U.S. Mass Timber Construction Manual

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Table of Contents

1 Introduction

Between 2015 and 2020, mass timber buildings gained real traction in the United States. Some products now considered part of the mass timber family had been around for years. Glue-laminated timber (glulam or GLT) had long been included in building codes and nail-laminated timber (NLT) was having a resurgence. But they were now joined by cross-laminated timber (CLT), a product strong and stable enough to be used in high-rises, which also had two decades of proven performance in Europe. It was the proverbial game changer. While there is no single answer to complex societal issues such as population growth and climate change, the 2021 International Building Code (IBC) allows CLT in buildings up to 18 stories—and taller and larger mass timber buildings are an opportunity to help address the need for both urban density and sustainable construction.

As an organization that provides free project support related to the design, engineering and construction of wood buildings in the U.S., WoodWorks experienced the momentum up close. We began seeing a significant increase in mass timber projects in 2015, driven largely by design team interest in wood's light carbon footprint, sustainability and aesthetics. Developers soon began seeing quantitative value in mass timber's installation speed and the market distinction offered by the beauty of exposed wood structures. However, as interest grew, we realized that a lack of general contractors and installers with mass timber experience—because there wasn't yet a critical mass of projects to gain experience on—was preventing more of these buildings from being realized. We found the answer in our core activities of education and project support.

To help contractors and installers gain the experience needed to successfully bid and complete projects, WoodWorks launched its Mass Timber Construction Management Program. Mass timber construction is unique in that it draws installation techniques from other construction types, so people with concrete, precast, tilt-up and structural steel experience can readily adapt to these materials. Most mass timber buildings are also hybrids, which eases the transition. However, understanding how mass timber *differs* from other building systems is key to cost effectiveness.

The Mass Timber Construction Management Program includes two distinct parts:

- **Project management curriculum** is offered by WoodWorks for individuals who estimate, procure and manage new commercial and multi-family construction projects in the U.S. Details on upcoming events can be found at woodworks.org.
- **Mass timber installer training** is created for crew leaders and installers who physically build structures. Programs are developed in partnership with training centers, community colleges, contractors and workforce programs that provide skills training to the construction industry. For a current list of programs, visit: www.woodworks.org/mass-timber-construction-management-program/.

This manual is intended as a resource for both aspects of the program, and for anyone who wants to know more about the construction of mass timber buildings.

WoodWorks also offers other mass timber resources, available at woodworks.org and as part of the *Mass Timber Design Manual*[1] published jointly with Think Wood. Documents that may be of particular interest to contractors and installers include:

- *Mass Timber Cost and Design Optimization Checklists*[2] – Includes guidance on how to estimate projects and make cost-related decisions
- *Insurance for Mass Timber Construction: Assessing Risk and Providing Answers*[3] – Focuses on insurance nuances and how make projects more insurable

If you're looking for inspiration or to connect with experienced mass timber project teams, visit the WoodWorks Innovation Network (WIN) at www.woodworksinnovationnetwork.org. WIN is an online community of developers and design/building professionals who have worked on mass timber projects that are under construction or complete. It includes a dynamic map of buildings across the country as well as project, company and individual team member profiles.

In publishing this manual, WoodWorks would like to recognize, not only the contributors included in the Acknowledgments, but the vast groundswell of effort that has allowed mass timber to advance in the market so quickly. In a relatively short timeframe, there has been an abundance of research and testing, code committees, education and technical resources. Organizations like the USDA Forest Service and Softwood Lumber Board invested in initiatives such as the U.S. Tall Wood Building Prize Competition. APA – The Engineered Wood Association developed ANSI/APA PRG-320 Standard for Performance-Rated Cross-Laminated Timber, which provides a basis for standardization of CLT quality, manufacturing and structural properties. The American Wood Council (AWC) participated in code development processes that led to CLT's recognition in the 2015 IBC and tall wood provisions in the 2021 IBC. Projects were built, companies invested in manufacturing and North American mass timber products are now readily available across the U.S.

This manual is a living document that will evolve over time as more mass timber projects are completed, best practices honed and new approaches developed. Comments about the content are welcome and should be directed to info@woodworks.org.

If you're working on a mass timber project and would like assistance, WoodWorks technical staff is comprised of architects, engineers and construction experts. Visit woodworks.org to find the expert in your region, or email help@woodworks.org. WoodWorks offers project assistance at no cost to design and construction professionals working on commercial and multi-family wood buildings.

Please note that images and examples in this document are not intended as recommendations for specific products. For suppliers of mass timber and related products such as connections and finishes, visit the WoodWorks Supplier and Manufacturer Directory at https://directory.woodworks.org/.

2 Mass Timber at a Glance

2.1 Mass Timber and Building Codes

The International Building Code (IBC) is a model building code developed by the International Code Council (ICC). Adopted as a base code by most jurisdictions in the U.S., it addresses health and safety concerns for buildings based on prescriptive and performance requirements.

Chapter 35 of the IBC provides a list of referenced standards, which represent consensus on how a material, product or assembly is to be designed, manufactured, tested or installed to achieve a specified level of performance. Key standards relating to design of mass timber structures include the following:

- National Design Specification® (NDS®) for Wood Construction – AWC[4]
- Special Design Provisions for Wind and Seismic (SDPWS) – AWC[5]
- ANSI/APA PRG 320: Standard for Performance-Rated Cross-Laminated Timber (PRG 320) – APA[6]

Section 2.2 includes basic information on code compliance as it relates to specific mass timber products.

Unless otherwise noted, this manual refers to the 2015 IBC, which is currently the most widely used version. Adoption of the IBC varies considerably across the country. It can be adopted on a statewide basis, by local jurisdictions within a state, by government agencies and/or with modifications, and many versions are in use. The code is updated on a three-year cycle and, at the time of publication, the latest version available for adoption is the 2021 IBC. For more information, AWC maintains a dynamic map showing the status of IBC adoption (Figure 2-1).

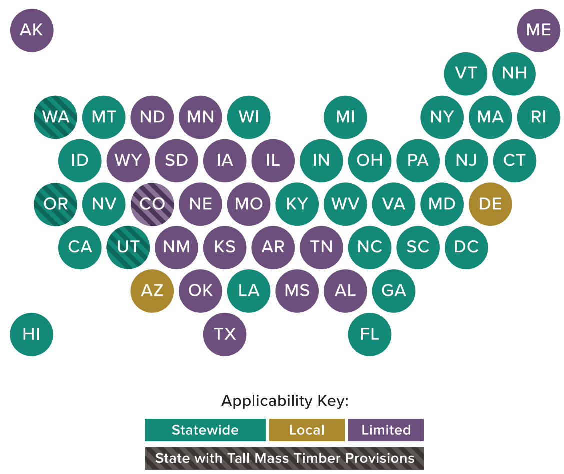


FIGURE 2-1: Interactive ICC code adoption map at awc.org
Image: AWC

New provisions in the 2021 IBC reflect the performance capabilities and increased use of mass timber in the U.S. This version of the code includes three new construction types specific to these materials—Type IV-A, IV-B, IV-C—and allows mass timber buildings up to 18 stories. Construction type is the main indicator of where and when structural systems can be used, and different construction types allow wood in different applications. While some people assume mass timber is only permitted in Type IV construction, this is not the case. Types III and V permit the use of wood framing throughout much of the structure and both are used extensively for modern mass timber buildings. Mass timber can be used in any construction type that allows wood structural systems.

2.2 Mass Timber and Hybrid Buildings

In this manual, the term mass timber refers to a category of framing styles typically characterized by the use of large, engineered wood panels. These panels are most frequently used in horizontal applications for floors and roofs, but can also be used vertically for bearing walls and shaft walls. They are often paired with engineered wood beams and columns (also considered mass timber for the purpose of this manual) to create an all-timber structural framework.

It is common to use mass timber in combination with other building systems to achieve benefits greater than those offered by each system alone. Examples include light wood-frame walls with mass timber floors and roof, steel elements in long-span floor systems, and concrete foundations, podiums, cores or floor toppings. Areas where different materials and systems intersect require particular attention with regard to tolerances and connections. This is described more fully in Chapter 5.

When describing a framing style, the term *heavy timber* is typically associated with large cross sections of solid sawn members (beams, purlins and columns), often using tongue-and-groove decking for floors and roofs. That style of construction is not the focus of this manual.

2.3 Mass Timber Products and Systems

2.3.1 Cross-Laminated Timber (CLT)

CLT consists of layers of solid sawn lumber—typically three, five or seven plies—or structural composite lumber (SCL), oriented at right angles to one another and glued to form structural panels. Lamination thickness varies depending on the manufacturer, species of lumber, structural and architectural requirements of the project, etc. Panel sizes also vary by manufacturer and shipping constraints, but finished panels are typically between 4 and 12 ft wide and 20 and 60 ft long. CLT offers exceptional strength, stability and stiffness, along with two-way spanning capability, and can be used for floor and roof applications, bearing walls, shear walls and shaft walls.

Although popular in Europe for 20+ years, CLT is relatively new to the U.S. It was first included in the 2015 IBC, which recognizes CLT products manufactured according to the PRG 320 standard. In this version of the code, CLT at the required size is specifically stated for prescribed use in Type IV buildings. However, as noted, CLT can be used in any construction type that allows wood structural systems.

FIGURE 2-2: CLT walls and ceiling in the five-story Catalyst in Spokane, WA
Image: MGA | Michael Green Architecture, © Ben Benschneider

FIGURE 2-3: Lumber CLT (left); SCL CLT (right)
Images: FPInnovations (left); Freres Lumber (right)

The 2012 IBC does not explicitly recognize CLT, but the 2015 IBC can be a basis for its use under alternative method provisions. The 2021 IBC allows CLT in buildings up to 18 stories in Type IV-A construction.

CLT panels are commonly made from solid sawn softwood lumber, including spruce-pine-fir (SPF), Douglas fir and southern yellow pine. These types of panels can be sourced from numerous manufacturers in the U.S., Canada and Europe. It can also be made with laminated veneer lumber (LVL), laminated strand lumber (LSL) and other SCL products. This type of CLT may be oriented so the laminations, typically visible on the panel sides, are visible on the panel face.

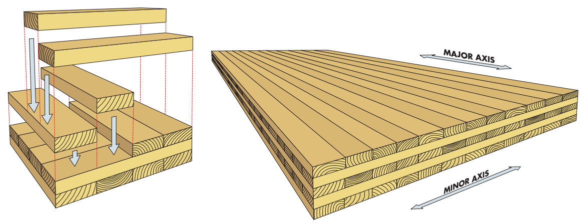


FIGURE 2-4: CLT panel assembly
Images: WoodWorks

2.3.2 Nail-Laminated Timber (NLT)

NLT has been used for more than a century but is undergoing a resurgence as part of the modern mass timber movement. It is created from solid sawn dimensional lumber members (2-by-4, 2-by-6, etc.), oriented on edge and fastened with nails or screws to create larger structural panels. NLT is typically fabricated off site in panels that range from 4 to 8 ft wide and 16 to 40 ft long; however, it can also be assembled on the jobsite. It is commonly used for floors and roofs, and less often for walls, elevator shafts and stair shafts. NLT is recognized prescriptively as mechanically-laminated decking in Chapter 23 of the IBC. Detailed design information can be found in the *Nail-Laminated Timber – U.S. Design & Construction Guide v1.0.*[7]

FIGURE 2-5: NLT decking in the seven-story T3 Minneapolis
Image: MGA | Michael Green Architecture, Ema Peter

FIGURE 2-6: NLT panel
Image: Think Wood

FIGURE 2-7: DLT decking in The Soto, a six-story office building by Hixon Properties
Image: BOKA Powell, photo StructureCraft

2.3.3 Dowel-Laminated Timber (DLT)

Common in Europe, DLT is gaining traction in the U.S. for its ease of use with computer-numerical controlled (CNC) machinery—such as lathes, routers and mills—and its all-wood composition. DLT panels are made from solid sawn lumber (2-by-4, 2-by-6, etc.) oriented on edge like the boards of NLT but friction-fit with hardwood dowels. The dowels hold the boards side-by-side, while the friction fit adds dimensional stability. Each board is planed, allowing a wide variety of visual profiles to be integrated inexpensively into the bottom surface of the panel. An integrated acoustic profile can be produced to achieve noise reduction objectives, while keeping the wood exposed. DLT laminations are typically finger-jointed, and the all-wood construction makes it easy to cut with hand tools to create openings or make other field modifications. DLT panels are commonly used for floors and roofs with accompanying third-party evaluation reports that address code compliance. Detailed design information can be found in the *Dowel-Laminated Timber Design & Profile Guide.*[8]

FIGURE 2-8: DLT panel
Image: StructureCraft

2.3.4 Structural Composite Lumber (SCL)

SCL is a family of engineered wood products created by layering dried and graded wood veneers or strands with moisture-resistant adhesive into blocks of material known as billets, which are subsequently re-sawn to specified sizes. In SCL billets, the grain of each layer of veneer or strands runs primarily in the same direction. SCL is sawn to consistent sizes and exhibits highly predictable physical and mechanical properties. The following SCL products are used in column and beam applications in mass timber buildings.

Laminated veneer lumber (LVL) is produced by bonding thin wood veneers with the wood fibers primarily oriented along the strong axis.

FIGURE 2-9: LVL beams
Image: APA

Laminated strand lumber (LSL) is made from flaked wood strands that have a length-to-thickness ratio of approximately 150.

FIGURE 2-10: LSL beams
Image: APA

Parallel strand lumber (PSL) is manufactured from veneers clipped into long strands and oriented primarily along the strong axis. The length-to-thickness ratio of the strands in PSL is approximately 300.

FIGURE 2-11: PSL beams
Image: Weyerhaeuser

2.3.5 Glue-Laminated Timber (Glulam or GLT)

Glue-laminated timber is typically referred to as glulam when used for columns and beams, and GLT when used in plank applications (e.g., decking). The material is created by combining solid sawn lumber members (typically 2-by), layered parallel on their wide faces, with adhesive between layers. Jigs are used to form curves, bends and a variety of radii. In mass timber projects, glulam beams and columns are more common than GLT planks. When utilizing GLT, consideration must be given to the design stresses and layups, lumber species and grade.

Glulam and GLT have the same code references and manufacturing standards. They are permitted under 2015 IBC Section 2303.1.3 when manufactured and identified as required in the ANSI 190.1[9] and ASTM D3737[10] standards. For more information, APA offers a variety of glulam-specific materials in its resource library.[11]

FIGURE 2-12: Glulam post-and-beam framing supports DLT at 111 East Grand in Des Moines, IA
Image: Neumann Monson Architects, photo Mike Sinclair

FIGURE 2-13: Glulam beams and GLT plank
Images: Boise Cascade, StructureCraft

2.3.6 Timber-Concrete Composite (TCC) Floor Systems

TCC floor systems can be used for longer spans and carry greater loads than non-composite alternatives, and are sometimes used in multi-story mass timber buildings. They consist of two distinct layers, a timber layer and a concrete layer, joined by shear connectors. The concrete layer is usually a reinforced concrete slab. The timber layer can be CLT, GLT, SCL, another engineered wood product or solid sawn lumber. The shear connectors can be common fasteners (e.g., nails or screws), notches cut in the wood, connectors such as embedded plates or glue that transfer the load to a larger surface, or a combination.

TCC floor systems may also include other materials. For example, the floor system at the John W. Olver Design Building at UMass Amherst includes 5-ply CLT panels, 1 in. of rigid insulation on top of the CLT (for acoustic performance), and 4 in. of reinforced concrete (Figure 2-14).

It is also possible for mass timber projects to utilize a *non-composite* timber-concrete floor system, where the mass timber elements carry the loads and a non-structural lightweight topping is applied to meet fire, acoustic and/or vibration objectives. To learn about TCC installation, see Section 5.8.5. For design information, the *Design Guide for Timber-Concrete Composite Floors in Canada, First Edition*[12] is a useful resource.

FIGURE 2-14: CLT-concrete composite floor system at the John W. Olver Design Building at UMass Amherst
Image: Alexander Schreyer

2.4 Support and Resources

WoodWorks – Wood Products Council

Mass timber buildings are unlike other building types and support is necessary to help developers and design/construction teams gain the expertise needed to achieve successful projects. WoodWorks provides free project support related to commercial and multi-family wood buildings, and is a leading provider of mass timber education and resources.

WoodWorks is a non-profit organization staffed with architects, structural engineers and construction experts who have the knowledge to assist with all aspects of wood building design and construction. To request support, contact the WoodWorks expert in your region (woodworks.org/project-assistance) or email help@woodworks.org. – www.woodworks.org

American Wood Council (AWC)

On behalf of the industry it represents, AWC is committed to ensuring a resilient, safe and sustainable built environment. To achieve these objectives, the organization contributes to the development of sound public policies, codes and regulations that allow for the appropriate and responsible manufacture and use of wood products. AWC also supports the utilization of wood products by developing and disseminating consensus standards, comprehensive technical guidelines and tools for wood design and construction, and providing education regarding their application. – www.awc.org

APA – The Engineered Wood Association (APA)

An accredited national standards developer, APA has developed performance standards for numerous structural engineered wood products, including structural glulam and CLT. APA combines the work of scientists and engineers at its research center, knowledge gained from decades of field work, and insight from its member manufacturers to support new engineered wood solutions and processes. APA Product Reports and other publications are widely used in the design and construction of wood buildings. – www.apawood.org

Think Wood

Think Wood provides commercial, multi-family and single-family home design and build resources to architects, developers and contractors. From accredited continuing education to the latest project profiles and AEC expert Q&As, Think Wood showcases innovative approaches to wood design and construction. – www.thinkwood.com

Canadian Wood Council – Conseil canadien du bois (CWC)

CWC represents the Canadian wood products industry through a national federation of associations. They provide technical and knowledge transfer services relating to building codes, standards and regulations. – www.cwc.ca

Other Material Associations

Mass timber buildings almost always involve concrete and/or steel in some form. Associations representing these materials offer valuable resources related to their use, limitations and requirements.

Mass Timber Publications/Resources

Since the U.S. CLT Handbook[13] was introduced in 2013, wood industry organizations, manufacturers, the research community and others have contributed to resources aimed at filling information gaps related to the design and construction of mass timber buildings. As noted, this manual is itself intended to expand the information available to contractors and installers. Those seeking information on mass timber building design, sustainability, insurance and other topics, may find the following resources useful.

The *Mass Timber Design Manual*, developed by WoodWorks and Think Wood, is a one-stop shop for a wide range of materials, and will be updated regularly as new work is produced. The manual includes WoodWorks technical papers, Think Wood continuing education articles, project case studies, expert Q&As, technical guides and other helpful tools. Topics include:

- Insurance for mass timber construction
- Cost and design optimization
- Mass timber fire design
- Acoustic and vibration design
- Tall wood buildings in the 2021 IBC
- Calculating carbon footprint
- Impact of wood use on North American forests
- Occupant well-being and biophilic design

Users can view each individual resource or download the master folder for all files. Download the manual at info.thinkwood.com/masstimberdesignmanual.

WoodWorks resources in the *Mass Timber Design Manual* are also available at woodworks.org, along with other resources and education opportunities.

3 Mass Timber Preconstruction

KEY POINTS

- A best practice is for the mass timber supplier(s), general contractor/construction manager (GC/CM) and key subcontractors to engage throughout the design process and even during the conceptual phase. This ensures that constructability and prefabrication coordination are considered as part of the design process.
- It is more cost effective to resolve issues before construction than discover them in the field.
- It is critical to allocate adequate time for shop drawing creation, review and approval.
- BIM processes require significant coordination and communication between the GC/CM, mass timber fabricator, installer and specialty contractors. This is a critical step and must be adequately anticipated and resourced.
- Shifting the preplanning, coordination and decision making to an earlier stage in the project does not necessarily increase the fees associated with design and preconstruction; it just shifts the timing of the fees within the overall project schedule.
- Mass timber is a collaborative service and not a commodity.
- Avoid using “soft metric” measurements to prevent issues in the field.

3.1. Preconstruction Considerations

Mass timber is exciting to a large number of developers and design/construction teams. However, as with any new technology, it takes time and education for everyone involved to become familiar with the new materials and comfortable with changes to the “typical” approach. The advanced use of modern planning and design technology tools is itself a potential risk mitigation strategy. With all that goes into producing prefabricated components such as CLT, it is important to get things right the first time. There is also little opportunity for value engineering or late modifications on site, so builders and their subcontractors are required to be more intensely involved in the planning phase. This requires more sophistication than the traditional workflow.

Early engagement of key parties—including the general contractor/construction manager (GC/CM), mass timber manufacturer, structural steel/concrete core manufacturer, installers/erectors (whether contracted by the GC or manufacturers), and mechanical/electrical/plumbing (MEP) and fire protection (FP) subcontractors—is critical. If these individuals are not up to the task, the burden of making the project buildable falls on engineers and architects, and this is not optimal. A better result will be realized when those who will build the structure are involved in the earliest possible details. This is why preconstruction is such a critical part of mass timber installation.

3.1.1. Understanding What's Unique or Critical to Mass Timber Projects

Before starting a mass timber project, it is helpful to be aware of activities that are unique or especially critical to achieving success with these types of buildings. The following checklist is not intended to be exhaustive and items may not apply to every project. Where relevant, detailed information is included elsewhere in this manual.

3.1.1.1. Coordination and Timing

- Early and continued interface with the project management team
- Coordination of mass timber with other building materials
  - Lateral and/or gravity systems
  - Other light wood-frame or metal assemblies if being used—e.g., non-load-bearing walls, furring, chases, soffits
- Interface between mass timber and other subcontractors—e.g., MEP and FP
- Responsibility matrix—bearing in mind the responsibility for certain activities may be different on a mass timber project
  - Contract alternates, revised drawings, contract amendments
  - Protection for mass timber material (upon delivery and after installation)
  - Fire protection requirements (See Section 3.1.1.5)
  - Crane operation—e.g., GC/CM, which is typical for high-rise buildings, or mass timber installer
  - Construction tolerances and adjustments
  - Building survey control
  - Delays due to weather and uncontrollable events, including costs (force majeure)
- Schedule summary and key milestones for mass timber design, manufacturing and construction
- Lock structural coordination models (concrete, steel and timber)
- Construction sequencing

3.1.1.2. Insurance Requirements

Insurance can be an issue for mass timber projects, but support and resources are available. Some insurers equate mass timber with light wood-frame construction and offer similar premiums, where others more familiar with mass timber offer lower premiums that reflect the enhanced performance capabilities of large panels, columns and beams. Some underwriters are also more familiar with the differences than others. As mass timber becomes more widely used, insurance premiums will adjust to account for larger risk pools and successful projects. For more information see: www.woodworks.org/mass-timber-building-insurance/.

Types of necessary insurance include:

- General and automobile liability
- Workers' Compensation, including the Experience Modification Rate (EMR)
- Additionally insured
- Builder's risk

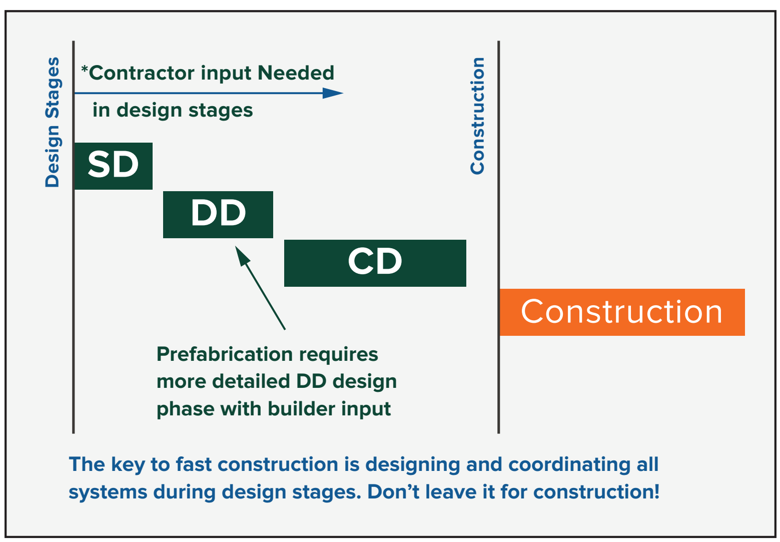


FIGURE 3-1: Builder input and engagement is essential during the design development phase.
Source: WoodWorks

3.1.1.3. Fabricator and Installer Experience

Because mass timber is relatively new to the U.S., there are additional considerations in terms of creating a team that can successfully implement a project, including:

- Qualifications and experience
- Crew availability (union/non-union)/wages
- Training needs/availability

3.1.1.4. Inspections

Regular inspections are required during construction to verify quality, code compliance and safety. Generally, the types and frequency of inspections will be determined by the Authority Having Jurisdiction (AHJ), the design team and owner, and expressed in the construction documents. If the AHJ is unfamiliar with mass timber, it can be useful for the design team to provide education and answer questions before the project breaks ground to help building officials gain confidence in the materials and their performance.

