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WOODWORKS WOOD PRODUCTS COUNCIL

Mass Timber in Affordable Multi-Family Housing

A blueprint for design

Mass timber has been successfully used in projects of all sizes, ranging from luxury to market rate to affordable. U.S. developers have built mass timber housing for residents making as low as 25% of the area median income (AMI), and there are numerous projects that include both market rate and affordable units. For mass timber to be cost competitive in this multi-family sub-segment, design efficiency, material optimization, and a wholistic understanding of where savings may lie are especially important. The potential benefits of a mass timber structural system include:

- **Sustainability**. Wood products have low embodied carbon compared to other building materials, which means they cause fewer greenhouse gas emissions throughout their life cycle. Mass timber also continues to store carbon absorbed by the trees while they were growing. Low embodied carbon + stored carbon = lower carbon impact.
- **Labor savings**. Projects located where on-site labor costs are high can benefit from the smaller crews and faster installation associated with mass timber construction.
- **Foundation savings**. For sites with poor soil conditions, mass timber can reduce foundation costs due to its light weight, especially when compared with a full concrete structure.
- **Reduced height**. Mass timber floor systems can result in thinner structure depths when spans are optimized and beams and headers are minimized within units. The reduced depth can translate to higher ceiling heights, or more commonly in affordable housing projects, shorter floor-to-floor heights (while maintaining an 8-foot or greater ceiling height). Shorter floor-to-floor heights result in a shorter overall building, which reduces costs associated with all vertical systems—e.g., exterior enclosure and facades, interior partitions, elevators and shafts, and mechanical, electrical, plumbing, and fire protection (MEPF). This can significantly influence the overall cost feasibility of using mass timber in an affordable housing project.
- **Occupant wellbeing**. The aesthetic of exposed wood can be part of a biophilic design strategy, which prioritizes occupant wellbeing through a connection to nature and the use of natural materials.
- **Differentiated product**. Developers may also select mass timber for its ability to create market differential, which can lead to enhanced leasing velocity, lower tenant turnover, higher building value at exit, and other economic benefits.

Photo Lara Swimmer

Heartwood – Seattle, WA
Community Roots Housing / atelierjones, LLC

This paper focuses on three structural typologies at the following size and scale:

- Small – low-rise – 1-3 stories
- Medium – mid-rise – 4-8 stories
- Large – high-rise – 9+ stories

To help project teams align their goals and design decisions with the capabilities of mass timber, WoodWorks developed the *Mass Timber Cost and Design Optimization Checklists*. This paper builds on that resource with a framework of design steps, code compliance options, and material optimization strategies for those looking to utilize mass timber in affordable housing projects. While there are differences in how luxury and market rate housing is designed, the framework may also be useful for those projects as the code compliance path and material optimization methods are nearly identical.

Common Structural Typologies

Mass timber refers to a category of framing styles characterized by the use of large engineered wood panels, often paired with engineered wood columns and beams. Panels are most frequently used in horizontal applications for floors and roofs, but can also be used vertically for walls. Products referred to in this paper include cross-laminated timber (CLT), glue-laminated timber (glulam or GLT), dowel-laminated timber (DLT), and nail-laminated timber (NLT).

The systems most commonly used in multi-family projects can be consolidated into three categories:

1. Mass timber floors and roofs on mass timber bearing walls
2. Mass timber floors and roofs on light-frame bearing walls (wood or steel)
3. Mass timber floors and roofs on post-and-beam framing

Mass Timber Floors and Roofs on Mass Timber Bearing Walls

Referred to as mass timber bearing walls, vertical and horizontal systems with mass timber, or honeycomb construction, this option was used for some of the earliest yet tallest mass timber multi-family projects. An example is Stadthaus in the United Kingdom, which includes eight stories of CLT over a one-level concrete podium. Stadthaus has 19 condominium units and 10 social housing units, and was completed in 2009.

A U.S. example is 340+ Dixwell in New Haven, CT. This project consists of two four-story buildings with a combined 69 units—14 of which are restricted to families earning 25 percent of the AMI, 26 to those making 30-50% AMI, and nine to those earning 60% AMI. Fourteen of the units provide supportive housing and services for chronically homeless individuals and families at risk of homelessness as part of New Haven's Housing Choice Voucher Program. The remaining units are market rate.

