phase, leading to predetermined slab and wall penetrations for ductwork, conduits, and piping. This is an opportunity to design utility systems within a building with ingenuity and precision, and it ensures that systems are installed according to plan. Having reliable as-built documents can lead to more efficient routine maintenance, and when systems issues arise, to more timely action.

11 https://www.ntc.blm.gov/krc/uploads/238/disposal.pdf

Coatings such as sealers or paints may be added to structural timber as protection from UV and weather, as an aesthetic choice, or to be more easily cleaned. Coatings on any surface require some upkeep and re-application. Maintenance timelines vary by product, application method, and exposure.

8.2 KEY BUILDING OWNER/ DEVELOPER BARRIERS

The following is a list of key issues that building owners/developers face when utilizing mass timber in the construction of a building.

8.2.1 PLANNING AHEAD

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 field labor and project overhead costs. 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 1/8 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 Builders, "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."[12]

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.

8.2.2 PROCUREMENT PROCESSES

Standard procurement processes can be a barrier to maximizing the cost benefits of mass timber.

A traditional Design-Bid-Build procurement process in building construction is common and preferred by many investors. For the purposes of this section, the issues are similar with a Construction Manager/General Contractor (CMGC) process, which is typically:

1. Design a building meeting the requirements of the local jurisdiction (with a CMGC this includes periodic cost estimates and feedback).
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 consultation with a mass timber manufacturer prior to putting the project out for bid. Each manufacturer has particular parameters that help a design team dial in the most efficient use of the material. Switching manufacturers at bid time could result in a costly and time consuming redesign. It is possible to design a mass timber building with average assumptions about dimensions, span capacity, fire ratings, cost, and availability. However, this is risky due to possible delays and costs associated with redesign and detailing, permit revisions, and constructability and availability issues. The earlier a manufacturer is brought into the process, the more refined and cost-effective the design and construction process will be.

12 Erica Spiritos and Chris Evans, Swinerton Builders, Mass Timber Conference 2019 presentation: Mass Timber Construction Management: Economics & Risk Mitigation

One option 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 CMGC. Advantages to this approach include design optimization, detailed pricing feedback during design, and early assurance of product delivery dates. 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, so having a design optimized early will help ensure fabrication timelines will be met.

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, where all parties are incentivized for project success, will naturally support early and efficient coordination.

8.2.3 INSURANCE

Insurance companies have little experience with mass timber buildings. According to a Perkins + Will study,[13] 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.

8.2.4 COST UNCERTAINTY

The cost uncertainty associated with a mass timber building project 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 grows, 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 learning to be a part of an up-front planning process. The number of manufacturers, designers, and builders who understand how to deliver efficient, cost-effective mass timber buildings is growing because the value of completed buildings is being proven in the marketplace.

8.2.5 PUBLIC PERCEPTION OF MASS TIMBER

According to a 2015 public survey[14] by Perkins + Will, the general public perceives the greatest barriers to wider adoption of mass timber as:

1. The flammability of wood
2. Wood’s strength compared to concrete and steel
3. 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 an obstacle building developers must address.

8.2.6 LIMITED 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.

13 Mass Timber Influencers: Understanding Mass Timber Perceptions Among Key Industry Influencers. Perkins + Will. October, 2018. Accessed at: https://perkinswill.com/sites/default/files/PerkinsWill_Mass%20Timber%20Influencers_%20Vancouver_Oct%202018.pdf

14 Perkins + Will Research Journal. Tall Wood Survey. Volume 08.01 2016. Accessed at: https://perkinswill.com/sites/default/files/ID_3_PWRJ_0801_02_Tall_Wood_Survey.pdf

8.3 CURRENT BEST PRACTICES

The British Columbia Construction Association sponsored a study of innovative technologies and strategies in building construction procurement.[15] The following is a selected list of best practices taken directly from the study:

- Owners engage with the market early to ensure the right level of technologies, skills and resources are available for their project. This includes undertaking early market engagement activities that can help to identify new technical solutions, achievable targets and appropriate performance assessment schemes. It also includes owners encouraging innovation by engaging with specialist contractors, product manufacturers and suppliers well in advance of tendering to ensure that the market can respond appropriately.

- Early involvement of all key project team members, including the general contractor and specialist trades. This fosters close team integration, a team-wide spirit of collaboration and trust. It maximizes the opportunity for innovation in the design, procurement and construction processes. It also includes dialogue with the project team early in the planning phase to help identify what could be achievable and the true short- and long-term cost implications.

- When incorporating innovative products and processes in buildings, more time and resources are allocated (and budgeted for) early in the project process to adequately understand the owner's requirements. Virtual mock-ups and digital models offer a powerful way to research design and construction ideas early in the project process. It also means that demonstration projects should be documented to institutionalize lessons learned.