Chapter 17 of the IBC includes inspection requirements for a number of building elements and is often the basis of a Statement of Special Inspections, with additional requirements to match those of the AHJ and other local amendments. With the exception of Type IV-A, IV-B and IV-C construction under the 2021 IBC, Chapter 17 does not include many special inspection provisions specific to mass timber buildings. However, it is common for design teams to add their own general requirements.

For example, designers may specify inspections of connections. Potential inspection items include bearing area, fastener type and spacing, steel sizes, and grout and/or embed placement. The inspection strategy will depend on whether the connection and fastener are visible once installed or require in-progress inspection, and whether the connection must be inspected more than once to verify appropriate installation.

The 2021 IBC requires special inspections for projects classified as Type IV-A, IV-B and IV-C construction (i.e., tall wood buildings up to 18, 12 and nine stories respectively). IBC Table 1705.5.3 requires special inspections as shown in Table 3-1, and IBC Section 110.3.5 requires connection fire protection inspection under certain circumstances. Further detail regarding special inspections in the 2021 IBC can be found in the American Wood Council/International Code Council publication, *Mass Timber Buildings and the IBC*.[14]

TABLE 3-1: Required special inspections for Types IV-A, IV-B and IV-C construction under the 2021 IBC

Table 1705.5.3
Required Special Instructions of Mass Timber Construction

Type			Continuous Special Inspection	Periodic Special Inspection
1.	Inspection of anchorage and connections of mass timber construction to timber deep foundation systems		—	X
2.	Inspect erection of mass timber construction		—	X
3.	Inspection of connections where installation methods are required to meet design loads			
	Threaded fasteners	Verify use of proper installation equipment	—	X
		Verify use of pre-drilled holes where required	—	X
		Inspect screws, including diameter, length, head type, spacing, installation angle and depth	—	X
	Adhesive anchors installed in horizontal or upwardly inclined orientation to resist sustained tension loads		X	—
	Adhesive anchors not defined in preceding cell		—	X
	Bolted connections		—	X
	Concealed connections		—	X

Source: International Code Council

Note that the registered design professional for the project is responsible for submitting the Statement of Special Inspections, which can be used to keep the GC/CM and installer informed of required inspections.

After each inspection, a report is issued to the GC/CM, owner and appropriate members of the design team and distributed to the specialty contractor(s). Third-party inspection costs are generally borne by the building owner and re-inspection costs charged to the specialty contractor.

3.1.1.5. Fire Protection Requirements

Contractors and subcontractors new to mass timber should be aware that these projects have unique fire protection requirements that must be implemented by the installation team and coordinate as needed. Requirements differ by construction type and are more stringent for taller and larger wood buildings. Examples include:

- Fire sealant caulking at abutting edges and intersections of fire resistance-rated mass timber elements
- Noncombustible protection—e.g., Type X gypsum—in concealed spaces and to comply with the maximum amount of exposed mass timber allowed for the construction type
- Protection of exposed and concealed mass timber connections
- Protection of MEP/FP penetrations through the rated timber structure
- Fire stopping
    - At exterior façade connections to floor and roof decks
    - At continuous shaft wall connections to floor and roof decks
- Automatic sprinkler systems, including redundant water connections for buildings over 120 ft tall

Because of the potential for increased fire risk during construction, the 2021 IBC also requires active and passive fire safety features specific to that phase, including standpipes and water supply. Unless otherwise approved by the Fire Code Official, minimum noncombustible protection and exterior wall coverings must also be installed on stories more than four floor levels below the active mass timber construction when the building's construction exceeds six stories. For more information, see Section 5.3.4.

3.2. Methodology, Technologies and Documents

3.2.1. Contract Methodology

The type of contract procurement between the GC/CM and mass timber provider (fabricator, installer or combined turnkey entity) will determine how the project proceeds and has a direct impact on schedule. If the project is a design-build ("Master Builder")/design-assist contract, other members of the team are likely to be involved in the early stages of the project, providing assistance that eliminates waste and reduces the overall schedule. A traditional "design-bid-build" linear style contract may limit the opportunity for savings and efficiency because the contractor has a limited or non-existent role in the design stage; the benefit of learned efficiencies and contractor experience is not weighed early in the project where it is most useful.

Several procurement options are available to the GC/CM, each with different scope requirements and a different level of risk to the mass timber subcontractor (Table 3-2).

TABLE 3-2: Example procurement risk strategies spectrum

GC/CM Hires Turnkey Mass Timber Subcontractor	GC/CM Buys Material, Self-Performs Installation and Coordinates	GC/CM Buys Material, Subcontracts Labor and Coordinates
RISK SPECTRUM		
+ Hiring experience + Single point of responsibility	+ Hiring experience + Single point of responsibility + Financial security of strong GC/CM	+ Potential added mark-up
– Prequalify capacity of subs – Potential added mark-up	– Lack of familiarity with supply chain – Steep learning curve for coordination	– Multiple layers of coordination – Prequalify capacity of sub

Source: Timberlab

3.2.2. Construction Software and Technology

All projects utilize software to create construction documents and manage project delivery, and the examples below do not comprise an exhaustive list. GC/CMs, architects, engineers, mass timber fabricators and installers may or may not elect to employ all of the available technologies.

3.2.2.1. Building Information Modeling (BIM) Software

BIM is a modeling system that condenses and coordinates all project details in one location. Architects, engineers, contractors and subcontractors can interface within the model and share information. Mass timber fabricators use BIM to extract data and communicate with the CNC manufacturing equipment to create customized panels.

The BIM digital database can render intelligent data, including product data and other specification information, 2D drawings, 3D images, image animation, elements of time/scheduling (4D) and cost elements (5D). The model allows everyone on the project team to review connections, “clashes” and un-erectable conditions. This stage requires significant coordination and communication between the GC/CM, mass timber fabricator, installers and specialty contractors. This is a critical step and should be adequately anticipated and resourced.

Within the BIM model, projects differ in terms of their required Level of Development (LOD) and Level of Detail, based on needs/objectives, budget and resource capabilities among collaborating parties. When working on a BIM model, it is important to have a BIM Execution Plan or BIM Protocol Manual as a framework to successfully define the goals, desired LOD and ownership and control of the model. LODs are references that clearly describe the content and reliability of BIM at different stages of design and construction. They are:

- **LOD 100 – Concept or Pre-Design** – Elements are not geometric representations. Information must be considered approximate.
- **LOD 200 – Schematic Design** – Elements are generic placeholders. They may be recognizable as the components they represent, or they may be volumes for space reservation. Information must be considered approximate.
- **LOD 300 – Design Development** – The quantity, size, shape, location and orientation of the element as designed can be measured directly from the model without referring to non-modeled information.
- **LOD 350 – Construction Documentation** – Parts necessary for coordination of the element with nearby or attached elements are modeled. These parts will include such items as supports and connections. The quantity, size, shape,

location and orientation of the element as designed can be measured directly from the model without referring to non-modeled information.

- **LOD 400 – Construction Stage** – Element is modeled at sufficient detail and accuracy for fabrication of the represented component. The quantity, size, shape, location and orientation of the element as designed can be measured directly from the model without referring to non-modeled information.
- **LOD 500 – As-Built** – Post-construction.

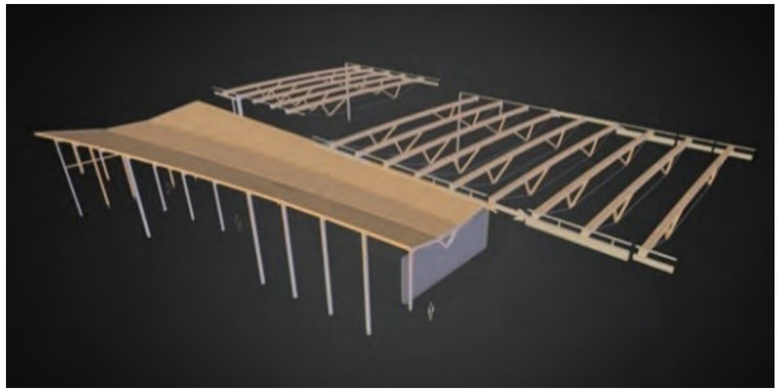


FIGURE 3-2: LOD 100 Model with CLT Panels
Image: StructureCraft

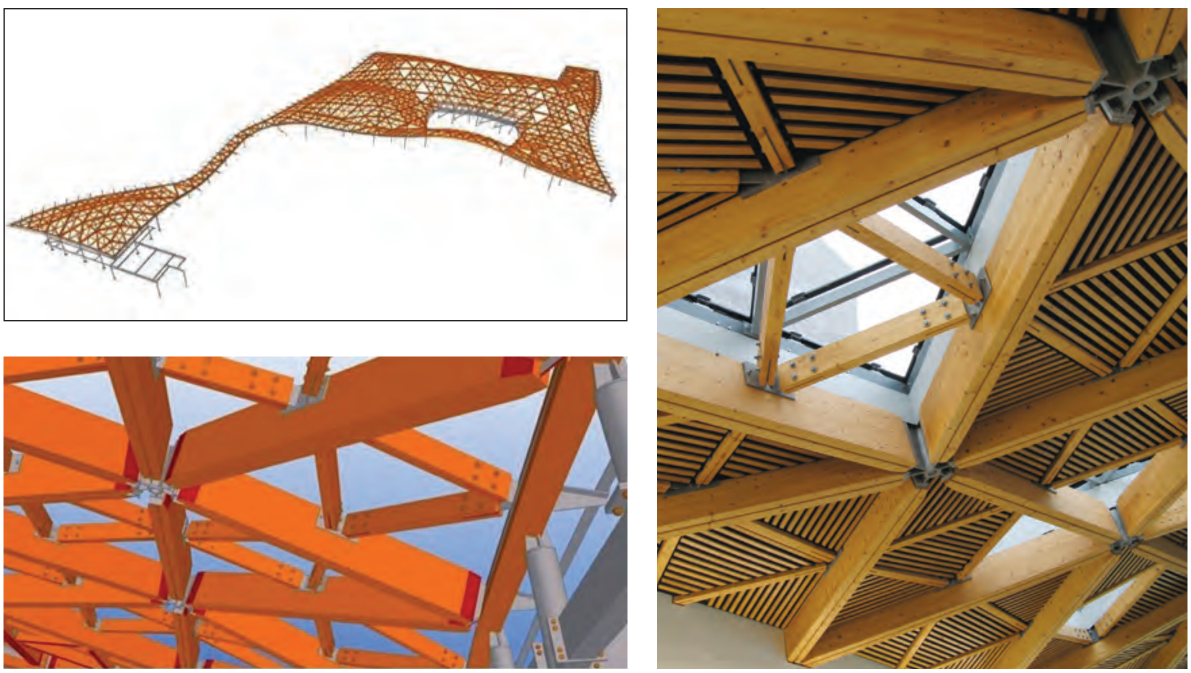


FIGURE 3-3: Exeter University forum roof
Images: SH Structures

Depending on the manufacturer, a BIM model from the design team may not be needed. Some fabricators will create a model using the 2D architectural and structural drawings to lock down the building's geometry and spacing of elements before producing the fabrication shop drawings.

3.2.2.2. Construction Management Software

There are many construction management software systems—typically cloud-based—for contract drawings, shop drawings, requests for information, scheduling information, field production reports and more. These platforms allow collaboration between all project stakeholders, and the resulting electronic documents are easily viewed on multiple device types, in any location with appropriate data coverage. The great advantage of electronic documentation is the ease of updating, tracking revisions and as-builts, and collaborating. The caution is that the market for these systems is constantly changing so verifying interoperability needs to be on someone's checklist.

3.2.3. Drawings and Specifications

3.2.3.1. Drawing Review and Approvals

It is important to make sure all stakeholders (architects, engineers, GC/CM, fabricator, installer and MEP/FP trades where applicable) are aligned regarding the timeframe and expectations to create and review drawings. This includes agreement on the chosen deliverable (e.g., BIM model, CAD drawings, 2D drawings) and a process suitable for all parties. In many cases, a project delay occurs when the fabricator is waiting on information from others. Depending on the structural elements, coordination is also required with the concrete and steel partners to minimize potential timing conflicts on site.

3.2.3.2. Architectural Drawings

Architectural drawings provide the overall concepts and requirements to construct the building. The drawings include general notes, site plans, plan and elevation drawings, sections and detail drawings.

3.2.3.3. Structural Drawings

Structural drawings provide specific information on how the structure is "to be." Using information from the architectural drawings, the engineer creates drawings that describe the materials and sizes that will be used to fabricate and install the framing system. The structural drawings include connection information and their locations so the detailers, fabricators and installers can perform their work.

Mass timber projects frequently utilize more than one structural engineer. The Engineer of Record (EOR) provides structural design drawings for the building foundations and frame elements but may not include design drawings for the mass timber framing and connections depending on their experience with these buildings. If the EOR is not familiar with mass timber, a timber specialty engineer can design the timber components and possibly connections. Due to the proprietary nature of mass timber and connection systems, the mass timber connections may also be designed by another engineer associated with the mass timber supplier. The GC/CM and design team must ensure that load paths and capacities are adequate and match across the various sets of drawings.

3.2.3.4. Design Drawings

Design drawing completion status can range from conceptual to 50% design for budgetary pricing to 100% design for final pricing. To maximize project savings, early collaboration is encouraged between the mass timber supplier, GC/CM and, if available, the mass timber installer. If design drawings are complete when the mass timber supplier is awarded the contract, opportunities for material efficiencies and other beneficial adjustments will be more limited, but the supplier can still offer valuable suggestions to the design team and GC/CM.

For the supplier to proceed, the design drawings should include:

- Floor plans and elevations
- Intended design loads and connection information
- Preliminary member sizing/thicknesses and basis of design, including species/grade and/or structural properties
- Structural drawings, including connections to other materials and their respective tolerances
- Locations and sizes of rough openings in the mass timber structure for doors, windows, stairs, elevators and MEP/FP penetrations

Using the architectural and structural drawings, the engineers produce detailed drawings for the HVAC, building power and distribution, and drainage and waste systems. It is critical that these systems and their penetrations through the timber be considered during design of the mass timber superstructure. Coordinating these elements during the BIM process will help the engineers complete the structural analysis and assess vibration design and transfer of external loads. The ability to custom route, detail and manufacture MEP openings and allowances in mass timber is a great advantage, but it does require advanced planning and strict adherence to BIM planning and usage to minimize field cutting and delays for engineering review of unplanned penetrations.

3.2.3.5. Shop Drawings

Once the building model is complete, the timber fabricator selects a detailer to create the shop drawings. This set of drawings provides all the information required to fabricate and install the mass timber system.

Key elements include:

- CNC data for the fabricator, including timber-to-timber, concrete-to-timber and steel-to-timber connections
  - The fabricator may not be responsible for fabricating steel connections, but the connections must be included in the shop drawings to provide CNC information to the timber manufacturer.
- Material to be used, grade(s) of material, dimensions and finishes
- Location of openings, cuts, holes and connections
- Weight and center of gravity for all members
- Connection hardware (if possible)
- Sequencing information, though in some cases this is added later
- Rigging connections requested by the mass timber installer
  - These are selected and coordinated between the fabricator, detailer and/or installer. Contractors are encouraged to review these connections with the EOR to confirm means and methods compatibility with structural performance.
- Installation drawings showing all member piece marks, locations, elevations and connection details; includes any drawing sections required to further clarify details
  - For NLT/DLT/GLT systems, drawings should include gaps required during construction to accommodate shrinkage and swelling until the building is closed in.

Fabrication and installation shop drawings are submitted to the GC/CM, architect and EOR for approval. All parties approve the drawings and return them to mass timber fabricator, at which point the detailer makes any required revisions and issues them for fabrication and installation.

3.2.3.6. Specialty Contractor Drawings

Approved shop drawings from specialty contractors are required as early as possible for timely fabrication and installation of the mass timber structure, including elevator and MEP/FP information. This is especially true if the mass timber is being connected to steel columns or beams. Coordination of design loads and connections must be communicated between all parties before fabrication begins.

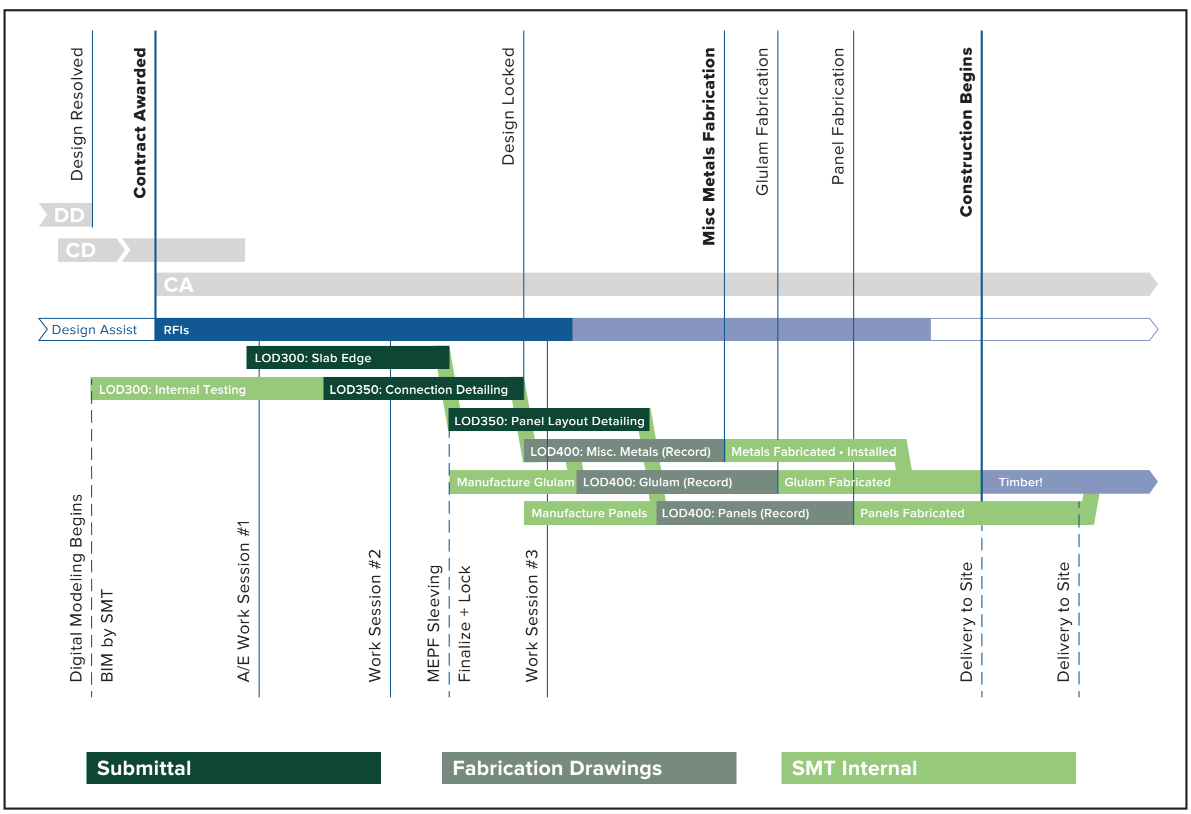


FIGURE 3-4: Shop drawing example
Source: Timberlab

3.2.4. Managing Construction Tolerances

Tolerances provide an allowable deviation from a specified value. They should be considered in the design phases, based on normal needs and common construction practices, and managed during construction. Restrictive tolerances can be difficult to achieve, costly and time consuming. Governed by building codes and controlled through inspection, tolerances provide performance expectations for the owner, architect, engineers, GC/CM and subcontractors. The architect, engineer, GC/CM, mass timber manufacturer and installer must understand the interrelationship between the different trades and requirements established by the drawings.

BIM is an excellent resource to review and coordinate connections and construction adjustability. Specific attention should be given to connections between dissimilar materials, including but not limited to timber-to-steel, timber-to-concrete, anchor rods, saddle plates and beam knife plates.

Tolerance limits for the fabrication and installation of materials can be found in trade association standards, which are typically recognized by the American National Standards Institute and referenced in the IBC as well as state and local building codes.

See Appendix 1 for a table of tolerances for mass timber materials.

FIGURE 3-5: Column base connection with vertical adjustability. The column has a recessed base and hides the connection from view.
Image: KL&A Engineers & Builders

3.3. Planning, Scheduling and Material Delivery

Mass timber offers significant advantages in terms of project speed and potential for labor savings. This advantage is secured early in the process during coordination with suppliers and installers. However, this type of construction also has several unique aspects that should be taken into account during planning.

First, code officials may not be aware of the suitability or applicability of mass timber under the IBC, and the local jurisdiction may still be operating under a version of the code that doesn't reference mass timber materials—particularly CLT. (The product descriptions in Chapter 2 include information on how specific mass timber materials are recognized in building codes.) Ensure permit discussions occur early enough in the process to allow an alternate means approval processes if required. As mass timber is more widely used and accepted, experience among building officials will increase; however, until that happens, be prepared to answer questions. For resources and support, see Section 2.4.

Second, the project schedule will very likely have more front-loaded requirements; constructability reviews, tolerances and MEP/FP coordination will be detailed several months earlier on a mass timber project than with other structural materials.

Constructability reviews will reduce delays during installation and ensure the building envisioned and designed can be built as described. For example, details for specific connectors and fasteners for joints and connections should be reviewed early. Some are better factory-installed by the mass timber supplier, while others can be field-installed with minimal delay. As noted, mass timber buildings typically include a combination of wood and other material systems to achieve benefits greater than those offered by each system alone. However, successfully realizing a hybrid of mass timber and other materials requires an acute understanding of their differences, from fabrication tolerances to installation techniques and connection details.

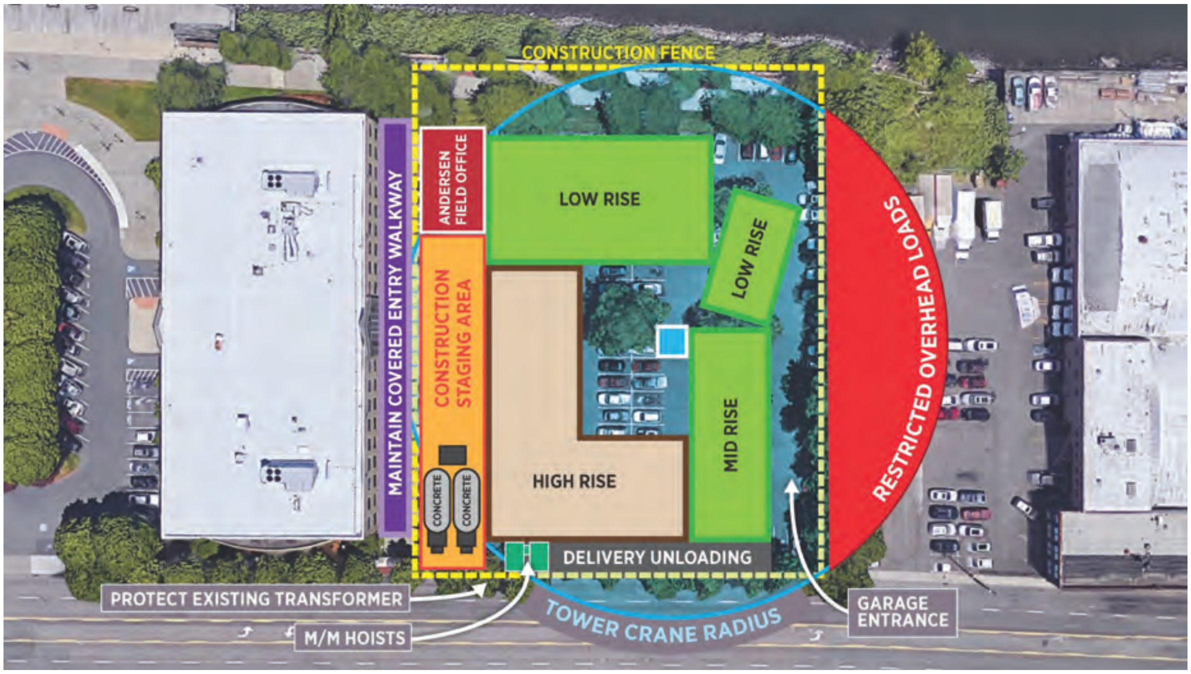


FIGURE 3-6: Site logistics plan for mass timber project site
Source: Andersen Construction

Tolerances between various structural materials should be reviewed and discussed with the mass timber supplier. Additional attention should be paid if using different suppliers; mass timber isn't a commodity product—one manufacturer's 5-ply CLT panel may not be the same thickness or species as another's.