Images: Waugh Thistleton Architects

Stadthaus – London, UK / Waugh Thistleton Architects

Images: GOA

340+ Dixwell – New Haven, CT / GOA

Also in the U.S., global real estate company Lendlease used an all-mass timber system to construct five hotels as part of the Privatization of Army Lodging (PAL) program, in Alabama, New York, Washington, and South Carolina. Projects are four to six stories, with timber protected by gypsum wallboard (GWB) to align with the hotel's branding guidelines.

Photo: Lendlease

Candlewood Suites –
Redstone Arsenal, AL / Lendlease

This style of construction hasn't been widely used the U.S., particularly for taller projects. This is due in part to the lack of code recognition for mass timber shear wall systems at certain building heights. CLT shear walls weren't prescriptively recognized in standards referenced in the International Building Code (IBC) until the 2021 version of the American Wood Council's Special Design Provisions for Wind and Seismic (SDPWS) and the 2022 ASCE 7, Minimum Design Loads and Associated Criteria for Buildings and Other Structures. Prior to this, IBC Section 104.11 required projects with CLT shear walls of any height to apply for a "code modification" or "variance request." Even with the new prescriptive methods, the height limit for CLT shear wall systems is 65 feet, and project teams seeking to go beyond this require a code modification. However, an effort is underway to test and validate the performance of tall CLT rocking shear wall systems. (See page 21, Lateral System Options.)

Mass Timber Floors and Roofs on Light-Frame Bearing Walls

This hybrid style of construction includes light-frame bearing walls (usually wood but sometimes cold-formed steel) supporting mass timber floor and roof panels. Users of this system say it plays to strengths of both structural materials.

- Light-frame wood bearing walls are a tried and true option for multi-family projects up to five stories, affordable and otherwise. They can function as shaft walls, corridor walls, exterior walls, and unit separation walls. They allow routing of electrical for outlets and switches, and accommodate plumbing lines for bathrooms and kitchens. Information is abundant on their design for fire resistance, acoustics, building enclosure, and lateral/gravity loads.
- Cold-formed steel stud bearing walls are a viable option, especially for Type IV-C projects where the IBC does not permit the use of light-frame wood. As an example, Bunker Hill Housing Building M in Charlestown, MA is a six-story, affordable housing project with CLT floor and roof panels supported on steel stud bearing walls. (See page 5.)
- Mass timber floor and roof panels are typically left exposed on the ceiling side, providing an enhanced aesthetic not possible with other structural systems. Benefits such as sustainability and faster construction can also be leveraged for cost savings and long-term development value.

To keep up with the installation speed of mass timber floor panels, it is often beneficial to prefabricate/panelize the bearing walls off site and erect them into place during construction.

Photo: 605 Creative Co., courtesy Co-Op Architecture

Photo: WoodWorks

Railyard Flats – Sioux Falls, SD / Co-Op Architecture

Junction Lofts

West Des Moines, IA / Pelds Design Services

Three stories of CLT made from structural composite lumber (SCL CLT), light-frame wood, and glulam • 11 units for households earning 30-80% AMI • Type V-B / 16,000 square feet

Photo: Cutler Development

Chiles House

Portland, OR / All Hands Architecture

Five stories of CLT and light-frame wood • 27 transitional housing units for people experiencing homelessness and international refugees • Type III-B / 16,700 square feet

Photos: Truebeck Construction (top); All Hands Architecture

TimberView

Portland, OR / Access Architecture

Eight stories of CLT and glulam with steel braced frames • 105 affordable housing units • Type IV-C / 74,385 square feet

Images: Access Architecture

Sonrisa

Sacramento, CA / 19six Architects

Five stories of SCL CLT and light-frame wood • 57 units for households earning 40-60% AMI • Type III-A / 23,600 square feet

Photos: 19six Architects

The Canyons

Portland, OR / Kaiser+Path

Four stories of CLT and light-frame wood over two-level concrete podium • 70 units, all Americans with Disabilities Act (ADA)-compliant, multi-generational housing • Type III-A over Type I-A / 110,000 square feet

Photo: Jeremy Bittermann

Bunker Hill Housing Building M

Charlestown, MA / Stantec

Six stories of CLT with cold-formed steel stud bearing walls • 102 affordable units • Type IV-C / 120,000 square feet