- Owners make every effort to create a highly effective and collaborative project team that puts the interests of the project first. This means owners may, when appropriate, consider multi-project engagements of consultants and contractors to foster collaboration, learning and team cohesion. There is an emerging body of research that shows greater collaboration is more likely to lead to successful outcomes and high-level team performance. Given that the project "innovation champion" may be the owner, consultant or builder, the procurement process should allow collaboration to start as early as possible in the project process for creative ideas to blossom. The project team should be allowed input into when opportunities for research and development, 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 IPD contracts (such as Multi-Party Agreements) that encourage collaboration may be best suited for innovative projects that are not well defined in scope.

- A qualified experienced project team includes the owner, contractor and the specialist trades. It may also include operations and maintenance personnel. Owners should 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.

15 Procuring Innovation in Construction: A Review of Models, Processes, and Practices. British Columbia Construction Association. 2016. Accessed at: https://www.naturallywood.com/resources/procuring-innovation-construction-review-models-processes-and-practices

- Businesses of all sizes should be encouraged to participate because some small- to medium-size enterprises (SMEs) are the most innovative. Owners can 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. Owners can provide greater opportunities for smaller, more innovative firms by focusing on the quality of the references rather than quantity. They can also request evidence of the quality of work, not just a list of relevant projects. For example, this may include the extent to which project sustainability, cost targets and time schedules were met. Enabling SMEs to participate in projects requiring advanced and/or expensive technology (e.g. BIM), training and financial assistance may be necessary.
- The business case for innovation may best be articulated using life cycle costing (LCC). Focusing on LCC rather than lowest cost will deliver owners greatest value overall and is a powerful motivator of innovation. Lowest first cost also does not reflect the financial and non-financial gains that are offered by environmentally and socially preferable assets as they accrue during the operations and use phases of the asset life cycle. Owners should identify a suitable model for LCC at project planning stage to inform decisions throughout the procurement process. This should at least cover: total construction costs, annual operation costs, annual maintenance cost, and end of life costs.
- The technical and logistical considerations of building with wood are factored into the procurement process. Opening up the procurement process to encourage innovation may allow wood to be considered as an option in a greater number of situations and project types.
- Creativity and "out-of-the-box" solutions may be sought through sanctioned design competitions.

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Extensive experience in wood products manufacturing across North America including lumber and mass timber panel operations with a focus on planning, benchmarking and analysis. Bryan also has experience in the construction industry.

BEN KAISER

OWNER
KAISER+PATH

Operating as the Owner, General Contractor and Architect, we are convinced that mass-timber is the way forward. It is the preferred path for feasibility, efficiency, constructability and beauty. It is the only path for the environment.

EMILY DAWSON

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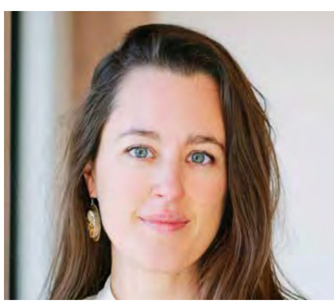
Emily has been investigating and implementing mass timber solutions for nearly a decade, including designing the first cross-laminated timber structure built in Oregon. At Kaiser + Path, she works exclusively on mass timber projects, from feasibility through construction.



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PRESIDENT & CEO,
FOREST BUSINESS NETWORK

Recognized as a national expert and leader in under-utilized timber and woody biomass with more than 40 years experience in the forest and forest product sector. FBN also owns and co-produces the International Mass Timber Conference.

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Oregon

THE LEADER IN MASS TIMBER INNOVATION

Oregon is a resource for deep expertise in forestry, wood-based materials, research, engineering, and architecture that is driving innovation across the entire advanced wood products supply chain, from forest to frame.

business oregon

Meet Business Oregon's Mass Timber Team

Text our team today for more information about Oregon's assets and incentives!

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TALLWOOD DESIGN INSTITUTE

Oregon is the place to be for Mass Timber

Timber Harvest

- About 63% of Oregon's forests are publicly owned and 37% are privately owned. Private owners account for about 75% of the annual harvest, which assures stability of supply.

Forest Sustainability

- Each year between 2006 and 2015 Oregon forests added approximately 1 billion cubic feet of standing timber volume.

Forest Economy

- Oregon's timber industry directly employs over 61,000 people.
- Oregon is home to 2 of the 14 existing North American mass timber panel manufacturers.

Production of Mass Timber Raw Materials (Lumber and Plywood)

- Oregon has been the leading softwood lumber producing state for decades.
- Oregon is the leading veneer/plywood producing state; producing 28% of the U.S. total in 2017.

Building Codes

- Mass timber can be used in buildings up to 18 stories.
- Use of mass timber in a variety of building types is fully adopted by State and Local authorities.

Market Size

- As of late 2019, Oregon accounted for 46 mass timber buildings either in design, in construction, or built; trailing only California (99) and Washington (69).

Supply Chain Integration

- Two businesses operate in Oregon that coordinate the output of mass timber producers with the needs of building contractors.

Images: Marcus Kauffman, Oregon Dept. of Forestry
Resources: https://oregonforests.org/sites/default/files/2019-01/OFRI_2019-20_ForestFacts_WEB.pdf; www.beckgroupconsulting.com