Planning is one of the biggest hurdles to the successful execution of mass timber projects. A successful project requires a highly collaborative approach that involves the mass timber supplier/installer as an early partner. The traditional design-bid-build approach is frequently antithetical to this kind of partnership. A design-build approach maximizes the benefits of early coordination and planning during the design phase, to optimize cost and schedule savings during construction. While the design-build approach works best for mass timber, that should not preclude the traditional design-bid-build approach if contractually required. If a project must proceed in this way, team members are strongly encouraged to collaborate as much as possible within contractual guidelines.

3.3.1. Site Planning Considerations

Mass timber logistics should also be discussed as early as possible when determining jobsite logistics plans. On-site delivery, road access, site conditions, overhead clearance and equipment are all typical site planning considerations. Mass timber presents a few additional areas for the general contractor to address; access is key to efficient mass timber installation.

Depending on the supplier, mass timber components may be delivered on typical flatbed trailers, in shipping containers or some combination of the two. In both cases, every attempt should be made to maximize efficient loading to reduce the number of times a piece is handled while maximizing load content to reduce the number of loads required.

While the contractor will seek to maximize efficiency by requesting that materials be loaded in reverse order (top panels install first while bottom panels install last) to accelerate field installation and minimize crane time, the supplier will seek to maximize shipping efficiency by filling the trailer or container to the maximum extent possible. If shipping cost is a risk (e.g., when using overseas seaborne cargo), maximum trailer/container efficiency saves trips and therefore costs, but the trailers and containers are loaded for maximum freight utilization and not installation efficiency. This will require shake-out of materials in the field and additional labor and/or heavy lifting equipment may be needed to maintain production on site.

3.3.2. Project Schedule

An effective construction schedule includes the sequence of activities, associated durations and resources needed to complete the tasks. Overall project schedule requirements (dates of completion) are typically established by the building owner and then managed by the GC/CM. The specialty subcontractors then use the master schedule to determine their schedule requirements. A project schedule is a collaborative effort between the GM/CM and specialty contractors. There is always "give and take" in creating a schedule and communication between all parties is vital for project success.

It is important for the mass timber subcontractor to identify all required activities, key milestones and constraints, and to communicate clearly with the owner and GC/CM to ensure alignment with other aspects of the project.

All projects, regardless of structural medium, require a significant amount of planning and decision making from design through construction delivery. Decisions can take place during the initial design process, shop drawing phase, and, if necessary, when materials are hoisted in the air awaiting direction due to a change in plans. Using mass timber requires more decision making during the preconstruction process to avoid delays on site. Shifting the preplanning, coordination and decision making to an earlier stage in the project does not necessarily increase the fees associated with design and preconstruction; it just shifts the timing of the fees within the overall project schedule. When properly executed, the delivery of the mass timber superstructure is accelerated and allows for compression of subsequent follow-on activities further decreasing the critical path of the schedule.

When preparing the schedule, it is critical to allocate adequate time for shop drawing creation, review and approvals. During the shop drawing stage, dimensional errors and constructability issues are often discovered, prompting additional collaboration between stakeholders. It is more cost effective to resolve these issues before construction than to discover them in the field.

The GC/CM, mass timber fabricator, mass timber installer and specialty subcontractors establish and coordinate sequencing installation of the building structural frame. To provide an accurate and meaningful schedule, it is important to have all of the necessary information and data. If information and data are missing, misunderstood or incomplete, the schedule and sequencing will require later revisions, which may adversely affect the mass timber installation.

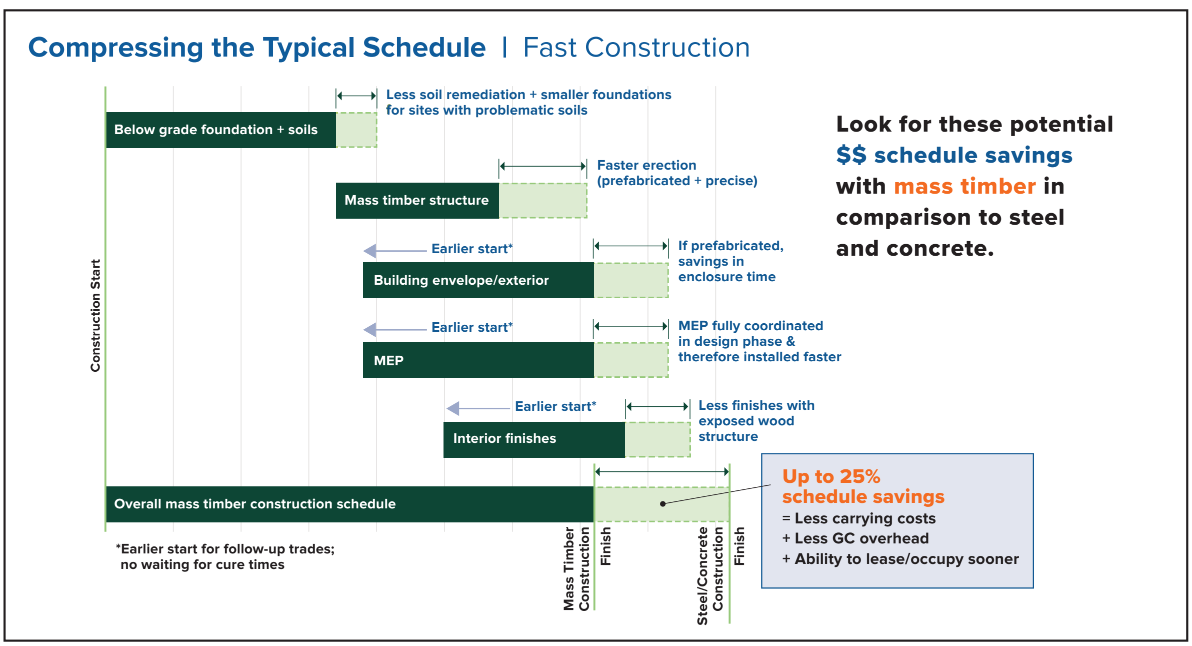


FIGURE 3-7: Typical mass timber project schedule
Source: Mass Timber Design & Cost Optimization Checklists, WoodWorks

3.3.3. Planning for Material Delivery and Staging

3.3.3.1. Material Delivery

Project site conditions may require just-in-time (JIT) deliveries, trailer drop-offs and swapping or marshalling yards. These logistical demands impact pricing as well as material fabrication lead times. If containers are loaded for maximum freight, the GC/CM must plan for shake-out of materials in the field, including additional lifting equipment if needed.

3.3.3.2. Material Staging and Storage

Determine sequencing and quantity of loads required for installation in coordination with the mass timber supplier, if feasible, and schedule sufficient time between truck deliveries to ensure that enough material is on hand and crane access is not jeopardized by idle time. Among the considerations:

- JIT deliveries or stockpiled material on site will require different crane/hoist availabilities. Ensure the schedule and plan account for flying panels from truck or stockpile to the installed location, and allow sufficient time to brace, shore or secure each panel or beam before disconnecting it from the crane/hoist and moving on to the next.
- Location of stored material, whether on site or at a nearby marshalling yard, will be dictated by site restrictions. Shake-out yards, local transportation, extra handling and organization may need to be coordinated based on installation plans.
- Materials kept on trailers or unloaded immediately will require different crane availability.
- Protection of stored materials prior to installation is crucial to maintaining quality. See Chapter 3 for information on how to protect materials from moisture and Section 5.9.1 for other types of protection during construction.
- Determine what connectors, hoisting hardware and moisture control is provided by the manufacturer vs. installer.

TABLE 3-3: Freight considerations by freight system

Mode	Benefits	Risks	Other Considerations
Truck	• Allows larger panels* • Easy to unload • Shorter lead time • High flexibility	• Weather delays • Truck breakdowns • Increased exposure to weather during shipment	• Heavier carbon footprint • Some large metro areas impose restrictions on deliveries during working hours or rush hours, or may only allow overnight deliveries due to lane closures
Rail	• Lower cost • Can ship much larger quantities than truck • Panels can be larger than standard shipping container size	• Slower speed • May require longer lead time • Double handling increases risk for damage	• Lighter carbon footprint • Rail car availability may impact ability to schedule • Flexibility constraints based on railhead locations
Ship	• Lower cost • Materials are well protected during transport	• Panels must be able to fit into standard or non-standard containers • Will require longer lead time • Double handling increases risk for damage	• Lighter carbon footprint • Potential customs delays • Standard container is 8'-0" (W) x 8'-6" (H) x 20'-0" or 40'-0" (L) • Non-standard container is 8'-6" (W) x 9'-6" (H) x 48'-0" or 53'-0" (L)

**As allowed per state and local Department of Transportation regulations*

3.4. Fabrication and Coordination

3.4.1. Manufacturing Facility vs. Jobsite

Thoughtful consideration is needed to determine the extent of prefabrication and other work undertaken at the manufacturing facility vs. the jobsite. Depending on the project location and contracts, field labor resources could be expensive and scarce and not as productive as an enclosed factory environment. CNC router cuts require time to coordinate, input into the fabrication model and execute; however, this work is far more challenging when attempted in the field. Field activities also come with higher site labor costs (the shop labor rate is included in fabrication and other material costs), less precision and increased risk of danger to installers and damage to materials. Prefabrication mitigates many of these issues.

That said, efficiency gains should be weighed against potential drawbacks. For example:

- Factory-installed rigging connections reduce on-site time to fasten and remove rigging to pick points. This may result in faster installation if significant time is required to measure, mark and install hardware for oddly shaped pieces. However, standard beams, columns and panels could be quickly rigged with jigs on site.
- If field-installing MEP/FP penetrations in floors, walls, columns and beams, the drawings should be updated as the design progresses to consider panel joints and splines. The goal is to prevent sub-contractors who may be unfamiliar with the products from drilling holes where penetrations already exist or creating penetrations in the middle of a spline. A safety consideration that weighs in favor of predrilling penetrations is that workers are required to use heavy power tools on a ladder for this type of work, creating potential safety issues if done on the jobsite.

Where door openings occur close to the edge of a CLT wall panel, it can be difficult to maintain rigidity of the panel during hoisting and installation. The narrow width “leg” can snap off under its own weight during hoisting. A good practice is to have the mass timber supplier precut most of the door opening at the plant and then field cut the remainder after installation is complete. This can also be done with door openings in elevator shafts to eliminate the risk of someone falling into the shaft during framing and rough-in operations.

FIGURE 3-8: Partially cut door opening
Image: Jeff Morrow

3.4.2. Alignment of Expectations and Production Capabilities

It is an advantage to select a fabricator early in a mass timber project. Depending on the stage of design, fabricators can provide valuable feedback on panel, column and beam layout and sizing to optimize material efficiency and reduce waste. Pricing is dependent on the volume of timber, degree of engineering analysis, type of connections and number of pieces and parts being fabricated. As noted, each manufacturer has slightly different production and fabrication capabilities. What might be an efficient connection notch/cut for one manufacturer may not be feasible with another’s CNC machinery. Having these discussions early in the project will mitigate risks associated with details that aren’t cost effective.

Just as every construction project is different, so are most teams of designers, contractors and suppliers. In addition to alignment of expectations and deliverables, timely decision making is imperative to ensure the prefabricated structural system meets intended requirements. For timber products to be fabricated and delivered as required, the fabricator must receive complete and timely information from the GC/CM, engineer, architect and specialty contractors.

It is important to reiterate that mass timber is a collaborative service and not a commodity. Unlike most material commodities, such as dimensional lumber and drywall, there are both significant and minor differences between each mass timber manufacturer's capabilities, which need to be assessed before selecting the mass timber partner.

For example, manufacturers may produce:

- Mass timber panels only
- Panels plus glulam columns and beams
- Glulam columns and beams only
- Other timber-related accessories (e.g., hardware, screws, fittings, connection plates, structural steel, misc. steel, embeds, etc.)

Similarly, they may have differing levels of production competencies:

- CNC router capabilities
- Automation vs. manual fabrication abilities

The following are important considerations when selecting a fabricator for a mass timber project.

3.4.2.1. Product Characteristics

Panel dimensions – Manufacturers produce panel products with different lengths, widths, number of plies and overall thickness. Fabrication tolerances also differ between fabricators and may vary within a company based on fiber species. Historically, panel thicknesses produced by North American manufacturers have tended to align with the raw lamella thicknesses of 1x or 2x commodity dimensional lumber after minor planing.

Column and beam sizes – Confirm that products available from the manufacturer will align with the structural drawings.

Species and grade (visual vs. stress rated) – Availability may be dependent on local timber resources.

Applicable product standards – Verify compliance of materials used with code-specified manufacturing standards. European products may not automatically comply with U.S. building material standards and products from a non-certified manufacturer may entail additional steps to demonstrate full conformance or equivalency through the local AHJ. This can require additional time and review expense.

Structural member performance – This includes desired spans and loading requirements as well as building element capacity. The element allowable structural capacity is dictated by loading conditions, element type and size, and material type and grade.

Fire-resistance ratings (FRR) – FRR requirements are stipulated in the locally adopted building code. They vary based on the structural element, type of construction, use and occupancy classification, distance from property line, and other factors. The FRR of individual elements will be determined through testing, calculations, fire engineering or other code-accepted means.

Finish appearance – Specification of appearance grades varies by mass timber product. For example, aesthetic expectations for CLT and NLT are agreed upon by the building designer and manufacturer/fabricator and described in the product specifications, whereas glulam grades are standardized.[15]

Green building rating system compliance – Building designers seeking certification through a green building rating system such as the Living Building Challenge, Leadership in Energy and Environmental Design (LEED) or Green Globes may specify the use of certified forest products. For more information on forest sustainability and certification, see Appendix 2.

3.4.2.2. Availability

Production capacity and commitments – Suppliers have a pipeline of projects and their production lines may already be reserved for other projects.

Physical location of fabrication plant(s) – Proximity of the plant to the jobsite is important if emergency shipments are needed due to damaged product. It is also relevant to the level of support the company may be able to provide. Time zone differences of several hours or more may affect the ability of the project team to coordinate and resolve issues with the fabricator. Proximity of the plant to the fiber supply may affect pricing due to freight costs.

Level of material protection during transport and installation – Options include plastic wrapped packaging, coatings, sealants, etc. If elements are to receive a plant-applied protective sealer or coating, review the time needed for drying and any limitations that may apply after application. It is critical to ensure compatibility with any product that will be subsequently applied in the field, including finish coatings, adhesive weather barriers, and touch-ups to address sealer or coating damage that occurs during shipping and storage.

3.4.2.3. Dimensional Standards

All stakeholders, including the design team, GC/CM, mass timber fabricator, mass timber installer and subsequent trades, need to agree on the measurement system (metric or imperial). Rounding errors often occur in both manual conversion calculations and BIM model calculations when switching from metric to imperial and vice versa, and the lack of accuracy in the interrelationship between the two systems cannot be overemphasized. Early coordination and communication between all parties is critical and alignment in this area should be continually verified.

Most mass timber manufacturing equipment (including CNC routers) in North America is of European origin and based on the metric system. European suppliers are also typically more inclined to use metric as it achieves tighter tolerances in manufacturing, while the American construction industry is traditionally based on imperial measurements (1 mm = 1/25.4 in. vs. 1/16 in.). Avoid using “soft metric” measurements to prevent issues in the field.

Expected durations for RFI responses – A mass timber project is highly collaborative in nature and the owner, design team and GC/CM must provide timely RFI responses to avoid delays in the required fabrication schedule. It is imperative that all stakeholders mutually agree on the expected response duration. This duration may be different than the traditional default time listed in the contract specifications.

Subcontractor coordination – A shop drawing and fabrication bottleneck can occur when the fabricator is waiting on information from other parties for coordination of embeds, openings and penetrations. If the fabricator proceeds with fabrication of panels without the required information, delays and additional costs will occur for subsequent corrective actions in the plant or field.

Expected lead times for shop drawing production, review and approval – All stakeholders have resource constraints. Allocate enough time for adequate and accurate coordination.

Expected fabrication and delivery durations – Make sure materials can be delivered in a timely fashion following approval of the drawings.

3.4.3. Financial Considerations

Suppliers vary in size of personnel and financial reserves. Timely cash flow is critical and must be factored into the final pricing. Items to consider include:

- Whether a deposit is needed before ordering materials
- Payment for modeling, engineering and shop drawings
- Stored material billing terms
- Retainage withholding percentages and release timeframe (installation vs. project)
- Currency exchange rate fluctuations
- Insurance and bonding requirements
- Legal review and capacity – Consideration must be given for smaller firms without significant in-house legal resources to quickly review and debate contractual terms from larger established contractors. Adequate review time must be allocated for the supplier to incorporate the contractual terms and assess potential impacts on material pricing.

3.5. Site Prep Considerations

Framing with structural steel and cast-in-place concrete offers multiple opportunities to "auto-correct" as construction progresses. The manufacturing tolerances of mass timber are precise, and the foundation must be "plumb, level and square" or have tolerances built into the initial connection interfaces for smooth installation. Check the following as part of site prep and adjust where needed:

Individual anchor bolt locations

- Line and grade conditions
- Cleanliness of existing anchor bolts; elevations set
- Plumbness of existing anchor bolts
- Required modification of anchor bolts if any
- Layout of post-drilled anchors

Concrete cast-in-place, masonry and embed work

- Line and grade of embeds
- Level of embeds
- Cleanliness of embeds
- Compressive strength of concrete in footings, walls, piers and walls, and mortar in masonry piers and walls

3.5.1. Building Survey

If construction discrepancies are discovered on site, including anchor bolts and/or cast-in-place embeds, evaluate the schedule and cost impacts of modification in the field vs. manufacturing facility. If on-site modifications are required, ensure they are completed, certified, inspected and approved prior to the mass timber installation. The GC/CM should provide a report of the completed modifications. A building survey conducted prior to installation can prevent having an install crew on site waiting on corrective actions by preceding trades.

4 Moisture Control

KEY POINTS

- Moisture protection cannot be overemphasized for mass timber. It is critical that all parties understand the potential effects of moisture, have input on strategies and establish expectations early on.
- In addition to building to approved drawings, which will include various elements to prevent moisture exposure, the contractor will be responsible for numerous on-site strategies—e.g., coverings, deflection/diversion and ventilation/drying. These should be detailed in a construction phase moisture management plan based on the specifics of the project.
- It is incumbent on the contractor not only to ensure that on-site elements of the moisture management plan are executed properly, but to anticipate and troubleshoot issues.
- For products with unidirectional grain such as NLT or GLT, it is important to leave gaps between tight-fitting elements to allow for swelling if the mass timber gets wet. Without gaps, expansion of the wood can cause out-of-plane issues that are hard to resolve.

4.1. Moisture and Mass Timber Buildings

Moisture control is an important consideration in the design and construction of all buildings, but its significance cannot be overstated for mass timber. Moisture on the jobsite is unavoidable—whether from rainfall, vapor and air movement, construction processes or groundwater sources—and, without preventive steps, can have negative impacts on the wood materials. While this chapter focuses primarily on strategies during construction, protection against moisture requires attention during all phases of the project. It is critical that all parties understand the potential effects of moisture, have input on strategies that reflect the local climate, and establish expectations early on.

The publication, *Moisture Risk Management Strategies for Mass Timber Buildings,*[16] by the building enclosure experts at RDH Building Science, features a useful moisture management tool for contractors, along with planning tools specific to different mass timber panel products.

There are too many climate and weather variables across the United States to have a single document addressing those specifics. Clearly, moisture management in Phoenix, AZ will be significantly different than in Orlando, FL. Likewise, freezing conditions will impact northern locations. The intent of this section is to demonstrate that there are sound principles to be followed and that a holistic moisture management plan must be developed for each project accounting for the specific conditions expected for the area where the project is being built.

There are three main reasons to keep mass timber elements as dry as possible and utilize techniques that promote fast drying when the materials inevitably get wet.

1. **Stains and dirt** – The beauty of exposed wood is one of the great advantages of mass timber buildings. An essential part of moisture control—and a significant part of the

construction team's role—is ensuring that wet mass timber dries quickly and doesn't become soiled. Stains and dirt on material destined to become an architectural feature can be challenging, time consuming and costly to remove.

2. **Shrinkage and swelling** – Wood is hygroscopic, meaning it has the ability to absorb and release moisture. This can cause dimensional changes—i.e., swelling when the material absorbs moisture and shrinkage when it dries. Factors affecting the magnitude of shrinkage and swelling and the amount of water absorbed include the wood species, grain orientation and length of exposure.

3. **Damage from prolonged exposure** – If mass timber materials are allowed to sit in standing water or remain wet for a prolonged period of time, the moisture can cause issues such as mold, decay and corrosion of fasteners.

Moisture challenges can be overcome by anticipating the issues and implementing appropriate moisture control strategies. Mass timber *can* get wet—and it *will* get wet on most projects. That is not a problem, provided an effective moisture management plan is in place.

4.2. Moisture Protection Plan and Responsibility

Planning for moisture management is front and center from the earliest stage of the project, influencing everything from siting to the selection of assemblies, enclosure design and detailing, and protection measures on site.

Techniques vary widely based on local climate, and there is no one-size-fits-all approach. It is incumbent on the contractor not only to ensure that on-site elements of the plan are executed properly, but to anticipate and troubleshoot issues. Expectations and responsibilities should be determined during the procurement process and fully understood by everyone involved—including installers, subcontractors who may have contact with installed materials, and whoever has the planning and cost responsibility for drying the mass timber elements once the exterior envelope is in place.

It is common on a mass timber project for the architect or engineer, through their specifications, to require a moisture management plan from the contractor. Although usually considered a means and methods item, mass timber is typically both structure and exposed finish. As a result the design team may have more input on construction moisture management practices than on a non-mass timber project. The design team and owner may choose to require a preconstruction meeting with the contractor to review on-site moisture management techniques.

Type and Extent of Protection

- Decision by architect/contractor
- Appearance requirements
- Extent and cost of protection methods
- Protection in fabrication plant and/or on jobsite
- Capability of fabricator
- Capability of installer/moisture protection subcontractor
- Schedule protection plan
- Protection prior to installation
- Protection during installation
- Protection after installation

Moisture Management Responsibility and Risk

- Responsibility for managing and cost of the plan
- Contractor and/or fabricator
- Conditions to be considered
- Schedule delays and revisions
- Construction weather conditions (worst case)

Monitoring Moisture Before, During and After Construction

- Coordination with concrete topping activities
- Roofing material
- Columns, beams and floor/wall panels

FIGURE 4-1: Typical moisture protection plan contents

4.3. Applied Protection – Factory and Field

There are many factory-applied options for protecting mass timber elements from moisture, ranging from standard plastic wrap to water-resistant and waterproof membranes, moisture-resistant sealants, and coatings to minimize water absorption. Note that membrane can refer to a spray-applied product, sheet product (non- or self-adhesive) or board/sheathing products. A sealant can refer to a clear coating applied to the end grain, a coating applied more broadly, or a bead product like caulking.

Lumber wrap is included on most materials but is generally intended for protection during transit only. If used during construction, the ends and underside should be loosened to allow air flow. Left fully wrapped, it could lead to trapped moisture, swelling, and/or mold. Wrapped members should be inspected on delivery and the wrapping replaced or reinforced as needed. Continued use of factory wrap or other temporary product coverings not designed for use during installation, or wrap that's been compromised, can trap moisture and/or otherwise damage the material. All manufacturers can wrap mass timber elements in a plastic membrane.