Image: Stantec

Star Lofts

Des Moines, IA / ID8 Architects

Three stories of SCL CLT and light-frame wood • 20 units for households earning 30-80% AMI • Type V-B / 6,500 square feet

Photo: Cutler Development

Mass Timber Floors and Roofs on Post-and-Beam Framing

The most common structural scheme for mass timber buildings in the U.S. is mass timber floor and roof panels supported on beams and columns. This can include steel or concrete beams, but more commonly entails mass timber products such as glulam. In a multi-family occupancy, corridor walls and unit separation walls are usually non-load bearing and are infill framed to the underside of beams and/or panels. This option allows more flexibility for future renovations and interior unit reconfigurations when compared to a bearing wall approach.

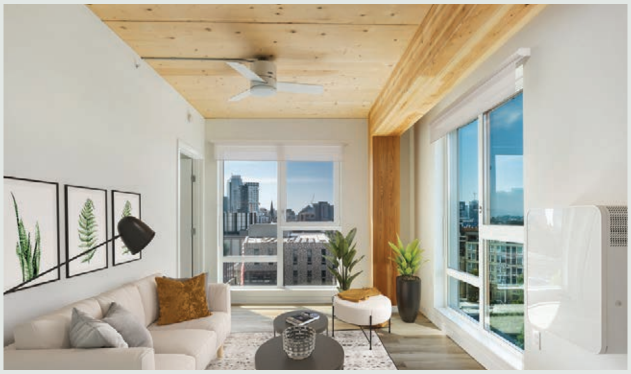
When a project includes parking, it is important to consider alignment of the grid in the mass timber residential levels with that of the parking levels. While an optimal grid in the residential units might provide columns at 14- to 18-foot intervals along the corridor, a more optimal grid for parking is 20 or 30 feet. One option is to use a structural transfer slab or beams at the transition from housing to parking. However, this can be costly. For taller projects, some designers are investigating other options to balance mass timber grid efficiencies while minimizing large structural transfer members.

Construction can be fast in this panel-over-beam approach. Once installers erect the mass timber structure on each floor, they move to the next while subtrades for infill walls, MEPF, and exterior facades start working on the floors below. With this structural scheme, it is common to install 10,000 to 30,000 square feet per week.

The "post-and-plate" system is a variation on the post-and-beam system and is similar to flat plate or two-way concrete construction. Post-and-plate is a beamless system that uses columns to support slabs (mass timber panels) that span in both directions. Mass timber panels have a major axis and a minor axis, and the structural properties are lesser in the minor axis direction. There are currently no code-recognized methods of creating fixity across a panel-to-panel connection, meaning that columns must be placed along the edges of all panels. Most CLT panels have widths between eight and 11 feet, which creates a tight column grid. In some projects—usually hospitality or multi-family residential—this can be accommodated. Here, the benefits of a post-and-plate system can be seen in a shorter floor-to-floor height due to the lack of beams, and faster installation (fewer pieces to install). An affordable housing project that used this structural framing system is 1510 Webster in Oakland, CA. (See sidebar.)

Projects with Post-and-Beam Structural Systems

Photos: Lara Swimmer (top); Blanton Turner



Heartwood

Seattle, WA / Community Roots Housing / atelierjones, LLC

Eight stories of CLT and glulam • 126 units for households earning 60-100% AMI • Type IV-C / 67,500 square feet

Photo: Andrew Nelson

Oakland, CA / oWOW

16 stories of SCL CLT plus one-story steel penthouse over two-level concrete podium • 222 residential units, 35 of which are affordable • Type IV-A / 179,020 square feet

Construction Type Options and Fire-Resistance Ratings

Construction type has a significant impact on cost and is therefore one of the most important design considerations for an affordable housing project. Mass timber can be used in any of the construction types shown in Table 1, which summarizes the allowable height limits for affordable mass timber multi-family projects (Group R2 occupancy).

Table 1 orders the construction types from least to most restrictive in terms of fire-resistance ratings (FRRs) and the use of wood materials. Construction types are defined in IBC Section 602, and Type V and III have subcategories A and B requiring different levels of fire protection. The 2021 IBC changed Type IV to Type IV-HT and introduced subcategories A, B, and C. Note that the least restrictive construction types have the greatest limitations on building size.