Coatings can be applied in the factory or field to protect against moisture and/or for aesthetics (protection against damage or staining). Coatings alone are not typically sufficient for weather protection, especially for mass timber elements in horizontal applications. Many mass timber manufacturers have the ability to apply spray-on coatings (also referred to as protective sealants) in their facilities. The project team should coordinate with the manufacturer(s) during bidding of the mass timber package and throughout production to ensure inclusion in the process. As part of the scope clarification process, the GC should make sure to understand what sides of the product (top, bottom, sides, ends) a manufacturer will include when the sprayed coating is applied and that this is in compliance with the specifications. A best practice is to apply spray-on coatings at the manufacturing facility, and to do touch-up work or apply additional coats in the field. If field-applied, it is crucial that the materials be dry before the coating is applied.

Protection techniques and products vary widely and continue to evolve as more projects are built. An option becoming more popular is to place a membrane (an adhered sheet good or pre-coated water-resistant sheathing board) on mass timber elements prior to shipping and tape the joints on site. As with coatings, it is crucial that the materials be dry before application if the membrane is field applied. RDH Building Science recommends that the moisture content of mass timber laminations, inclusive of any plywood or OSB sheathing layer, be 16% or lower before applying temporary or permanent membranes. There is also a need to coordinate structural attachments of the floor panel with the membrane and/or temporary protection. (See Section 4.4.)

If a portion of a membrane must be removed—e.g., at connection points during construction—RDH recommends checking to ensure that the mass timber hasn't been exposed to water, mechanically drying the wood if needed and patching the membrane after confirming the substrate is dry.

Platte Fifteen: A Lesson in Protection

For Platte Fifteen, a five-story mass timber office building in Denver, Colorado, the project team took several steps to protect the materials from damage. The manufacturer applied a sealer to both the CLT panels and glulam columns and beams in the factory. Denver experienced an unusually wet winter with a lot of rain during construction, and the sealer helped protect the wood, making it easier to keep clean.

The construction company, Adolfson & Peterson, also took time to share its vision for the finished space with everyone on the team, including subcontractors. This allowed people on site to understand how their activities would impact the beauty of the building. Workers wore gloves when handling the wood to protect it from staining and, once the columns were installed, crews wrapped them with foam and OSB to protect from dents and other damage. After the wood system was erected, they wrapped the building and installed a temporary roof to prevent water intrusion for the remainder of construction.

FIGURE 4-2: Column coverings applied by Adolfson & Peterson on Platte Fifteen
Images: David Hanley, WoodWorks

4.4. Protection During Staging

Coordinating shipping to align closely with the construction schedule is common on mass timber projects to limit the amount of time materials must be staged on site. However, even with just-in-time delivery, some material storage is inevitable. Mass timber elements need to be protected, with the degree dictated by considerations such as climate, season and distance from the manufacturing facility. Techniques include keeping the materials raised several inches off the ground with dunnage, slitting the underside of plastic wrap to prevent moisture from accumulating inside and tarping the material to avoid direct exposure to the elements.

FIGURE 4-3: Staging area; CLT exterior wall façade with field-applied self-adhered water-resistive vapor permeable air barrier
Image: Jeff Morrow

Do This Simple Thing to Avoid a Costly Lesson Learned

The importance of slitting the underside of protective wrapping to prevent moisture from accumulating within stored material loads cannot be overstated, as one developer learned the hard way. The team was using imported CLT and North American glulam. The CLT was delayed in the port by several weeks, during which time the glulam sat on site. This was in an area known for high humidity and, without slits in the bottom of the wrap, the beams swelled considerably. When the CLT arrived, the beams were too big for the pre-cut pockets in the panels, so the materials were modified in the field to make it work. Once installed and allowed to dry, the beams shrank, creating a gap in the shaft wall—which meant they now had a fireproofing issue. A solution was found, but not without a lot of extra work for the crew and design/engineering team.

4.5. Managing Moisture On Site

In addition to building to approved drawings, which will include various techniques for preventing moisture exposure, the contractor will be responsible for numerous on-site strategies. These should be detailed in the construction phase moisture management plan based on the specifics of the project. As a major benefit of mass timber construction is the early start of follow-on work, a strategy for adjusting and modifying moisture protection measures should be included. For instance, how will coverings be adjusted and protection replaced during glass or curtain wall installation at the exterior walls?

Strategies include:

Coverings – In addition to applied protection such as membranes, it may be appropriate to install temporary covering over some or all of the project. Keeping the roof dry is especially important when the roof has a vapor impermeable membrane to manage in-service moisture loads, which cannot under any circumstances be applied to wet mass timber. Note that keeping horizontal surfaces free of snow in winter is also important. The risk is that ice/snow will melt, get the wood wet and damage the material, or the wet wood will freeze and cause volumetric change.

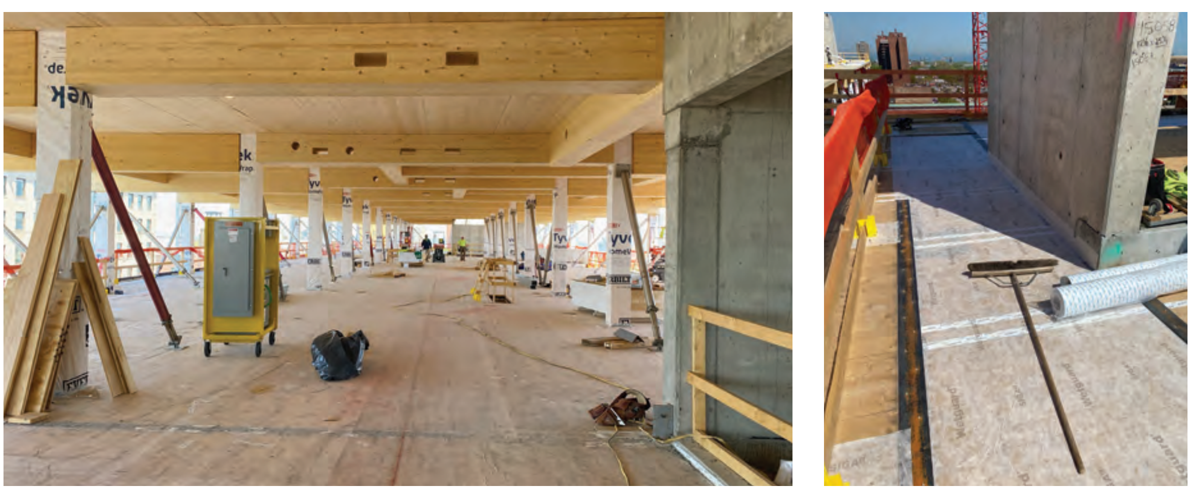


FIGURE 4-4: Construction/moisture water-resistive barrier on CLT floor panels, installed after the spline is completed and joints taped. This reduces moisture flow to lower levels, allowing dry-in and finish material installation while structural work continues on upper levels. It is left in place without impact to the concrete topping. Also note the wrap on columns, installed to protect from UV damage.
Images: Jason Reynolds, WoodWorks

Deflection/diversion – Drainage techniques such as back-drained cladding help ensure that mass timber materials have an opportunity to dry after installation and will be specified in the structural or architectural details. However, deflecting and diverting water during installation is the responsibility of the construction team. RDH Building Science recommends developing a drainage strategy as part of the moisture management plan to ensure that water sheds off of mass timber elements toward drains and floor or roof edges, and that drains are able to effectively discharge to the building exterior. Regardless of the approaches chosen, regular removal of standing water, debris and dirt/grime on any surface is recommended to reduce the risk of absorption.

FIGURE 4-5: Vapor-permeable water-resistive barrier on CLT floor panels, draped over the wall system below to deflect water from the lower floors

Image: Used with permission from Moisture Risk Management Strategies for Mass Timber Buildings, *© 2020 RDH Building Science Inc.*

Ventilation and drying – When wood gets wet, drying can be promoted through natural and/or mechanical means—e.g., fans, heaters and dehumidifiers. If the material is covered in an impermeable material (e.g., membrane), it may need to be removed to speed drying.

The best way to minimize exposure to moisture during construction is to close in the project as quickly as possible. In addition to installation

TABLE 4-1: Production types and example products

Source: RDH Building Science

Protection Type	Protection Name	Description	Example Product	Risk Level
Coat	Edge Coat	High build paraffin edge protection sealer	Broda Check Stop or similar	ALL
	Top Coat	Hydrophobic wood sealer	Sansin KP-11 or similar	3
Membranes (CLT & MPP)	Membrane 1 (M1)	Vapor-permeable self-adhered (VP SA) membrane	VaproShield SlopeShield Plus with sealed laps or similar	2
	Membrane 2 (M2)	Vapor-impermeable self-adhered (VIMP SA) membrane	Textured or sanded impermeable peel and stick with sealed laps	2
	Membrane 3 (M3)	Vapor-impermeable self-adhered SBS membrane with torched laps (VIMP SA Torch Lap)	Soprema Elastophene Flam Stick with sealed laps or similar	1
Membranes & Joint Protection (NLT & DLT)	Membrane and Joint 1 (MJ1)	Membrane: None, sheathing is exposed Joint treatment: Taped and/or sealed	SIGA Wigluv, Rothoblaas Frost Band, ZIP flashing tape, or similar	3
	Membrane and Joint 2 (MJ2)	Membrane: Precoated, moisture-resistant bonded water-repellent sheathing Joint treatment Taped and/or sealed	ZIP sheathing, ZIP flashing tape	2
	Membrane and Joint 3 (MJ3)	Membrane: Vapor-impermeable self-adhered (VIMP SA) SBS Joint treatment: Fully adhered or welded membrane (torched laps)	Soprema Elastophene Flam Stick with sealed laps or similar	1
Acoustic Mat	Acoustic Mat 1 (A1)	Acoustic loose-laid (LL) vapor-impermeable mat	Per acoustic design with sealed laps	3
	Acoustic Mat 2 (A2)	Acoustic self-adheredd (SA) vapor-impermeable mat	Per acoustic design with sealed laps	2

LEGEND

1 **Risk Level 1: Low Risk** No immediate action required and low chance of damage.	2 **Risk Level 2: Moderate Risk** Low risk of damage if action is taken in a timely manner.	3 **Risk Level 3: High Risk** Immediate action needs to be taken to avoid the risk or permanent damage.

FIGURE 4-6: Panel-to-panel joint taped prior to placement of spline; the spline will be taped after installation.
Images: Jason Reynolds, WoodWorks

speed, this includes minimizing schedule delays between construction of adjacent floor levels. It is also helpful to install enclosure components (e.g., roof, temporary roof membranes, water-resistant barriers on walls) in parallel or soon after that part of the structure is erected.

Don't underestimate the value of a crew member with a broom or squeegee after a storm; this is an essential moisture control tactic.

Panel Joint Treatment – Taping the joints of panels below the spline board can be required for fire stop/smoke seal purposes. However, it is preferable to tape the joints after the spline has been installed to avoid trapping moisture under the board. Clarification of taping for fire stop/smoke seal and timing of protection placement should be coordinated during design and as part of the GC/CM preconstruction coordination with the installer. The extent of taped joints per floor deck can vary by manufacturer based on panel sizing and layouts. Due to the material cost of the tape and labor required for installation, it is imperative to establish the extent of joint taping before commencing work. Ideally, every floor joint should be taped to minimize the volume of bulk water flowing from one floor to the next during installation. For example, if you pour gypcrete topping over an untaped CLT floor, water in the mix can seep into the joint and either get trapped or stain the underside of the panel. It is also helpful to maximize panel size to decrease the number of taped joints.

FIGURE 4-7: Upper level with completed spline/tape and in-process areas
Image: Jason Reynolds, WoodWorks

FIGURE 4-8: Fully taped/installed spline
Image: Jason Reynolds, WoodWorks

4.6. The Contractor's Role in Moisture Content

Moisture content (MC) is the weight of water in wood as a percentage of the completely dry wood weight. During the life of a tree, its MC can exceed 200%, meaning the total water weight in a given volume of wood makes up two thirds or more of the total weight. Initial MC (at the time a wood product leaves the manufacturer) is typically specified on a project's structural drawings. In many parts of the country, the specification for solid sawn lumber would read "a maximum MC of 19 percent." However, many mass timber products are manufactured with lower MC as required in their applicable manufacturing standards.

The structural engineer calculates the potential for shrinkage in a mass timber project based on the initial MC of the material, the equilibrium MC, and the cross-grain dimensions of the timber. The percentage can be measured again at the time of installation to confirm the assumptions. It is the construction team's role to monitor the moisture content of wood materials throughout the project. Some moisture management plans require that a log be kept of these on-site measurements, which RDH considers a best practice.

There are several tools available to check the MC of mass timber during construction, including handheld meters that either measure moisture on the material's surface or have a pin to measure 1/4-in. into the panel or member. MC should be checked when the materials are received and at intervals, after rainfall, to ensure moisture management techniques are having the desired effect, and before drying in the building. For example, if a panel has been rained on and the contractor has removed the standing water or used other means to promote drying, a moisture meter can be used to indicate when tape can be applied or the building can be dried in.

TABLE 4-2: MC requirements at fabrication vs. project close-in

Product	MC at Manufacture	Desired MC at Project Close-in with Direct-Applied Concrete Toppings
CLT	12% +/- 3%[a]	<16%
GLT	12-16%[b]	<16%
NLT	<19%[c]	<16%
DLT	15-19%[c]	<16%

Sources: [a]PRG-320 standard, [b]ANSI A190.1, [c]Nail-Laminated Timber Design Guide – U.S. Edition, and [d]DLT Design and Profile Guide

Wood absorbs moisture much more rapidly through its end grain (i.e., longitudinal direction) than through the transverse direction, which is why some design teams choose additional factory-applied end grain protection. Direction of the grain is another consideration. Products with bidirectional grain such as CLT have cross layers that limit shrinkage and swelling, while products with unidirectional grain such as NLT, DLT and GLT have greater potential for dimensional change.

For products with unidirectional grain, such as NLT or GLT, it is important to leave gaps between tight-fitting elements to allow for swelling if the mass timber gets wet. Without gaps, expansion of the wood can cause out-of-plane issues that are hard to resolve.

For more information on moisture content and wood shrinkage, see the WoodWorks publication, *Accommodating Wood Shrinkage in Multi-Story Wood-Frame Buildings.*[17]

Design Best Practices Rely on Proper Installation

A well-designed building enclosure is essential to protect the building from moisture during its in-service life. The effectiveness of the enclosure relies on proper implementation of the project drawings as well as good installation techniques. As with other moisture control elements, a good building enclosure will protect the structure from getting wet and promote drying when wetting does occur. While a detailed discussion of building enclosures is beyond the scope of this manual, the RDH Building Science publication, *Mass Timber Building Enclosure Best Practice Design Guide,*[18] offers helpful insight for contractors constructing a mass timber project.

5 Installing Mass Timber

KEY POINTS

- If site logistical constraints do not allow for on-site storage and necessitate JIT deliveries, consider utilizing a nearby marshalling yard to store material loads.
- Deliveries must consider the project schedule, sequencing and order that material will be installed. It is important to understand and coordinate how the contents of shipping containers are loaded to minimize double and triple handling of materials on the project site.
- Efficient material handling will do more to enhance workflow than almost any other element. It is imperative to develop and execute an effective plan for project success.
- On a mass timber construction site, maintaining the appearance of timber that will be visible in the final building is everyone's job. The GC/CM must clearly understand which elements will be left exposed and communicate that information to the subs.

Mass timber construction is unique in that it draws installation techniques from other construction types, which makes it relatively easy for people with precast, tilt-up and structural steel experience to adapt to these materials. However, understanding how mass timber *differs* from other building systems is key to cost effectiveness. This chapter covers typical construction topics with a focus on the nuances of mass timber, including equipment, safety, transportation, unloading and staging, rigging, connections, acoustic assemblies, installation and finishing.

5.1 Site Considerations

When the mass timber installer arrives on a jobsite, the following items should be verified prior to commencing work. Even if some have been completed, best practices recommend checking them again.

- Review site conditions, including construction progress, access roads, perimeter control and security, and staging areas.
- Verify that all necessary drawings (paper and electronic) and the virtual building model are available and up to date. Confirm on-site internet connectivity for data communication.
- Perform additional layout if required, including control lines and elevations. Verify that connections embedded in concrete foundations/slabs or affixed to steel structure are in the correct locations and installed per the mass timber shop drawings. Provide a discrepancy list to the GC/CM for corrective action. Errors should be repaired prior to the start of mass timber installation.
- Determine what materials (e.g., anchor bolts, plates, angles, columns, beams, panels) require pre-installation work and ensure that all connection material is available. Review manufacturer requirements and determine what tools are needed to correctly install the connections, anchors and driving screws. Establish a pre-installation schedule and work areas.

- Identify supplemental electronic devices (e.g., laptops, tablets, robotic surveying equipment, chargers, etc.) and related software needed to complete the work and ensure power is available.
- If not already done, submit the site-specific installation and safety plan to the GC/CM, including all necessary certifications (e.g., equipment, equipment operators, riggers and welders) and Safety Data Sheets (SDS).
- Review the progress of mass timber fabrication and confirm the fabricator's ability to deliver material as needed. Review the delivery schedule, truck unloading requirements, and the suitability of staging areas.
- Confirm that all equipment has been procured and deliveries scheduled. Advise the GC/CM what equipment will arrive and when. This data should be included in the site-specific installation and safety plan.
- Identify and mitigate hazards, including power lines, trees and underground items.

5.1.1 OSHA Subpart Part R Anchor Bolt Modification Requirements

The mass timber installer should ask the GC/CM if any modifications have been made to the anchor bolts and, if yes, request a report verifying that the changes are complete and certified. Similarly, the installer should notify the GC/CM if any bolts require modification and should not start installation until the changes are complete.

OSHA standards 1926.752(a)(2) and 1926.755(b) related to the repair, replacement and modification of anchor bolts or rods in steel construction also apply to mass timber.

FIGURE 5-1: Tower crane positioned for access at T3 in Atlanta, GA
Image: StructureCraft

5.2 Equipment Considerations

A preconstruction site inspection allows the GC/CM to identify any location-specific conditions that obviate the use of specific crane styles, material handling, storage, lifts or other equipment. Overhead obstructions, accessibility, slope and grading, building orientation and building design will dictate the equipment necessary to safely and efficiently install mass timber panels, beams and columns.

The quality of training and qualifications of equipment operators are paramount to safe operations. Ensure that all equipment operators are trained and understand the capabilities, limitations, hazards, safety features, emergency conditions and environmental impacts of equipment before use.

5.2.1 Cranes

Hydraulic, crawler and/or tower cranes may be appropriate, depending on the project. Selection will be based primarily on site-specific considerations and maximum lift and reach requirements. While there is no one-size-fits-all solution, site access, stability, restrictions or hazards and capacity should be considered and discussed with the GC/CM well before installation. Restricted access to the crane (i.e., proximity to building and laydown area) will increase the size of the install team and slow installation, reducing two of mass timber's benefits. Detailed lift requirements and planning are an absolute necessity to ensure that load capacity charts are not exceeded, and any critical lifts (greater than 75% capacity) are identified and planned properly. See Appendix 3 for a sample critical lift plan.

5.2.2 Material Handling Equipment

Lifts are essential for material handling and providing safe access for workers at height. Every project will require different quantities and types of lift equipment depending on the building size and configuration, site logistics, etc. Forklifts (including standard, all-terrain and high capacity), boom lifts and scissor lifts are all commonly used.

FIGURE 5-2: Hoisting anchors on CLT panels at The Canyons in Portland, OR
Image: Kaiser+Path, photo Marcus Kauffman, Oregon Dept. of Forestry

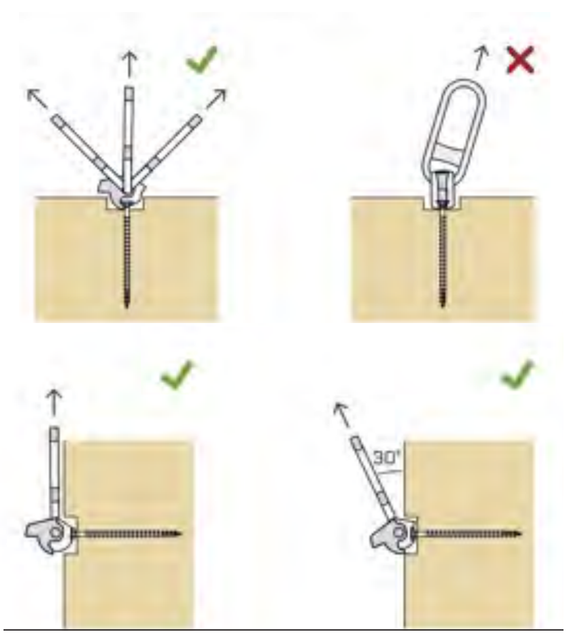


FIGURE 5-3: Allowable lifting and transport hook directions
Image: Rothoblaas

5.2.3 Specialty Lifting Connectors

The architect, engineer and GC/CM must approve the selection of specialty lifting connectors, though the manufacturer or fabricator may have a preferred choice and provide input. Holes or repaired holes may be unacceptable in mass timber elements for appearance reasons. Additional fireproofing may also be required to fill the holes, adding cost and time to the installation.

Surface-mounted hoisting anchors and transport hooks may or may not have directional limitations (Figure 5-3). Understanding what is being attached along with the limitations or restrictions can mean the difference between a speedy install and delays caused by the need to replace panels.

5.3 Safety

As with other project types, the GC/CM is responsible for the overall safety of the jobsite and will assign staff to ensure the safety of workers, equipment and material conditions. Site-specific safety plans with job and task-specific procedures to mitigate risk and injury are provided by the mass timber installer and approved by the GC/CM. A mass timber plan is similar to a precast concrete, tilt-up or structural steel installation and safety plan.

5.3.1 OSHA Construction Safety Requirements

The references below identify major OSHA construction requirements and guidance materials that may apply to a mass timber jobsite. The information is provided on OSHA's website and should be reviewed to ensure compliance with OSHA requirements and prevent workplace injuries and illnesses. While these requirements are not all encompassing, they are designed to frame the necessary discussions before, during and after construction.

Step 1: OSHA Requirements Related to Leading Hazards at Construction Sites[19]

Step 2: Other OSHA Requirements That May Apply to Your Jobsite[20]

Step 3: Survey Your Workplace for Additional Hazard[21]

Step 4: Develop a Jobsite Safety and Health Program[22]

Step 5: Train Your Employees[23]

Step 6: Recordkeeping, Reporting and Posting[24]

Step 7: Find Additional Compliance Assistance Information[25]

FIGURE 5-5 Guardrails installed at The Soto
Image: Cheyne Smith, BOKA Powell

5.3.2 OSHA Fire Requirements

To avoid fire risk for installed materials, materials waiting for installation and construction debris, hot work activities should be avoided wherever possible. If hot work activities must occur, it is important to comply with the following OSHA regulations:

- OSHA Construction Regulations 1926.352 (Fire prevention), 1926.353 (Ventilation and protection in welding, cutting and heating) and 1926.354 (Welding, cutting and heating in way of preservative coatings) govern the rules and requirements for welding, cutting or heating material.
- OSHA General Industry Regulation 1910.252 governs basic and special fire-protection precautions and delineates the fire protection and prevention responsibilities of welders and cutters, their supervisors (including outside contractors) and management/property owners.

The GC/CM, building owner and/or AHJ will determine how the OSHA rules are implemented.

5.3.3 Fire Safety During Construction

Buildings are most vulnerable to fire during construction when passive and active safety systems are not yet in place. It is important to be aware of the risks so appropriate measures can be taken.

Mass timber construction has several benefits in the context of on-site fire safety.

- As with large solid wood members, large mass timber elements have inherent fire resistance. In a fire, a char layer forms on the surface while the interior remains undamaged and structurally sound. The predictability of wood's char rate has been well-established for decades and has long been recognized in building codes and standards. This is why mass timber can be left exposed in a building and still achieve a fire-resistance rating, but it also contributes to protection during construction.
- Mass timber construction doesn't require welding or grinding, eliminating a major source of sparks and heat.
- Prefabricated mass timber structural systems generate almost no wood waste on site. With little sawdust and few cut-offs, there is less potential for ignition.
- Mass timber buildings tend to be constructed faster than buildings made from other materials.[26] A shorter schedule means less exposure and reduced risk.

The Construction Fire Safety Coalition,[27] a multi-stakeholder group that operates under the supervision of the American Wood Council, offers a wide range of resources to help builders address fire safety during construction. It recommends the following five steps:

- Identify the risks and hazards
- Determine who is at risk
- Evaluate and protect
- Record, plan and train
- Review, review, review

Construction fires are generally started by hot work, heaters, careless fire safety practices or poor housekeeping. These risks are fairly straightforward to reduce—e.g., by eliminating hot work near mass timber, restricting flame or significant heat-generating activities such as grills and personal heaters, enforcing no smoking policies on site, and not allowing debris to accumulate. The potential for arson must also be considered and appropriate action taken.

It is essential that everyone working on the jobsite be appropriately educated and trained on the risks and procedures, and that measures are in place to quickly alert site personnel and first responders in the event of a fire. A 24-hour security detail or fire watch should also be considered.

5.3.4 Construction Fire Safety in the 2021 IBC

In the 2021 IBC, Section 3308.4 includes fire safety requirements for mass timber buildings of Types IV-A, IV-B and IV-C construction. These are recommended best practices even in jurisdictions that have yet to adopt the 2021 IBC.

Among the requirements, a maximum of four stories can be left without at least one layer of noncombustible protection (where required) and exterior wall coverings at any time (Figure 5-4). This includes mezzanines, and means starting finishing work on lower stories as upper levels are added. Exceptions are shafts and vertical exit closures, which are not considered part of the active mass timber construction.

Other requirements include standpipes, a water supply for fire department operations, and a fire watch for non-working hours where construction exceeds 40 ft above the lowest adjacent grade (when required by the fire code official).

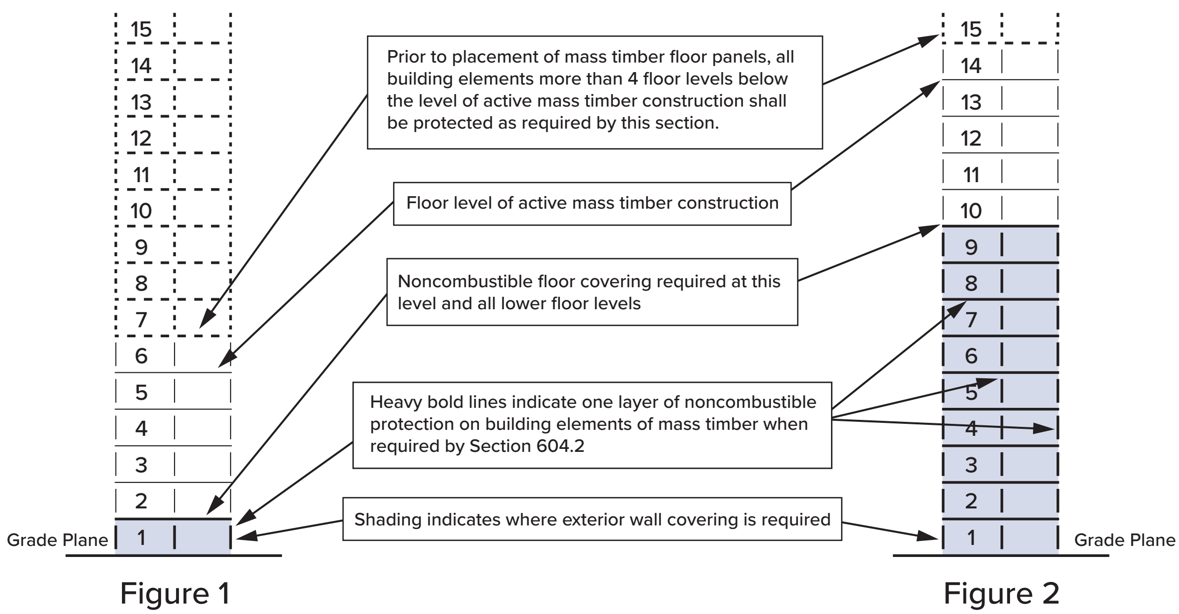


FIGURE 5-4: Examples of protection during construction for mass timber buildings greater than 6 stories above grade plane
Image: International Code Council

5.4 Transportation, Unloading and Staging

5.4.1 General Freight Considerations

Deliveries must consider the project schedule, sequencing and order of installation. It is important to understand and coordinate how the contents of containers are loaded to minimize double and triple handling of materials on the project site. Will the panels be loaded in reverse order (top panels install first while bottom panels install last) to accelerate field installation or loaded for maximum trailer/container efficiency (i.e., fewer trips/lower costs)?

As noted, trailers and containers loaded for maximum freight utilization require shakeout in the field, and possibly more labor and/or lifting equipment to maintain jobsite production.

5.4.2 Intermodal Containers

Standard intermodal containers (referred to as "ISOs" or "vans") are 8 ft wide, 8-ft-6-in. high and 20 ft or 40 ft long. Non-standard containers are 8-ft-6-in. wide, 9 ft-6-in. high and 48 ft or 53 ft long. These sizes are designed to be used across rail, sea and truck transport modes with standardized equipment, thus minimizing risk to the cargo. Material from outside North America will likely be shipped via containerized systems such as ISO intermodal vans.

Shipping time from Europe to the U.S. East Coast is typically 3-4 weeks but can vary depending on fabrication duration and backlog, freight to port, shipping transit to North America, customs requirements and freight to jobsite. Proper scheduling of material delivery is critical and it is important not to underestimate the time to required.

5.4.3 Jobsite Access and Sequencing

Jobsite suitability will often determine material flow onto the site. When receiving material, it is important to consider road access, site conditions, overhead clearance, equipment required to unload containers from the carrier and/or remove material from the containers, and gross weight of the packages. Removing material from the container may require additional lifting equipment (forklift or crane) and/or staging equipment (flatbed trailer or rack).

Individual mass timber components can be large. Understanding and coordinating potential constraints on the movement of finished pieces is important for proper planning and scheduling.

As with concrete or steel members, transporting large mass timber elements can be costly and, depending on the size of the element, may require specialized transportation services. Determining the best way to transport mass timber elements for a particular project may involve the building designer, contractor/installer and mass timber manufacturer.

5.4.4 Oversize and Overweight Permits

It is important to be aware of federal and state requirements for vehicle size and weight, as oversize and overweight permits are required when the limits are exceeded. For more information, the Federal Highway Administration website[28] includes a consolidated guide to weight and size limitations.

Oversize and overweight transportation requires planning and organization by the mass timber manufacturer and a transportation company specializing in this type of work. The GC/CM should be involved in this process to make sure the site plan and material delivery plan are aligned.

5.4.5 Schedule Quantity and Timing of Truck Deliveries

The mass timber installer tells the manufacturer what material is needed on the jobsite when. The manufacturer then plans the loads and sends specifics to the installer regarding number of loads, contents of each and special delivery requirements. The manufacturer, GC/CM and installer should work together to generate this information as early as possible, as it influences the production and delivery schedule.

If site logistical constraints do not allow for on-site storage and necessitate JIT deliveries, consider utilizing a nearby marshalling yard to store material loads. Weather, holidays, factory shutdowns and other extenuating circumstances can play havoc with JIT. Idle cranes and erection crews can be expensive and cause delays.

5.4.6 Material Deliveries

Continuous communication with the mass timber fabricator during fabrication and delivery will keep the jobsite well organized and the project moving forward. Ensure the fabricator is aware of the installation plan, desired delivery timelines, storage capacity on site, shake out limitations and any other hindrances to efficient delivery and offloading.

- Confirm the first load includes all drawings, fasteners and additional dunnage if required.
- Upon delivery, confirm all material has been properly protected during shipping and the shipping ticket matches the material on the load.

- Inspect the material and report any damage or panel deformation to the fabricator. Deformation can occur during shipping or storage at the manufacturing facility. For example, when stored for an extended period on a trailer, panels can begin forming to the cambered arch of the trailer, developing a slight curve unless they are properly supported to accommodate the camber. This issue can be more pronounced with softer species of timber.
- Follow best practices for material protection, including:
  - Keep beams, panels and columns covered. This protects them from exposure to moisture as well as UV rays, which can impact appearance. Keep materials wrapped until installation and use a secondary cover.
  - Ensure there is no direct ground contact or contact with moist or wet surfaces. Use dry lumber blocking to provide ventilation.
  - Leave protective wrappings intact but slit the undersides to prevent moisture from accumulating inside.

5.5 Rigging and Lifting Requirements

OSHA standards related to rigging and lifting apply to mass timber buildings just as they do to other project types. In particular, the GC/CM and installer should be familiar with:

- OSHA 1926.251 – Rigging Equipment for Material Handling
- OSHA 1926 – Cranes and Derricks in Construction: Demolition and Underground Construction
  - OSHA 1926.1501 – General requirements
  - OSHA 1926.1427 – Operator qualification and certification
  - OSHA Subpart DD – Additional requirements
  - OSHA 1926.1417(w) – Tag or restraint lines

For information on rigging qualifications, see the OSHA fact sheet, *Personnel Training for Riggers.*[29]

5.5.1 Lifting Principles

There are parallels between moving large mass timber elements and precast concrete or structural steel. Similar techniques and principles are used for lifting, rigging, slings and spreader bars for longer members. Material type does not change the rigging and hoisting math and overarching dependence on calculating the center of gravity—and knowing what the piece will do when it leaves the ground—is still crucial.

Efficient material handling will do more to enhance workflow than almost any other aspect of the project, and it is imperative to develop and execute an effective plan for project success. Key tasks and best practices include the following:

- Plan all lifts before starting the project. The GC/CM and installer should both have a clear understanding of how the building will be installed.
- Where a mobile crane will used, the installer and/or crane company must provide crane pressures for the GC/CM to develop a suitable crane path.
- Be aware of the crane's capacity and reach relevant to each lift.
- Stage materials to ensure the most efficient lifts.
- Avoid double handling of materials.
- Ensure all pick points or slings are properly located and oriented.
- Avoid interference with other trades or temporary braces.
- Establish clear communication between the crane operator and the crew setting panels.

The GC/CM, manufacturer, installer/riggers and crane company should discuss hoisting requirements and agree on what equipment is being provided by the manufacturer/installer and what must be acquired separately. This is especially important if the needs are complex and/or require special equipment—e.g., timber elements are irregularly shaped, have cutouts for doorways, stairwell voids, large windows or large penetrations, or asymmetric anchors will be installed.

Mass timber differs from other materials in the wide variety proprietary and generalized hoisting devices and lifting anchors that can be used. This is because wood is relatively lightweight; mass timber buildings are approximately one fifth the weight of comparable concrete buildings.[30] This is a benefit for overall construction but must be accounted for when planning hoisting operations. Construction sites are dynamic places and subject to every possible environmental effect. Understanding how a large mass timber panel will respond to a strong gust of wind (or other condition) on a tight site—and planning for it—is important. Using tag lines is an easy way to prevent problems in the middle of a lift.

5.6 Connections

The following section draws information from the WoodWorks Index of Mass Timber Connections[31] and accompanying paper.[32] For more details and examples, please see those documents.

Please note:

- Red symbols indicate the primary load path and direction for the connection
- Light blue symbols indicate the secondary load paths and directions for the connection
- Loads across the page
- Loads into the page
- Loads out of the page

The spectrum of standard and custom connections used in mass timber construction is already very broad, and the options will only increase as the industry matures and more buildings are designed. Depending on the project, connections must balance multiple objectives—including availability, cost, load capacity, tolerances, aesthetics, fire and seismic performance, ease of construction and inspection requirements—and there will always be creative new approaches. While the topic of connections could fill its own book, the intent of this section is to provide an overview and some examples, with an emphasis on information helpful to installers.

Considerations to keep in mind include:

Factory vs. field – A general rule is that holes, notches and other alterations to members should be made during fabrication to the greatest extent possible. However, it is important to discuss options and determine which if any should be done in the field. For example, when diagonally-oriented screws are required as part of a connection, it may help with installation to pre-drill the outer side of the member during fabrication, though it could be done in the marshalling yard or with a jig on site. Note that fabricators may have limitations with regard to very small openings, and field tolerances may result in misalignment. It may be preferable to cut small openings (less than a few inches) in the field.

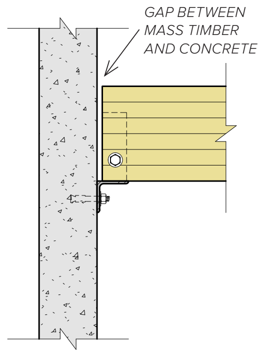
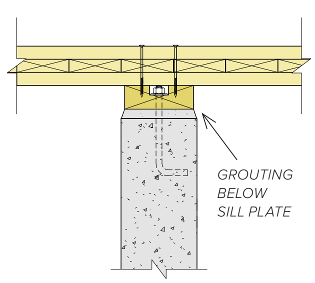
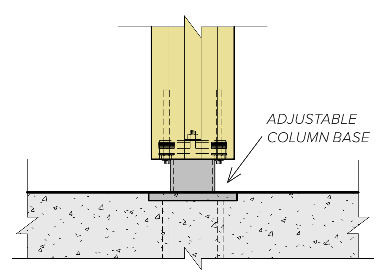
Solution	Gap Between Mass Timber Beam and Concrete Wall	Grouting Below Sill Plate at Mass Timber Panel to Concrete Wall	Adjustable Column Base at Mass Timber Column to Concrete
Connection example			
	Beam Perpendicular to Wall Connected to Face of Wall	Panel Bears at Top of Wall	Column Bears on Concrete with Adjustable Standoff Base

FIGURE 5-3: Tolerance Solutions

Source: WoodWorks Index of Mass Timber Connections, Table 11, 5 and 15 (respectively)

Tolerances – In most structures, there will be interface between mass timber and other materials, including steel, concrete and masonry. Fabrication tolerances for mass timber are extremely precise, while tolerances for other materials are typically larger. The design drawings will specify how to address these differences. For example, options for addressing different tolerances between timber and concrete include leaving a gap between members of differing materials, using grout to adjust elevations, or providing built-in adjustability in the connection itself. Oversizing holes in plates is a simple and effective method of allowing minor tolerance adjustments in a connection.

Fire resistance – Depending on the construction type and/or local jurisdiction requirements, connections may need to be fire rated. Acceptability of the fire rating is determined by the AHJ, and approaches include wrapping/covering with wood, gypsum board, etc. For fire-rated connections, exposed steel connection hardware and fasteners must be concealed entirely using wood, concrete, gypsum or other approved materials. Alternative methods of protection may also include spray fireproofing or intumescent paint, where approved by the AHJ.

Inspections – As noted in Chapter 3, connections are also likely to have specific inspection requirements.

FIGURE 5-7: Gap between wood floor and concrete core allows for different tolerances
Image: Anthony Harvey, WoodWorks

5.6.1 Mass Timber to Mass Timber

5.6.1.1 Panel to Panel

In the following examples, panels are shown as CLT. However, in most cases, CLT is interchangeable with DLT, NLT or SCL-CLT without any change to the connection. Please note that these examples are not intended to achieve a specified fire-resistance rating.

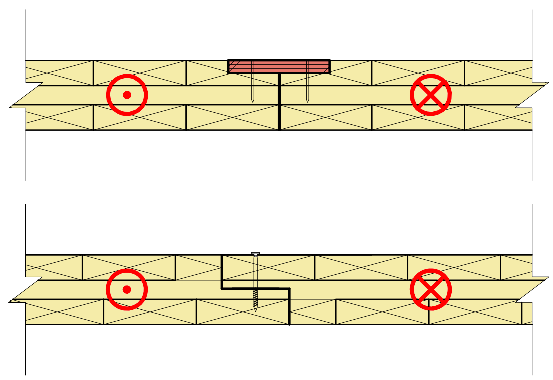


FIGURE 5-8: Typical surface and half-lapped panel connections
Source: Index of Mass Timber Connections, Table 14

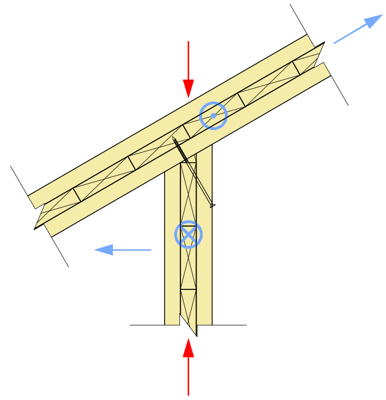
Horizontal Applications

Mass timber panels can be jointed in several ways. They can be half-lapped and screwed or nailed, butt-jointed with a surface spline, or double-splined for increased strength. The surface spline is typically recessed by the thickness of the spline to allow a level surface. These splines are used for CLT, DLT, NLT and SCL-CLT panels.

Surface splines and half-lap joints are commonly used for in-plane connections on floors. The half-laps are milled along the panel edges at the manufacturing facility and long self-tapping partially-threaded screws are typically used to connect the panels on site. For a detailed discussion of fasteners, see Section 5.6.5.

Typical Wall-to-Floor and Roof Connections

As with other panel applications, mass timber roof panels can bear directly on other mass timber elements or indirectly using ledgers or angles. Connection options range from simple to complex—e.g., self-tapping partially-threaded screws to proprietary steel brackets when increased load transfer is required.



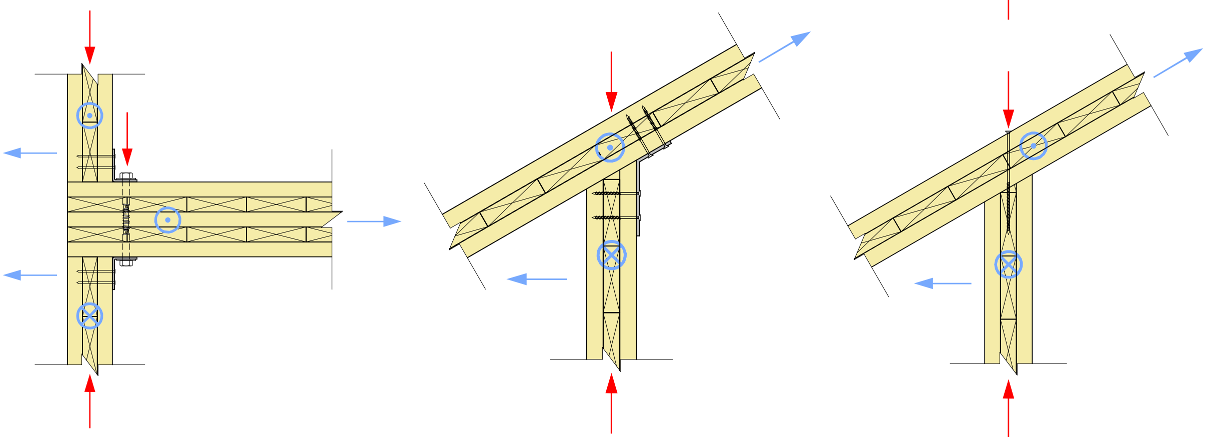


FIGURE 5-9: Mass timber elements bearing directly on mass timber elements
Source: Index of Mass Timber Connections, Table 4

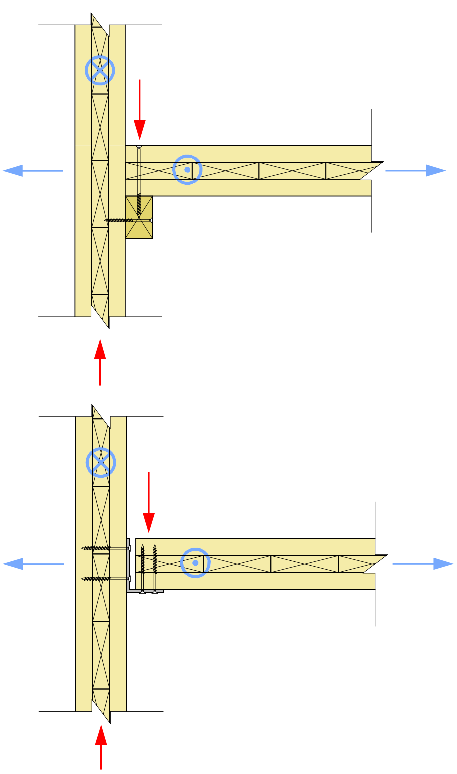


FIGURE 5-10: Mass timber elements bearing on ledger (top) and bracket (bottom)
Source: Index of Mass Timber Connections, Table 4

FIGURE 5-11: Wide angle view of CLT shear wall brackets installed prior to floor deck placement
Image: Jeff Morrow

Vertical Applications

The photos below show shear wall panels connected using plates along their vertical edges. Plate size, quantity, thickness, location and fastener type will vary based on the design requirements. The installer must ensure that plates are properly located and connected. Depending on aesthetic and fire protection requirements, the plates may need to be recessed into the panel or, if surface mounted, be considered in the subsequent installation of wall furring, insulation and finished drywall.

Concealed metal plates, either perforated or non-perforated, can also be used to connect wall panels in the transverse direction using power-driven nails or self-tapping screws. These connectors have aesthetic and fire performance advantages, but require precise profiling at the fabrication facility using CNC technology. Proprietary self-drilling screws able to penetrate through wood and steel can be used to reduce on-site alignment issues if plates are not pre-drilled.

Wall connections are similar to floor panel connections, namely butt joints with single or double splines, steel plate splices, half-lapped joints, proprietary connection systems and internal splines.

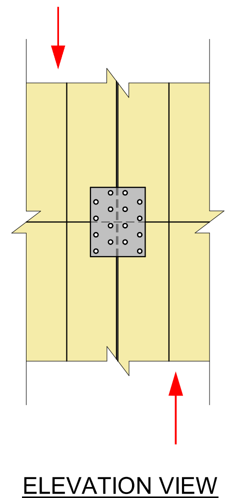


FIGURE 5-13: Vertical splice with steel plate
Source: Index of Mass Timber Connections, Table 14

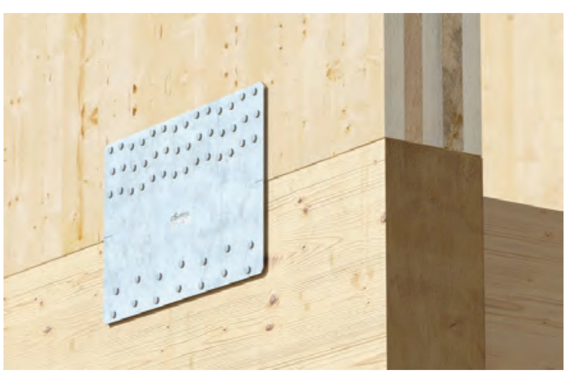


FIGURE 5-12: CLT shear wall brackets
Images: Jeff Morrow (top); Rothoblaas (bottom)

Internal splines are preferable for conditions that require a hidden connection or where one side of the panel is inaccessible during construction. However, this connection is susceptible to damage while placing panels, and the extra care required during installation can result in increased time and costs. It is advisable to have any internal splines routed during fabrication.

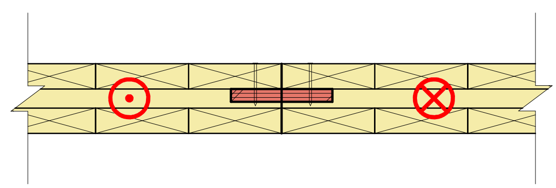


FIGURE 5-14: Internal spline wall connectors
Source: Index of Mass Timber Connections, Table 14

5.6.1.2 Panel to Beam

Examples of this type of connection include a roof or floor panel bearing on top of a wood beam, on a notch in the wood beam, on ledgers connected to the beam, and to steel angles connected to the side of the beam, all with partially-threaded screws. Continuity of the floor panel (Figure 5-15) will result in a more efficient structural design and typically be easier to install, but will decrease the clear height of the space below.

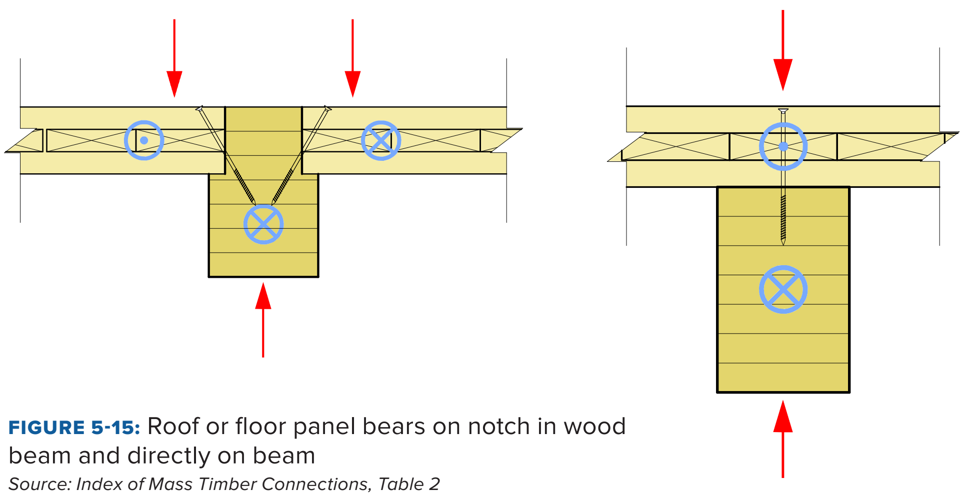


FIGURE 5-15: Roof or floor panel bears on notch in wood beam and directly on beam
Source: Index of Mass Timber Connections, Table 2

5.6.1.3 Panel to Column

Examples of panel-to-column connections include a roof or floor panel bearing on top of a wood column or on steel brackets connected to the side of a wood column with dowel-type fasteners. Columns above will not typically bear directly on the floor panel as it can result in crushing of the panel perpendicular to grain. See section 5.6.1.5 for examples of column-to-column connections.

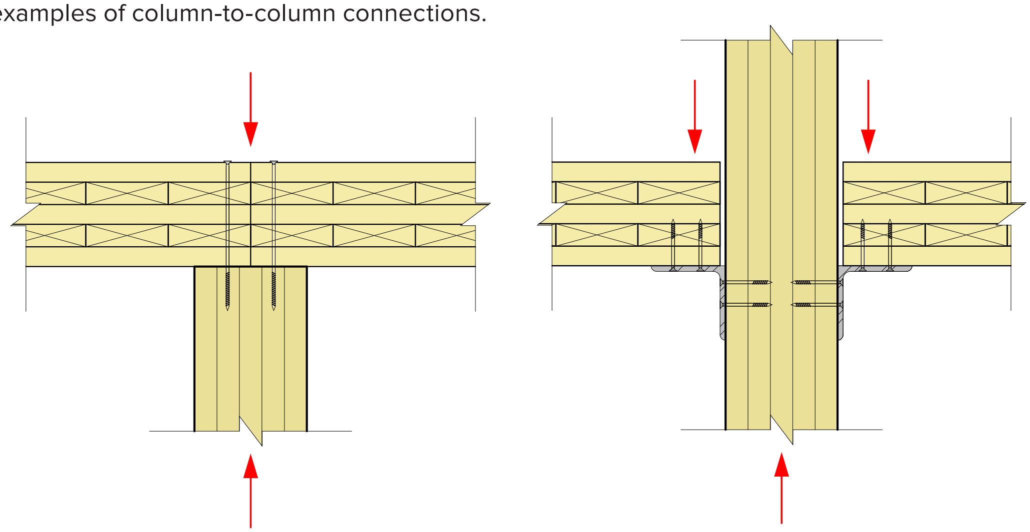


FIGURE 5-16: Roof or floor panel bears on top of a wood column and on steel brackets connected to the slide of a column
Source: Index of Mass Timber Connections, Table 3

5.6.1.4 Beam to Column, Beam or Girder

The same connections can generally be used to connect beams to columns, beams or girders. There are many options to choose from, also ranging from simple to complex. Beams can bear on the top of the other mass elements, into notches, on custom-fabricated steel column collars, connectors, plates or standoffs, and more. Connection can be made with screws or dowel-type fasteners, via knife plates, etc.; however, bearing connections generally allow for much greater capacity than dowel-type connections, and require less labor and materials.

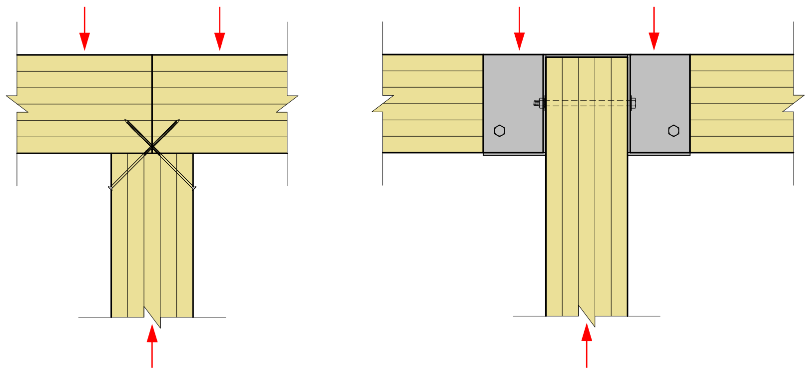


FIGURE 5-17: Beam bears on column (left), multiple beams bear on combined bearing plate and beam hanger (right)
Source: Index of Mass Timber Connections, Table 9

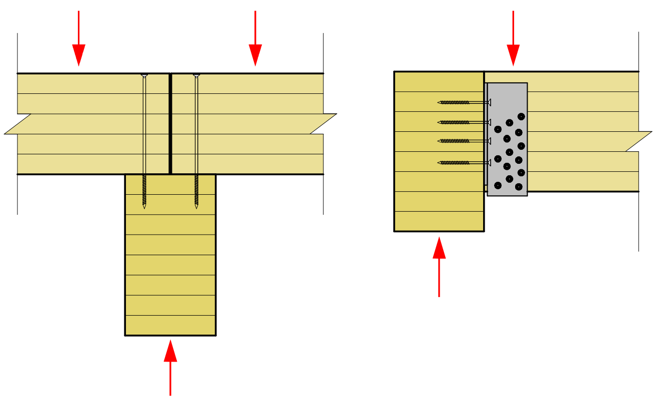


FIGURE 5-18: Beam bears on girder (left) and beam connected to girder with proprietary exposed hanger (right)
Source: Index of Mass Timber Connections, Table 8

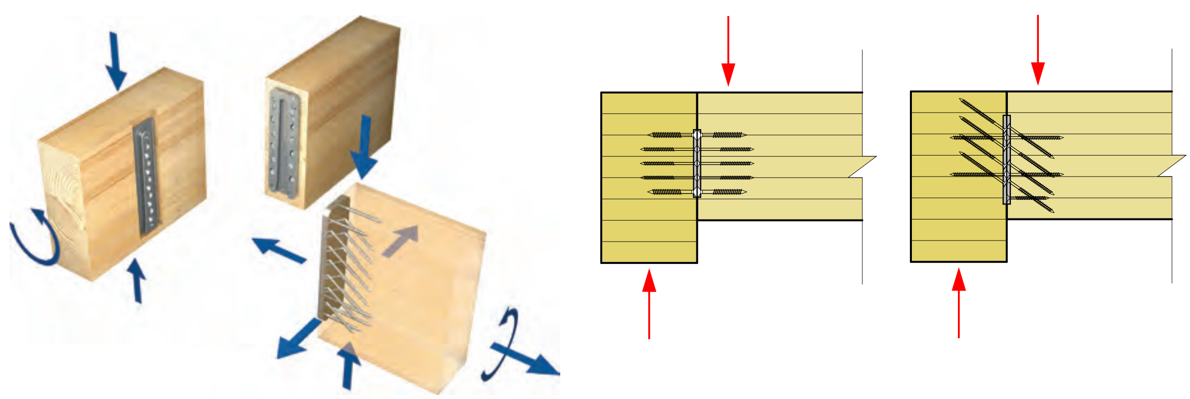


FIGURE 5-19: Examples of concealed connectors
Images: SHERPA Connection Systems (left); Index of Mass Timber Connections, Table 8 (right)

FIGURE 5-20: Beam-to-beam-to-column corner connection
Image: Ricky McLain, WoodWorks

A more complex configuration includes knife plates with glulam beams, columns and cross braces. In this connection, steel pins are placed into the beam and through the plates and the exposed “pin” holes concealed by wooden plugs (Figure 5-21).

FIGURE 5-21: Concealed metal plate connections
Image: Jeff Morrow

Ideally, pilot holes are pre-drilled on one side of the beam to guide field drill placement for the steel pins through the steel plates. While attractive, robust and sometimes necessary, these connections are also time consuming to complete in the field. The pin connection requires field drilling through the plates into one side of the beam without drilling through the other side. If holes are drilled too far, they must be filled with wooden dowel plugs. Drilling through the plates consumes a lot of drill bits as the adjacent wood stores the heat created by drilling thus accelerating wear and tear—and cutting oil isn’t advisable as it can stain the wood. It can take a lot of time to fit the pieces, drill through the steel plates, insert steel pins, insert wooden dowel plugs and cut plugs flush to the timber surface.

5.6.1.5 Column to Column

Column-to-column connections can be complex and often include custom solutions. In Figure 5-22, for example, the upper column and panels bear on a standoff, and the standoff bears on the column below. The standoff consists of an upper bearing plate welded to an alignment guide and a lower bearing plate welded to another standoff. The alignment guide nests inside the lower standoff. Positive connection of bearing plates is made to columns with epoxied threaded rods or partially-threaded screws. Positive connection of the panel to bearing plate is made with welded threaded rods.

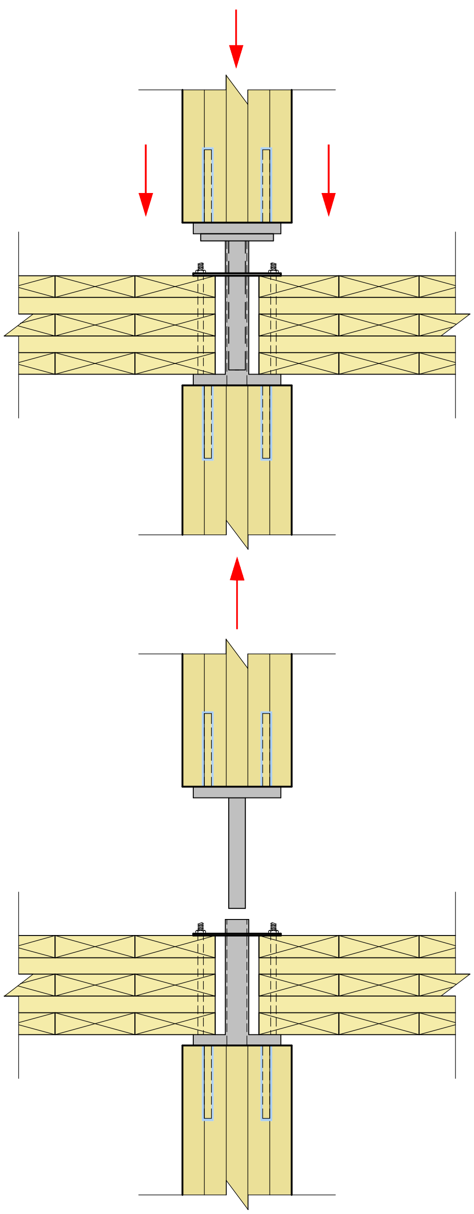


FIGURE 5-22: Upper column and panel bear on a standoff, which bears on the column below
Source: Index of Mass Timber Connections, Table 3

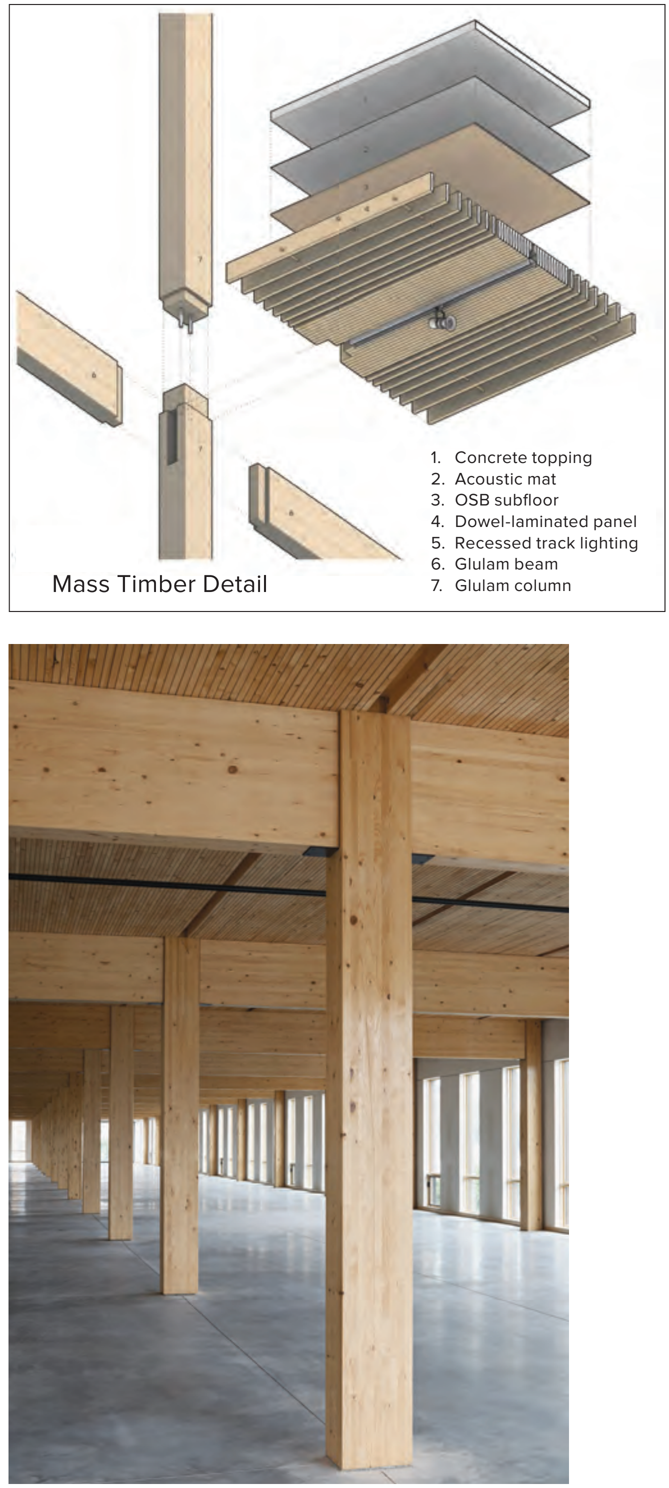


FIGURE 5-23: Column-to-column connection at 111 East Grand in Des Moines, IA
Images: Neuman Monson Architects; photo Mike Sinclair

5.6.2 Mass Timber to Light Wood Framing

This type of hybrid allows the designer to incorporate the beauty of mass timber and cost effectiveness of light wood-frame construction. In a platform-frame system, when mass timber floor and roof panels are combined with light-frame bearing walls, the walls can also be utilized to run MEP services. Note that this type of hybrid applies to Type III or V construction and would not be permitted in Types IV-A, IV-B or IV-C projects under the 2021 IBC.

FIGURE 5-24: CLT and glulam construction with fire retardant-treated light-frame infill walls at Carbon12

Image: Scott Breneman, WoodWorks

An emerging trend in mid-rise multi-family applications is to use mass timber walls (typically CLT) for stair and elevator shafts in otherwise light-frame buildings. In this scenario, the mass timber shaft walls are balloon-framed and the adjacent floors are platform-framed.

In balloon-frame construction, wall panels are continuous and the floor system is attached to the side of the wall. Sawn lumber, glulam, SCL or wood I-joists can be attached to CLT walls using traditional metal hangers commonly used in light-frame and heavy timber post-and-beam construction (Figure 5-25). Alternatively, the joists could be supported by engineered wood ledgers or metal brackets attached to the walls. Self-tapping screws and traditional fasteners would be used to attach the hardware to the wall.

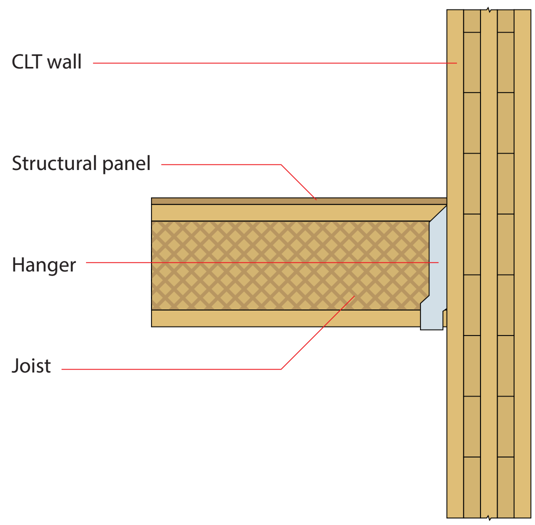


FIGURE 5-25: CLT wall with I-joist

Source: Adapted from TRADA 2009

In the project shown in Figure 5-26, CLT shaft walls were set after two floors of light wood-frame walls and floors were erected. In this type of installation, the GC/CM should coordinate a detailed safety plan, clear areas under the panel flight path, and ensure that workers not involved in the installation are cleared from the area. In other applications, the CLT shaft walls would be installed prior to the light wood framing.

FIGURE 5-26: CLT elevator shaft walls flying into place in light-frame hybrid
Image: Avesta Housing

5.6.3 Mass Timber to Steel

Steel and mass timber elements are often used together to achieve longer spans with fewer columns, accommodate heavy loads or as an aesthetic choice. Examples include incorporating both steel and mass timber beams, steel beams with mass timber columns, walls or floor/roof panels, and open-web steel joists with mass timber walls.

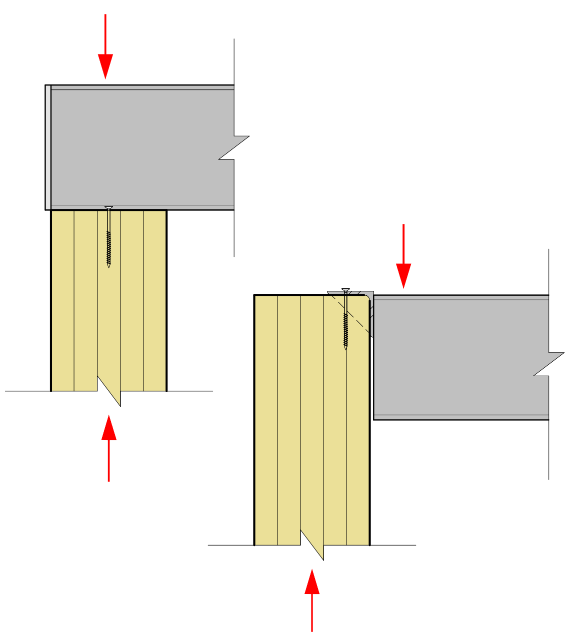


FIGURE 5-27: Steel beams bearing on top of wood column
Source: Index of Mass Timber Connections, Table 13

FIGURE 5-28: Steel beams bearing on timber columns
Images: Alex Schreyer

FIGURE 5-29: Roof with open-web steel joists supported by CLT walls
Images: Moses Structural Engineers, Inc.

5.6.4 Mass Timber to Concrete

It is common for mass timber buildings to include concrete foundations, walls and/or columns. In all cases, connections must prevent the wood and concrete elements from touching unless the wood is pressure treated. Concrete is a source of moisture and can damage mass timber if the materials are in direct contact and pressure-treated wood isn't used.

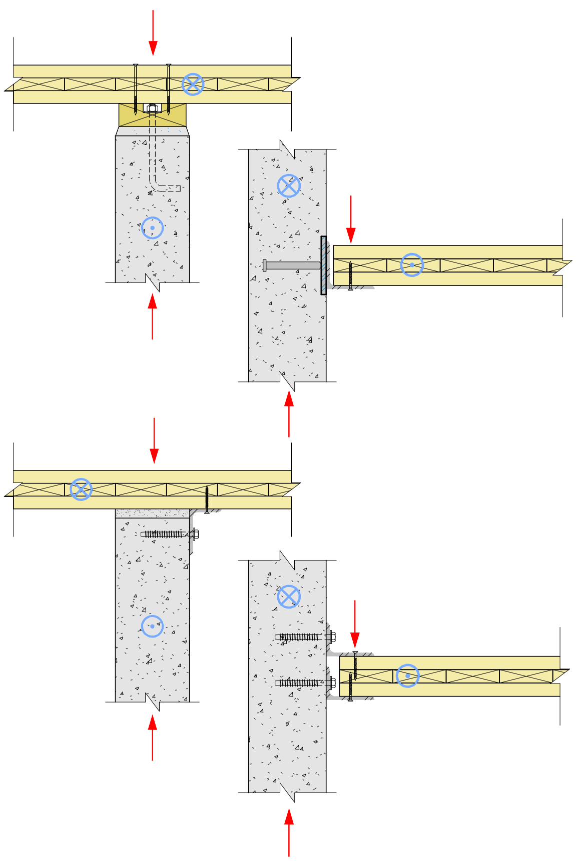


FIGURE 5-30: Panel-to-wall connections
Source: Index of Mass Timber Connections, Table 5

5.6.4.1 Panel or Beam to Concrete or Masonry Wall

In this type of connection, the mass timber panel can bear on top of the concrete or masonry wall, on a bracket or ledger, or on a bracket with a collector plate.

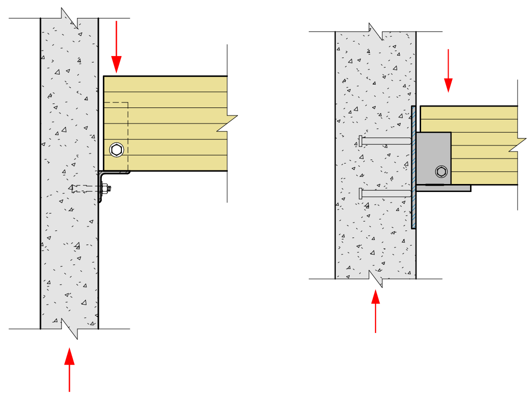


FIGURE 5-31: Example beam-to-concrete or masonry wall connection using steel bucket or angle with knife plate
Source: Index of Mass Timber Connections, Table 11

FIGURE 5-32: Note the gap between the mass timber and concrete
Image: Ricky McLain, WoodWorks

5.6.4.2 Column to Foundation

Mass timber columns can be attached to foundations in numerous ways. In Figure 5-33, the timber column bears on custom steel connections consisting of a knife and bearing plate or side and bearing plates. The side plates are positively connected to the column with dowel-type fasteners. The bearing plate is connected to the concrete with post-installed anchors. Grout is provided below the bearing plate for elevation control and tolerances.

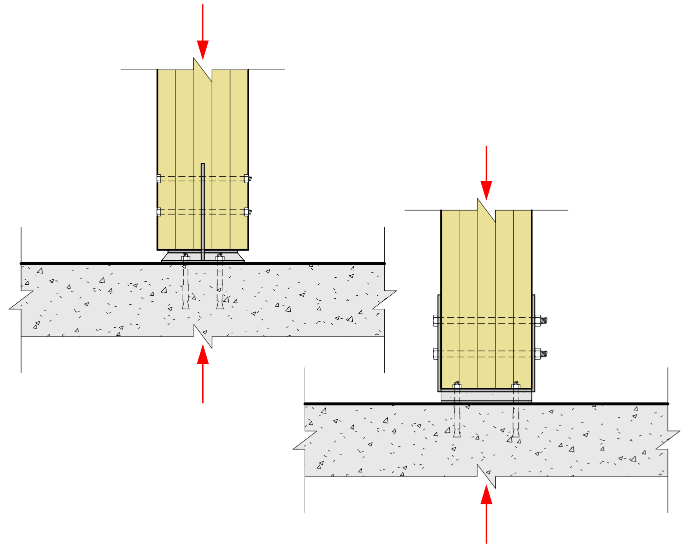


FIGURE 5-33: Mass timber column base connected to concrete
Source: Index of Mass Timber Connections, Table 15

5.6.4.3 Wall to Foundation

If the design includes mass timber wall panels, they will typically bear on a pressure-treated sill plate and be positively connected to the concrete using a side plate. The plate and panel connection can be made with toenails and the concrete connection with cast-in or post-installed anchor bolts. In the second detail in Figure 5-34, the side plate is positively connected to the panel with partially-threaded screws and to the concrete with post-installed anchors. Grout is provided below the plate for elevation control. Both of these connections could be installed without grout, but the connection wouldn't be able to accommodate variations in the top-of-concrete elevation, even within the range of appropriate concrete tolerances.

The side plate connection pictured below can also be connected without sill plates. However, this increases the risk of moisture intrusion and moisture would then have to be mitigated by other means. Several proprietary options exist for panel-to-concrete connections.

One option is a prefabricated panel connector (bucket) shown in Figure 5-35. The panel is positively connected to the bucket using partially-threaded screws and the bucket is positively connected to concrete using post-installed anchors. Grout is provided below the bucket for elevation and tolerance control.

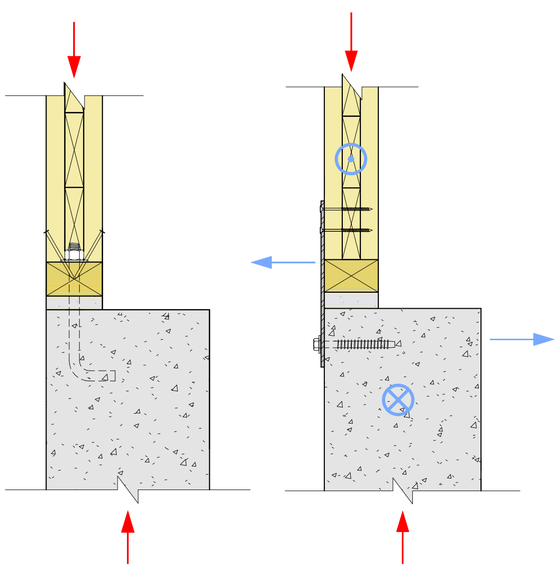


FIGURE 5-34: Typical panel to base with sill plate connections
Source: Index of Mass Timber Connections, Table 16

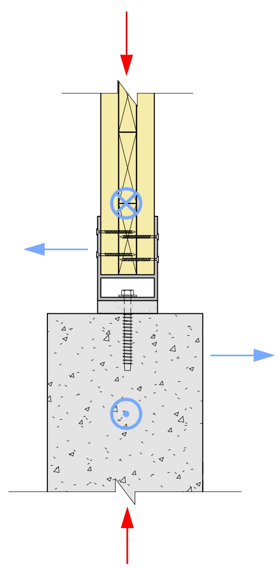


FIGURE 5-35: Panel bears on intermittent buckets
Source: Index of Mass Timber Connections, Table 16

5.6.5 Fasteners

Many connections in mass timber construction are connected using dowel-type fasteners, including bolts, screws, nails and pins. The required fastener will depend on the connection geometry and loading conditions, and the contractor, architect and fabricator will all have input. For many connections, especially those distributed over long joints, capacity can be increased or decreased simply by adjusting the size and spacing of fasteners.

It is important to ensure that fasteners are not loaded in withdrawal from the end grain of members as this eliminates or greatly reduces load capacity. This can be challenging on the edges of CLT panels where every other ply presents end grain and there are tight constraints due to edge distance requirements.

5.6.5.1 Screw and Nails

Screws are the most common fastener used in mass timber connections. However, where nails work instead of screws—especially nail-gun compatible nails—they are easier and less expensive to install.

Where screws are used, they can be either lag or proprietary screws, and many fabricators have preferred screw manufacturers. Proprietary screws are specified by the manufacturer and are typically self-tapping. Screw are generally 1/4-in. diameter and greater and come in a wide range of lengths. Smaller-diameter screws are preferred because they are easier to work with and have smaller edge distance and spacing requirements. It may also be possible to use smaller edge distances and spacing when screw holes are pre-drilled, but this can add expense.

There are two primary screw types to choose from: partially-threaded and fully-threaded. Partially-threaded screws are more common in mass timber construction and have a smooth shaft between the screw head and threads, whereas fully-threaded screws have threads along their entire length.

- Partially-threaded screws are used for fastening two members to each other and work to pull the members together. Ideally, the threads will be fully embedded in the main member.

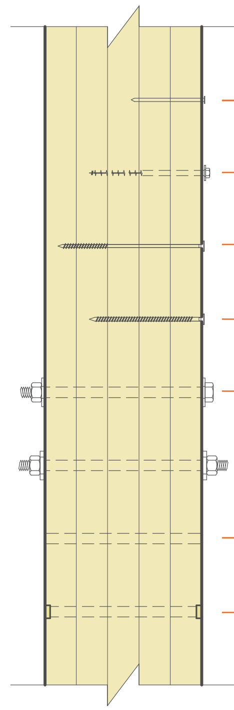


FIGURE 5-36: Fastener types
Source: KL&A Engineers & Builders

- Fully-threaded screws are used where thread withdrawal capacity is required either on both sides of a connection joint or a possible failure plane within a single member. Fully-threaded screws do not pull members together and improper installation can create a gap.

In some cases, diagonally-oriented screws are desired for a connection. In these applications, it is important to ensure accurate installation so the screw does not penetrate the opposite surface of the member, where it can impact the aesthetics.

5.6.5.2 Anchors to Concrete

When attaching to concrete or masonry, a connection can be achieved with either embedded or post-installed anchors. Location, geometry and contractor preference will drive which connection type is most appropriate. The design of such attachments should consider minimum edge distances and spacing requirements as specified by the supplier, the American Concrete Institute (ACI) ACI-318 Building Code Requirements for Structural Concrete and/or The Masonry Society (TMS 402) Building Code Requirements for Masonry Structures. Embedded anchors are capable of greater capacities, but it is often difficult to ensure correct placement in concrete. Post-installed anchors generally have more placement flexibility but can be difficult to install in areas of congested reinforcement. ACI requires adhesive anchors to be installed in concrete that is at least 21 days old.

Types of anchors include:

Cast-in-place concrete anchors are commonly used to connect a concrete foundation to structural and non-structural elements. Typically bolts but sometimes plates, these anchors transfer shear and tension loads from the structure to foundation.

Mechanical concrete anchors are installed after placement of concrete or masonry. This lessens the chance they'll be put in the wrong spot or damaged. Both the anchors and installation method must be approved by the EOR, and holes drilled for anchor installation must be in compliance with OHSA 1926.1153 – Protection from respirable silica hazards.

Wedge anchors are used to permanently anchor materials to masonry or concrete. Anchors are inserted in pre-drilled holes the same size as the nominal diameter of the anchors. To use, assemble the anchor so the top of the nut is flush with the top of the anchor. Place the anchor in the fixture, and drive it into the hole until the washer and nut are tight with the fixture. Tighten to the required torque.

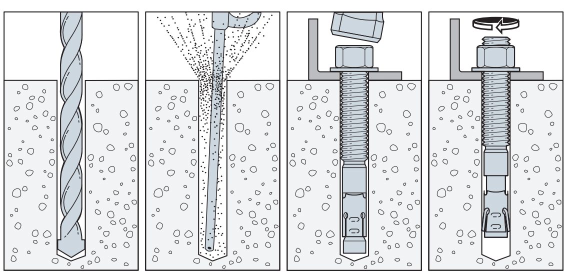


FIGURE 5-37: Installation sequence for wedge anchors
Source: Simpson Strong-Tie

Sleeve anchors are rated for heavy loads in masonry and concrete. They come with a pre-installed screw or threaded stud that expands the anchor once inside the hole, which needs to be pre-drilled the same size as the anchor diameter. Sleeve anchors are also known as acorn nut sleeve anchors, flat head sleeve anchors, hex nut sleeve anchors, round head sleeve anchors, one-step anchors and bolt anchors.

Screw anchors attach all types of components to masonry and concrete. Various designs exist for different conditions, including cracked and uncracked concrete.

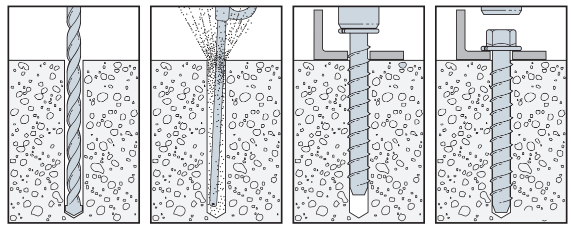


FIGURE 5-38: Installation sequence for heavy duty screw anchors
Source: Simpson Strong-Tie

Hammer drive anchors can be used in concrete, masonry, block and stone, and are best suited for light-duty fastening. The required hole diameter is equal to the anchor diameter, and a pin is used to expand the anchor when it is in position.

Adhesive chemical anchors are installed in hardened concrete using holes drilled through the wood and into the concrete. The concrete holes are filled with adhesive material and an anchor (rod, stud or rebar) is inserted in the hole. After the adhesive has cured, the anchor can be used. The installer must adhere to the EOR's design and follow the chemical anchor manufacturer's installation instructions. The GC/CM should make verification part of their quality control process.

Anchors appropriate for use in mass timber are available from a variety of manufacturers.

5.6.6 Welded Connections

Welded connections can be used to attach mass timber to steel via hangers and cleats. This type of connection can also be used to modify already installed steel and timber hybrids by welding a plate to a plate, column shoe to a beam, or plate washer to a base plate. Use of welded connections should be avoided or limited as much as possible to mitigate "hot work" fire risks on site.

5.6.7 Tie-Down Rod Systems

When a tie-down rod system is used in conjunction with a mass timber superstructure, considerable coordination needs to occur between the interface of the vertical rod system, foundation and mass timber structure. When rods are installed adjacent to CLT walls, wall panels may require vertical recesses to access the rod couplers. Factory-drilled holes in the deck reduce the need for on-site layout and drilling, which can be important if the locations are hard to access with a cutting or coring device. However, installing deck panels with pre-drilled holes for tie-downs requires extra diligence for field installers to ensure panels are in the right position and not turned 180 degrees, which can easily occur when setting multiple panels of the same size and shape. Pre-drilled holes in deck panels can also introduce opportunities for rainfall penetration. The decision of whether to pre-drill holes should be based on panel layout configuration, moisture protection requirements and the degree of exposed floor panels on the project.

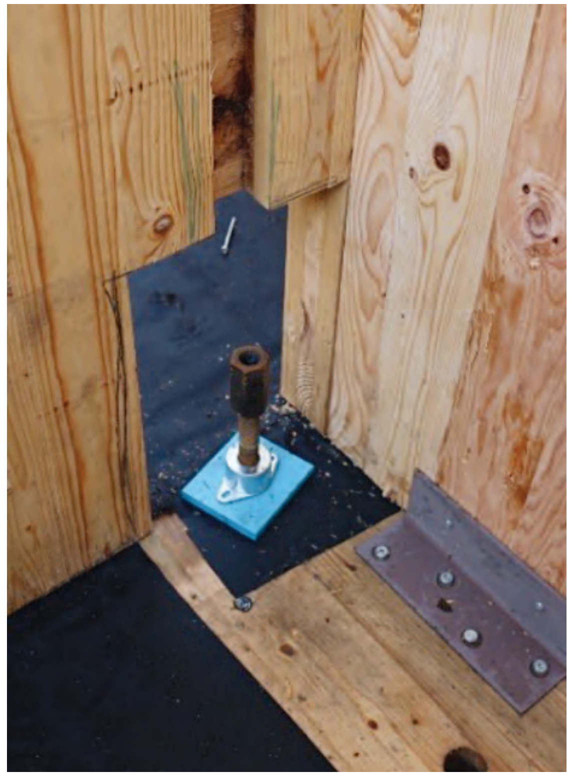


FIGURE 5-39: Tie-down rod interface at CLT floor and walls
Image: Jeff Morrow

FIGURE 5-40: Hold-down rod recessed into routed slot of CLT wall
Image: Jeff Morrow

5.7 Acoustic Assemblies

Components are typically added to mass timber assemblies to improve their acoustic performance. In floor/ceiling applications, owners and design teams often want to expose the ceiling side of mass timber panels for aesthetic reasons, which means acoustical components must be installed on top of the assembly. Two of the most common acoustical components added to the top of mass timber floor panels are a poured concrete or gypsum-based topping layer, usually in the range of 1-3 in. thick, and underlayments and mats placed between the mass timber panel and concrete or gypsum-based topping. The type and thickness of material varies by product line and manufacturer, but the purpose is the same: to break the direct connection between finishes on one side of the assembly and the other.

Acoustical floor underlayments

Photo: AcoustiTECH

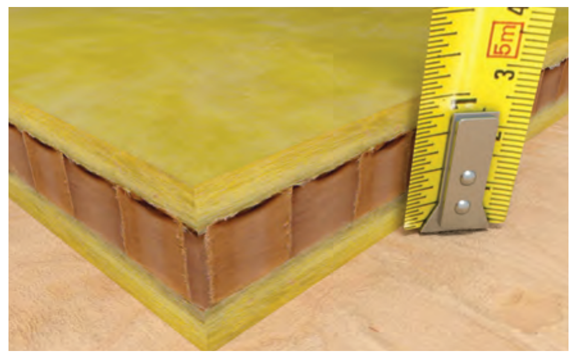


Photo: Kinetics Noise Control, Inc.

Photo: Maxxon Corporation

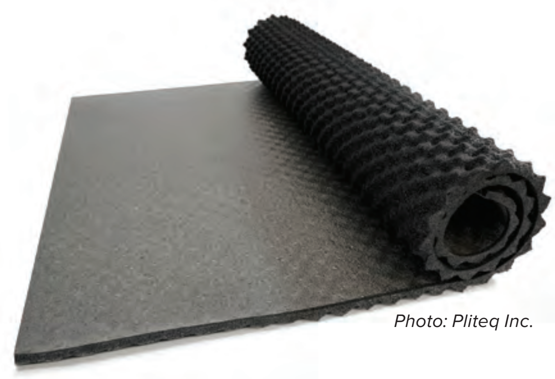


Photo: Pliteq Inc.

FIGURE 5-41: Acoustic floor underlayments
Source: Acoustics and Mass Timber: Room-to-Room Noise Control, WoodWorks

A common mass timber floor/ceiling assembly includes the following (from top to bottom):

- Finish flooring (if applicable)
- Concrete/gypsum-based topping (usually 1-3 in. thick)
- Acoustical mat/underlayment
- Mass timber panel

The mass timber installer is responsible for installing the panel and sometimes the topping (as determined in the contract documents), and work must be coordinated with the flooring subcontractor and GC/CM.

Where higher acoustical ratings are required, installing ceiling gypsum board, either directly attached to the underside of the mass timber panel or hung from resilient channels or similar resilient clip systems, is a viable approach.

Mass timber panels can also be used for interior and exterior walls, both bearing and non-bearing. For interior walls, the need to conceal services such as electrical and plumbing is an added consideration. Approaches include building a chase wall in front of the mass timber wall or installing gypsum wallboard on resilient channels that are attached to the mass timber wall.

For more information on acoustic assemblies for mass timber buildings, see the WoodWorks paper, *Acoustics and Mass Timber: Room-to-Room Noise Control,*[33] and *Inventory of Mass Timber Acoustic Assemblies.*[34]

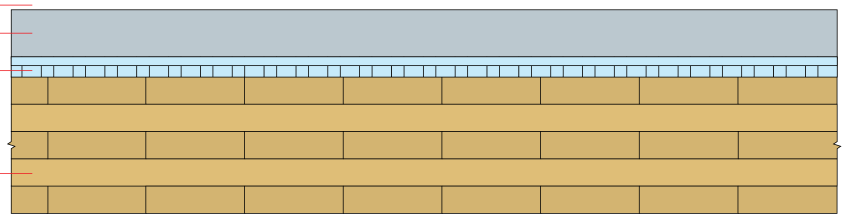


FIGURE 5-42: Typical mass timber floor assembly, section view
Source: WoodWorks

5.8 Installation

5.8.1 Installing Columns

Select column to install

- Select the correct piece mark following the requirements of the site-specific safety plan and engineered bracing plan, referring to the tagging, date of fabrication and direction mark. If the member will remain exposed, make sure the directional mark is in an inconspicuous location.
- Establish clear communication with the crane operator and crew setting the columns.

Set the column

- Remove column protection material as needed.
- Set column to the correct elevation and location.
- Connect the column base to its support and plumb.

Install column braces

- Use adjustable steel shoring.
- Refer to the drawing showing the correct size, location and connections required. (Drawings and bracing design require approval by the engineer.)
- Attach bottom of brace to slab, footing, deadman, helical anchor or other mass timber element.
- Attach top of brace to column with a fastener specified by the brace manufacturer.
- Remove the brace when approved by the EOR.
- For exposed columns, repair holes at the bracing connection point.

Plumb the column

- Use the primary control surface or centerline of column.
- Measure using actual size of the column.

- Check exterior vs. interior column plumb tolerances.
- Equipment to plumb panels includes transit, total station unit, laser, level and plumb bob.
- After columns are plumb, tighten anchor bolts and/or connection bolts, or weld to embed.
- The crane/rigging should be disconnected from the column only after all connections are fully complete and confirmed to be plumb, square and level.

FIGURE 5-43: Setting beams at the John W. Olver Design Building, UMass Amherst
Image: Alex Schreyer

5.8.2 Installing Beams

Select beam to install

- Select the correct beam with correct inconspicuous marking. Mark at N/S-E/W ends.
- Verify that the piece mark has legible tagging with date of manufacture, and all holes or attached elements are properly located (end or top and bottom).
- If required, verify beam cut dimension and location.

Set the beam

- Remove beam protection material as required for connections.
- Set the beam and make the connection to supporting material:
  - Mass timber panel or column
  - Steel column or beam
  - Concrete steel embeds
  - Bracing in accordance with bracing plan

Making connections

Bolted and screwed connections:

- As connection work is completed, ensure all correct fasteners are installed per the installation drawings and fastener manufacturer instructions. As installation work proceeds, connect the correct quantity of screws and/or bolts to ensure stability of the building. Do not release rigging until fasteners are in place. If necessary, consult the bracing engineer or EOR for quantity of fasteners required.
- If fasteners will be concealed, confirm all fasteners are installed prior to setting the beam.
- Pre-drill all holes prior to lifting the beam. While helpful to have holes drilled by the fabricator where possible, it may be preferable to drill smaller holes in the field laydown area.
- Use a reamer to make small modifications to bolted connections.
- To achieve proper connection alignment, use jigs or templates for field drilling.
- Use sharp tools when field drilling/cutting to prevent splintering.
- Do not over-torque screws. This will damage the wood fiber and reduce screw capacity.

Welded connections:

Note: Welded connections should be eliminated or minimized as much as possible as a best practice to avoid or minimize the need for hot work.

- Ensure the weld is the proper size and length and made using correct welding material.
- Use certified welding operators.
- Protect the surrounding structure with fire blankets.
- Maintain a fire watch during welding operations and after.

Drilled anchors:

- Use correct size bit to make holes.
- Drill holes to the correct depth.
- Maintain OSHA silica protection requirements.
- Take care to avoid MEP locations and other openings.

5.8.3 Installing Panels

Select panel to install

- Select the correct piece mark following the requirements of the site-specific safety plan and engineered bracing plan, referring to legible tagging, date of fabrication and direction mark. Put the direction mark in an inconspicuous location.
- Establish clear communication with the crane operator and crew setting the panels.
- Review plans for directional joints (i.e., half-laps) to avoid delays.

Set the panel

- Remove panel protection material.
- Double check panel orientation for installation. Use N/S-E/W and plan north vs. true north direction for setting the panel.
- Ensure that openings are correctly located.
- Complete panel layout prior to setting panels and make adjustments for building tolerances as required.
- Set panels per latest revised installation drawings, including any gap(s) required.
- Adjust panel location to accommodate width change due to moisture.

FIGURE 5-44: Setting floor panels at The Canyons in Portland, OR
Image: Kaiser+Path, photo Marcus Kauffman, Oregon Dept. of Forestry

FIGURE 5-45: Tight fit between panels is ensured using special installation devices, though it's important to maintain required gaps
Images: Rothoblaas

Making connections

Screwed connections:

- As connection work is completed, ensure that all correct fasteners are installed per the installation drawings. As installation work proceeds, connect the correct quantity of screws to ensure stability of the building. Do not release rigging until fasteners are in place. If necessary, consult the bracing engineer or EOR for quantity of fasteners required.
- To achieve proper connection alignment, use jigs or templates for field drilling.
- Use sharp tools when field drilling/cutting to prevent splintering.
- Do not over-torque screws. This will damage the wood fiber and reduce screw capacity.

Plumb the panel

- Use shores to plumb panels.
- Measure wall for plumbness:
  - Use the primary control surface or centerline of panel
    - Panel face inside of building or at building exterior
    - Centerline of panel
  - Measure using actual width of panel at top and bottom
- Check allowable tolerances:
  - Building exterior
  - Elevator shaft, shear wall and stairwell
- Equipment to plumb panels includes transit, total station unit, laser, level and plumb bob.

FIGURE 5-46: Three and a half-story stair shaft walls required engineer approval of temporary bracing and additional foundations outside the building footprint.
Image: Jeff Morrow

5.8.4 Multi-Story Columns and Wall Panels

As a timber installer, there may be a desire to reduce the number of crane picks by utilizing taller multi-story columns or wall panels in a more balloon-style framing application. However, working with taller elements introduces other challenges.

- In a post-and-beam application, the tight tolerances of mass timber make it difficult to drop in floor panels through the vertical web of multi-story columns. It is challenging for a crane to lower a panel in perfectly and for the installer managing the tag lines.
- In a platform CLT load-bearing wall application, three and four-story shaft walls can also pose challenges. Bracing can bow the walls, making it difficult to keep them truly plumb. The bracing and associated foundations for such large walls also need to be engineered and the quantity and size of the bracing may interfere with framing the adjacent mass timber elements.
- Large bracing for multi-story walls must often be removed and reinstalled when installing adjoining framing elements.

5.8.5 Timber-Concrete Composite Floor Systems

Timber-concrete-composite (TCC) floor systems include a wood layer connected to a concrete topping with shear connectors. The strength of the connection allows the materials to work together and the system as a whole is able to carry much greater structural loads. This connection is what differentiates a TCC system from an acoustic assembly that simply includes a concrete topping. However, like an acoustic assembly, the added mass of a TCC system also improves acoustic performance.

Elements of a TCC system include:

- Wood element – CLT, SCL, glulam, other engineered wood product or solid wood
- Shear connectors – Fasteners such as nails and screws, connectors such as embedded plates and glue, or a combination
- Concrete topping

Shear connectors can be installed by the manufacturer or on site by the mass timber installer. Both have advantages and this decision should be made collaboratively by the installer, manufacturer and design team. While the controlled environment of a manufacturing facility lends itself to accurate and fast installation, panels with installed shear connectors can't be laid flat on top of each other, which creates transportation considerations. Whether connectors are factory of field-installed, work safety must also be considered—connectors can be sharp and pose a lifting and tripping hazard.

Coordination is important to avoid impinging on other work being done on site, and because other trades may be embedding elements such as electrical into the concrete topping. TCC systems can also require shoring to support the added weight of the concrete while it cures, which can be cumbersome. Unless well-coordinated, this can negate some of the speed benefit of mass timber in the sense that follow-on trades can't begin their work as quickly. Pouring the concrete topping is typically one of the later activities on a project. It may be done as the crew completes one floor and moves to the next, or it may be that all the timber is installed prior to pouring toppings on any floor.

TCC systems may also have inspection and testing requirements. Inspectors would be looking for things like appropriate shear connector size, spacing, penetration into the timber, angle of connector install (relative to top of mass timber panel) and extension above the timber. Load testing for new, unique or innovative shear connectors may be required to validate design assumptions.

FIGURE 5-47: (Top) Panels with pre-installed shear connectors being installed and subsequent shoring on the TCC system.
Images: Alex Schreyer

5.8.6 Installing Stairs

Responsibilities of the stair installer (wood or steel stairs)

- Schedule and coordinate installation with the mass timber installer.
- Coordinate stair connections with the existing structure.
- Be familiar with stair requirements for building access.

Guardrails and handrails required during construction

- Even if the mass timber installer furnishes and/or installs the guard and handrails, the GC/CM must approve and accept the rails.
- Before commencing work, determine:
  - Furnishing and installation responsibility
  - Whether temporary or permanent rails will be used
  - Who is responsible for maintenance and protection of the rails during construction and subsequent removal

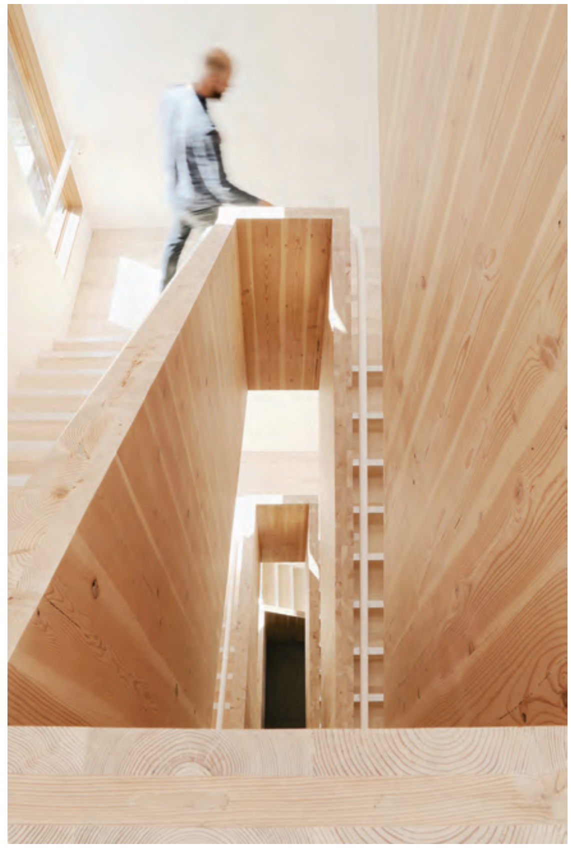


FIGURE 5-48: Example of egress stair
Image: Jeff Morrow

FIGURE 5-49: Examples of feature stairs at Albina Yard (top) and the Earth Sciences Building at the University of British Columbia
Images: LEVER Architecture (top); Jeff Morrow

5.8.7 Bracing and Shoring

During construction it is necessary to brace wall panels and beams as they are installed to account for wind loads, seismic considerations, incomplete shear structures and other jobsite risks. Among the best practices:

- Only use specified braces per an approved bracing plan. This may include adjustable steel shoring or wood braces.
- Do not use field-modified braces (due to potential reduced capacity) unless approved by the EOR.
- Use drawings showing the correct size, location and connections required for braces. Both the bracing design and drawings should be approved by the EOR.
- Coordinate panel brace locations with architectural requirements.
- Attach the bottom of braces to a slab, footing, deadman or helical anchor.
- Attach the top of braces to wall panels with lag bolts, nails or screws.
  - Ensure braces are properly attached and panels are plumb, level and true before detaching rigging.
  - Remove braces only when approved by the EOR.
  - For exposed panels, repair holes at the bracing connection point.

FIGURE 5-51: Coordinate placement of braces to avoid conflict with other work/trades
Images: Jason Reynolds, WoodWorks

FIGURE 5-50: Don't remove bracing without approval from the EOR
Image: Jeff Peters, WoodWorks

5.9 Finish Considerations

The ability to leave wood structural elements exposed as an architectural feature is a well-known benefit of mass timber, but it creates additional requirements to protect the wood's appearance. Protecting mass timber elements from moisture is important both for aesthetics and performance and is covered in Chapter 4. This section covers other protection and remedial measures that may be undertaken to meet the expectations of the architect, client and future tenants.

On a mass timber construction site, maintaining the appearance of timber that will be visible in the final building is everyone's job. The GC/CM must clearly understand which elements will be left exposed and communicate that information to the subs.

FIGURE 5-52: Column protection and acoustic membrane before concrete topping is poured
Image: Anthony Harvey, WoodWorks

5.9.1 Protection During Construction

To avoid damage to the material before, during and after installation, the GC/CM and installer must consider and plan for the potential risks. For example:

- Water, mud, rust and other substances can all stain mass timber. Even hot-dipped galvanized nails can bleed metal stain as the coating is damaged when they are driven into the wood.
- Unprotected elements may be vulnerable to dings and dents.
- UV discoloration will occur to any wood exposed to the sun. There will likely be differences under flags, banners or signs hung during installation, but UV discoloration does fade over time.

In addition to moisture management techniques covered in Chapter 4, best practices include:

- Adding another protective barrier such as foam encased in wood structural panels. A rule of thumb is that extra protection is generally less time consuming and costly than having to take corrective action when members that will be left exposed in the finished building are stained or damaged during construction.
- Removing metal shavings from holes when drilling metal plates connecting to mass timber elements. If shavings remain, they can rust and stain the wood.
- Making sure that any necessary metal grinding is done well away from the mass timber elements to avoid stains (and protect against fire).
- Wiping down connections between steel and wood in hybrid buildings immediately after installation. High-strength bolted connections need to be properly oiled to install correctly, but excess oil residue can seep into the adjoining mass timber material and cause stains. Any oil on the surface of the wood or steel adjacent to the wood should be wiped off.
- Painting utilities being installed on an exposed mass timber ceiling in loose pieces or assemblies on the ground and touching up after installation. In addition to protecting the wood, touch-ups on an elevated work platform should take less time than a full paint job in in an elevated area, especially if the ceiling doesn't have to be masked off.

5.9.2 Cleaning Mass Timber

Some stains can be removed using simple methods and some may require assistance from a company that specializes in this work. The decision on how to proceed should be made with the Architect of Record and/or owner.

Options for removing stains include sanding, cleaning solutions and dry ice blasting. Cleaning solutions such as hydrogen peroxide, wood bleach or oxalic acid may require experimentation to determine the correct concentration and length of application. Consultation with the supplier or installer is always advisable. Note that there may be aesthetic implications beyond the member being corrected—e.g., a wood column that is freshly sanded toward the end of construction may be a different color than one that has been exposed to UV for the duration of the job.

5.9.3 Applying Finishes

Finishes are often applied to exposed mass timber to maintain its appearance long term. Similar to prefabricated penetrations, shop-applied coatings are an option with many suppliers and can limit field work to minor touch-ups to repair dings and scrapes that occur during installation. However, some exposed applications will have multi-layer finishes that are applied in the field. For detailed instructions, refer to the design requirements and manufacturer's installation instructions.

Note that the heartwood of most softwood species contain tannins (which are water soluble) or pitches and resins (which are not water soluble) that can bleed through paint or stains, especially lighter colored shades. If painting or staining is specified, understanding the type of wood being used and paying special attention to exposed knots can avoid problems later. Proper surface preparation that leaves the wood dry and free of any dirt, oils or waxes will have a better final result.

6 Closeout & Turnover

As a mass timber project nears completion, it is incumbent on the installer to finalize all remaining activities to avoid unnecessary delays in occupancy—and associated costs—and facilitate timely payment to trades. The following list is not exhaustive, but rather intended to serve as a guide.

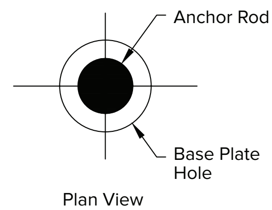
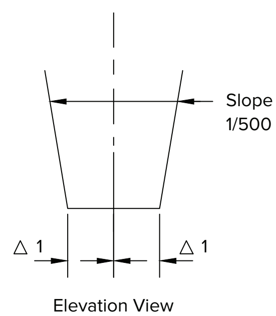
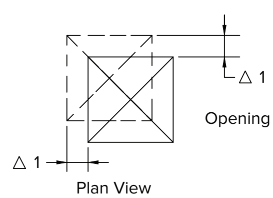
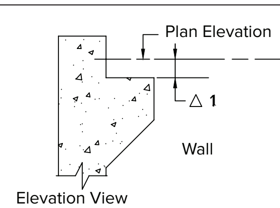
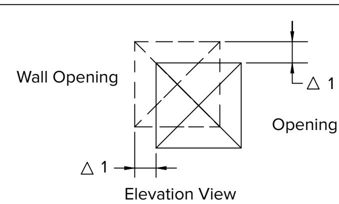
Punch list – The GC/CM will issue a preliminary punch list during installation and a final punch list once installation is complete. The mass timber installer undertakes the punch list work and the GC/CM signs off on completion. Final activities will include:

- **Post-inspection changes** – Any aspects of the project rejected by inspectors must be corrected. The inspector, engineer and/or architect will sign off on the corrected work, and the inspector will issue a revised report indicating that the work is now approved.
- **Site clean-up** – Remove any remaining braces and repair all bracing connection points in exposed wood elements. Remove excess material, fasteners and trash, as well as all equipment, tools and toolboxes.
- **Other contractually required closeout items**
  - Final lien waivers
  - Approved certified payrolls
  - Documentation required for green building certification (e.g., Living Building Challenge, LEED, Green Globes, etc.)
  - As-built drawings
  - Certificates of conformance
  - Acceptance and maintenance responsibility statement of installer-furnished items, including but not limited to safety equipment (temporary railings, etc.) and moisture control systems.

The contract will define which of the entities is required to complete the final building survey—e.g., the GC/CM survey crew or a third-party team hired by the GC/CM or building owner.

1 Appendix 1: Mass Timber Tolerances

APPENDIX 1: Industry Tolerance Standards for Mass Timber

Tolerance Condition	Construction	Allowable Tolerances		Standard Reference
Anchor Rod Holes in Base Plates	Steel Base Plate	Rod / Hole Diameter 3/4"Ø / 1-5/16"Ø 7/8"Ø / 1-9/16"Ø 1"Ø / 1-7/8"Ø 1-1/4"Ø / 2-1/8"Ø 1-1/2"Ø / 2-3/8"Ø 1-3/4"Ø / 2-7/8"Ø 2"Ø / 3-1/4"Ø 2-1/2"Ø / 3-3/4"Ø		AISC-360 (Recommended Sizes for Anchor Rod Holes)
Steel Column Location at Base	Steel Column	Δ1=+1/4"		AISC-360 (Recommended Sizes for Anchor Rod Holes)
Edge Location of All Openings Deviation from Plan	Slap Opening	Δ1=±1/2"		ACI-117-10
Vertical Deviation for Wall or Opening	Wall & Column	Δ1=±1"		ACI-117-10
Horizontal & Vertical Deviation for Wall Opening	Wall Opening	Δ1=±1/2"		ACI-117-10

2 Appendix 2: Sustainable Forestry

The following information is excerpted from the CEU, *How to Calculate the Wood Carbon Footprint of a Building,* written by Edie Sonne Hall, PhD, and published by Think Wood (www.thinkwood.com/education/calculate-wood-carbon-footprint).

FOREST CERTIFICATION

Forest certification assesses a landowner's forest management against a series of agreed standards related to water quality, biodiversity, wildlife and forests with exceptional conservation value. Wood is one of the few building materials that has third-party certification programs in place to demonstrate that products being sold have come from a responsibly managed resource. As of 2020, more than 600 million acres of forest in the United States and Canada were certified under one of the four internationally recognized programs used in North America.

About 47 percent of forests in Canada are certified and 19 percent in the United States, both above the global average of 11 percent. The four primary systems in North America, Sustainable Forestry Initiative (SFI), Forest Stewardship Council (FSC), Canadian Standards Association (CSA), and American Tree Farm System (ATFS), all have slightly different principles and procedures. SFI is a single-standard North American program. FSC is a global program with regional standards. CSA is the Canadian National Forest Management Standard, and ATFS is geared toward smaller U.S. landowners.

Given the cost of third-party verification, wide-scale certification is not feasible for the small family landowners that make up the largest percentage of land ownership in the United States (almost 290 million acres). U.S. federal timberlands are not certified, but this does not mean they are not being sustainably managed.

In 2007, the Pinchot Institute conducted a study of five national forests and found their management practices met many of the certification requirements in terms of forest planning, protection of threatened and endangered species, and others.

Another type of certification aimed at the mills, fiber sourcing certification, focuses on assurances that can be made in the supply chain. There are three major responsible fiber sourcing standards in North America (see sidebar on the following page). In addition, every U.S. state has developed best management practices (BMPs) guidelines for water quality and other environmental concerns such as soil erosion and regeneration. Some of these are codified into state forest practice regulation and others are voluntary. Water quality BMPs, whether regulatory, quasi-regulatory, or non-regulatory, are tracked in the United States and achieve above 90 percent compliance in all states. This is important because roughly 60 percent of drinking water is sourced from forests across the nation, up to 75 percent in the U.S. West.

THE FOREST SIDE OF THE EQUATION

Responsibly managing forests in a way that balances harvesting and replanting, and provides a sustainable source of wood products that continue to store carbon and offset the use of fossil fuels, can significantly reduce the amount of carbon in the atmosphere over the long term.

The U.S. Forest Service (USFS) keeps track of the volume and health of U.S. forests by measuring permanent plots scattered across the country through its Forest Inventory Analysis (FIA) program (www.fia.fs.fed.us). These measurements are rolled up into the national GHG inventory that is reported to the IPCC every year as part of the U.S. commitment under United Nations

Framework on Climate Change. In 2018, U.S. forests and harvested wood products were a net sink on the order of 663 million metric tons CO_2e, which offsets about 10 percent of the nation's GHG emissions.

The FIA program can also provide information about trends on different forest ownership and types, as well as impacts of growth, mortality, and harvest in different regions over time. For example, the amount of forest area has remained constant since about 1900, and U.S. forests have been net sequesterers since the 1950s. During this same period, harvests have remained stable or have increased in some cases, such as in the U.S. South.

Every 10 years, the USFS reports on the state of the U.S. forests as well as future projections through the Resources Planning Act mandate, established by the Forest and Rangeland Renewable Resources Planning Act of 1974. The most recent report found the following highlights:

- Forest and woodland area in the United States has plateaued at 823 million acres following decades of expansion. Forest land area alone occupies 766 million acres. Together, forest and woodlands comprise more than one-third of the U.S. landscape and contain 1 trillion cubic feet of wood volume—enough wood to fill the Great Pyramid of Giza 12,000 times.

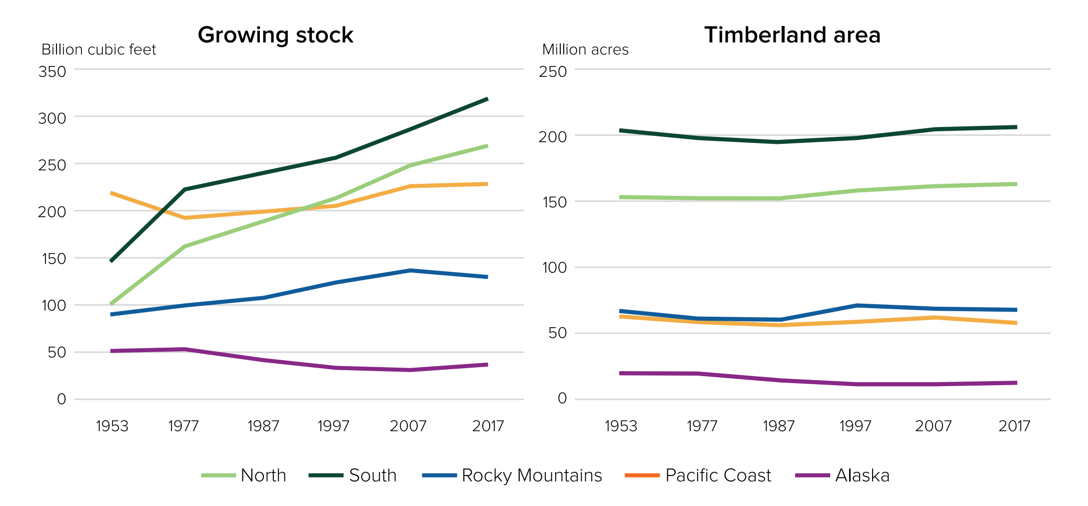
FIBER SOURCING STANDARDS IN NORTH AMERICA

PEFC Controlled Sources: In May 2013, PEFC published a revised PEFC Chain of Custody standard which allows organizations to handle fiber from non-PEFC certified forests and to sell it with a "PEFC Controlled Sources" claim. This claim demonstrates that a risk assessment was implemented to ensure that the fiber from these uncertified forests is legal and in compliance with relevant regulations. In addition, it avoids controversial sources and does not allow fiber to be sourced from genetically modified trees or from land converted to non-forest use.

FSC Controlled Wood: A company-level certification developed and published by the Forest Stewardship Council (FSC). This standard specifies material from acceptable uncertified sources that can be mixed with FSC-certified material in products that carry the "FSC Mix" label. This standard aims to ensure the avoidance of wood that is illegally harvested, harvested in violation of human rights, harvested in threatened forests with high conservation values, harvested in forests being converted to plantations or non-forest use, or wood from forests with genetically modified trees.

SFI Fiber Sourcing: A standard to certify manufacturers of wood products, which source fiber from a variety of sources, requiring them to show that the raw material in their supply chain comes from legal and responsible sources. The standard aims to avoid controversial sources by avoiding illegal logging and fiber sourced from areas without effective social laws. The fiber sourcing requirements also go further by including measures to broaden the practice of biodiversity, use forestry best management practices to protect water quality, provide training to foresters, engage in research, and outreach to landowners. This standard encourages the spread of responsible forestry practices such as conserving water quality, providing outreach to landowners, and using the services of trained forest management and harvesting professionals.

Source: greenblue.org/module-2-the-role-of-forest-certification



Forest Inventory (billion cubic feet) by region 1953-2017 as well as acres of timberland.

- Forest industry in the United States makes up 17 percent of global roundwood production, and the nation has the highest intensity of industrial roundwood consumption per capita. The impact of the 2007 recession on wood product demand is still reflected in inventory data, with a 19 percent decline in Southern timber removals between 2006 and 2016. However, that trend should reverse as housing markets continue to recover.
- While forest land is becoming more accessible to people and 67 percent of forest land is legally available for harvest activities, tree cutting and removal occurs on less than 2 percent of forest land per year. Contrast that with the nearly 3 percent disturbed annually by natural events like insects, disease, and fire.
- Wildfire, insects, and disease are among the biggest threats to forests and woodlands in the nation. Low harvest rates, aging forests, mortality from insect and disease infestations, and extreme weather events have combined to create conditions that facilitate wildfire.

Changing environmental conditions have made the active management of forests critical. For example, wildfire is a natural and inherent part of the forest cycle. Today, however, wildfires must be prevented from burning unchecked because of danger to human life and property. As a result, many forests have become over-mature and overly dense with excess debris, which, combined with more extreme weather, has caused an increase in both the number and severity of wildfires.

The combination of older forests and changing climate is also having an impact on insects and disease, causing unprecedented outbreaks, such as the mountain pine beetle, which further add to the fire risk. Active forest management, which includes thinning overly dense forests to reduce the severity of wildfires, helps to ensure that forests store more carbon than they release. Forest management activities aimed at accelerating forest growth also have the potential to increase the amount of carbon absorbed from the atmosphere.

The Canadian Forest Service also tracks the health and productivity of Canada's forests. Canada is the third-most forested country in the world with 857 million acres forest with low levels of land-use change, just like in the United States. Only 0.3 percent of standing wood volume and less than half of 1 percent of land area was harvested in 2017. Disturbances have a much larger impact on Canada's forest area and inventory, impacting almost three times the area that was harvested in 2017.

HOW WOULD AN INCREASE IN DEMAND FOR WOOD PRODUCTS IMPACT FORESTS?

Many builders and architects are concerned with the impact of increased demand for wood products on forests. Through both empirical evidence as well as economic models, we have found that demand for wood products results in more forest land, not less. One USFS study noted, "In general, the data show that global regions with the highest levels of industrial timber harvest and forest product output are also regions with the lowest rates of deforestation." The study goes on to add, "The alternative economic hypothesis suggests that forest products and industrial roundwood demands provide revenue and policy incentives to support sustainable forest management, and, in turn, industrial timber revenues and economical forest management have helped avoid large-scale systematic deforestation in those regions with the highest levels of industrial timber harvest."

Markets provide economic justification for sustainable forests and good forestry practices. The USFS states in the 2010 RPA assessment that, "Enhancing the flow of timber revenues helps to sustain forest management and provides an economic rationale for policies favoring sustainable forests and good forestry practices. If future technology development and wood demands provide enhanced timber revenues, then historic experience suggests that forests and forest management will thrive. If the value of timber declines, however, through low-value use, limited demand, or insufficient forest product technology development, the future sustainability of forests will be compromised."

The Intergovernmental Panel on Climate Change (IPCC) also concludes: "Sustainable forest management aimed at providing timber, fiber, biomass, non-timber resources, and other ecosystem functions and services can lower GHG emissions and can contribute to adaptation."

Increasing demand for timber can also increase carbon storage in product stocks and substitution benefits. According to the Forest Climate Working Group, which collaborates on forest carbon strategy and policy recommendations, the current inventory of wood structures in the United States is estimated to store 1.5 billion metric tons of carbon, which is equivalent to 5.4 billion tons of CO_2. Most of this resides in the nation's housing stock, about 80 percent of which is wood-frame construction. Increasing wood use to the maximum extent feasible in multifamily housing, low-rise non-residential construction, and remodeling could result in a carbon benefit equal to about 21 million metric tons of CO_2 annually—the equivalent of removing 4.4 million cars.

For references related to the above as well as information on wood's carbon footprint in the context of building materials, life cycle assessment tools and Environmental Product Declarations, read the complete CEU, *How to Calculate the Carbon Footprint of a Building,* at www.thinkwood.com.

3 Appendix 3: Critical Lift Form

Form 16-3

CRITICAL LIFT PLAN

For use of this form, see EM 385-1-1, Section 16. Proponent agency is Crane HHWG.

LOAD CALCULATIONS

Show here or attach calculations, drawings, etc.

Apr-13

Form 16-3

CRITICAL LIFT PLAN

For use of this form, see EM 385-1-1, Section 16. Proponent is Crane HHWG.

Date:	Prepared By:
Location:	USACE District:

A "critical lift" is defined as any non-routine crane lift requiring detailed planning and additional or unusual safety precautions. Critical lifts include: lifts made where the load weight is greater than 75% of the rated capacity of the crane; lifts which require load to be lifted, swung or placed out of the operator's view ; lifts made with more than one crane; lifts involving non-routine/technically difficult rigging arrangement; hoisting personnel with a crane or derrick; or any lift which the crane operator believes should be critical.

A. TOTAL LOAD

1. Load Weight ______ lbs
2. Wt. of Aux. Block ______ lbs
3. Wt. of Main Block ______ lbs
4. Wt. of Lifting Beam ______ lbs
5. Wt. of Sling/Shackles ______ lbs
6. Wt. of Jib/Ext. (erected/stowed) ______ lbs
7. Wt. of Hoist Rope ______ lbs
8. Other: ______ lbs

TOTAL WEIGHT ______

Note: Source of load weight (Drawings, Calcs, etc.) must be attached on Page 2.

B. CRANE

1. Type of Crane Mobile Hydraulic Truck
2. Maximum Crane Capacity ______ lbs.
3. Radius (Maximum) ______ ft.
4. Radius (Minimum) ______ ft.
5. Boom Length (Maximum) ______ ft.
6. Boom Length (Minimum) ______ ft.
7. Crane Capacity (Max Radius) ______ lbs.
8. Crane Capacity (Min Radius) ______ lbs.
9. Boom Angle (Maximum) ______ deg.
10. Boom Angle (Minimum) ______ deg.
11. Gross Load of Crane ______ lbs.
12. Lift is ______ % of the Crane's rated capacity
13. If Jib/Ext. is to be used:
    Length ______ ft.
    Offset ______ ft.
14. Rated Capacity of Jib/Ext. ______ lbs

C. HOIST ROPE	*Main*	*Aux 1*	*Aux 2*
1. # of Parts			
2. Rope Diameter			
3. Capacity			

D. RIGGING

1. Hitch Type(s) ______
2. No. of Slings: ______ Size: ______
3. Sling Type: ______
4. Sling Assembly Capacity: ______ lbs.
5. Shackle Size(s): ______
6. Shackle Rated Capacity(s) ______ lbs.

E. CRANE PLACEMENT *(Mobile Cranes Only)*

1. Maximum Bearing Pressure ______ PSF
   Note: Bearing Pressure Calculations must be attached on Page 3.
2. Ground Conditions Suitable for Load? ______ YES / NO
   Note: Ground Condition Calculations must be attached on Page 3.
3. High Voltage or Electrical Hazards? ______ YES / NO
   Note: If Electrical Hazards are present they must be shown on Page 4.
4. Obstructions to Lift or Swing? ______ YES / NO
   Note: If Obstructions are present they must be shown on Page 4.
5. Travel with Load Required? ______ YES / NO
6. Other? ______

F. OPERATOR QUALIFICATIONS

1. Certified Operator? ______ YES / NO
2. Option? ______
3. Certified for Type, Class & Capacity? ______ YES / NO
4. Designated in writing by employer: YES / NO

G. PRE-LIFT CHECKLIST	*(YES)*	*N/A*	*(NO)*
1. Crane Inspected			
2. Rigging Inspected			
3. Crane Set-up			
4. Overhead Hazard Check			
5. Swing Check			
6. Counterweight Check			
7. Operator Qualifications			
8. Signal Person Qualifications			
9. Rigger Qualifications			
10. Load Chart in Crane			
11. Load Test			
12. Tag Lines			
13. Wind Conditions			
14. Traffic Hazard Check			
15. Site Control			
16. Signatures			

H. SIGNATURES

1. Crane Operator ______
2. Rigger ______
3. Signal Person ______
4. Lift Supervisor ______
5. Other ______
6. Other ______

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