A common assumption is that exposed mass timber framing necessitates the use of Type IV construction, but this is not the case. While Type IV can be used for mass timber projects, other options deserve equal consideration—and may offer advantages for affordable housing.

To optimize construction type, it is most cost-efficient to start with the least restrictive—Type V-B—and increase as needed based on the project specifics:

1. Identify the two or three least restrictive construction types that allow the proposed building size.
2. Determine where mass timber is permitted in each of those types and which align with the project goals. (See page 10, *Where Wood Can Be Used in Each Construction Type*.)
3. Consider whether the structural system includes materials other than mass timber. Does the design include light-frame wood bearing walls? If so, IV-A, IV-B, and IV-C are not viable options because they don't allow light-frame wood. Does the design include CLT exterior walls? If so, III-A and III-B are not viable options (within prescriptive code limits) because they require fire retardant-treated wood (FRTW) exterior walls.

Bear in mind that using a combination of mass timber and other materials will not entail more than one construction type. Except where complying with the special provisions of IBC Section 510, or where separated with fire walls in accordance with IBC Section 503.1, buildings are only classified as a single type of construction.

TABLE 1: Light-frame wood and mass timber construction types
Building size, FRR, and materials permitted in Group R-2 occupancy

Construction type	V-B	V-A	III-B	III-A	IV-HT	IV-C	IV-B	IV-A
Number of stories	3	4	5	5	5	8	12	18
Height (ft)	60	70	75	85	85	85	180	270
Maximum floor area	21,000 SF	36,000 SF	48,000 SF	72,000 SF	61,500 SF	76,875 SF	123,000 SF	184,500 SF
Maximum building area	63,000 SF	108,000 SF	144,000 SF	216,000 SF	184,500 SF	230,625 SF	369,000 SF	553,500 SF
Primary frame FRR	0-hour*	1-hour	0-hour*	1-hour	HT**	2-hour	2-hour	3-hour
Floor FRR	0-hour*	1-hour	0-hour*	1-hour	HT**	2-hour	2-hour	2-hour
Roof FRR	0-hour	1-hour	0-hour	1-hour	HT	1-hour	1-hour	1-1/2-hour
Wood permitted in exterior walls	Any wood / mass timber	Any wood / mass timber	FRTW	FRTW	FRTW or CLT	Mass timber	Mass timber	Mass timber
Wood permitted in interior walls	Any wood / mass timber	Any wood / mass timber	Any wood / mass timber	Any wood / mass timber	Mass timber	Mass timber	Mass timber	Mass timber

Assumes NFPA 13 sprinkler system throughout building, no frontage increase
**Horizontal assemblies and fire partitions that separate dwelling units or that separate a dwelling unit from other occupancies are required to have a minimum 0.5-hour FRR in construction Types III-B and V-B per IBC Sections 708.3 and 711.2.4.3.*
***Horizontal assemblies and fire partitions that separate dwelling units or that separate a dwelling unit from other occupancies are required to have a minimum 1-hour FRR in construction Type IV-HT per IBC Sections 708.3 and 711.2.4.3.*

IBC Section 602.1.1 permits some elements to be of a higher construction type without requiring that the entire building meet all the provisions of that construction type. For example, if a building's size permits the use of Type V-B construction, it could still be completely framed with noncombustible materials while being classified as V-B (even though most designers tend to associate Types I and II construction with noncombustible materials). Doing so would keep cost associated with fire-resistance strategies low while also keeping material use flexible, negating the need for future code analysis if wood elements were to be introduced into the building. Similarly, a Type III or V building could be framed with a combination of combustible and noncombustible materials as permitted within the definitions of those construction types in IBC Chapter 6. This code provision is the basis of compliance for the hybrid systems noted earlier.

Prior to the new Type IV subcategories in the 2021 IBC, designers utilizing mass timber for multi-family projects were limited to a maximum of five stories using Type III-A, III-B, or IV-HT. While options exist for placing a five-story building on top of a podium (discussed in the next section), they are limited by number of stories and building height. Types IV-A, IV-B, and IV-C construction allow the use of mass timber in affordable multi-family projects up to 18, 12, and eight stories, respectively.

Construction types permitted for the common mass timber structural systems are as follows:

- Mass timber floors and roofs on mass timber bearing walls – All of the construction types shown in Table 1
- Mass timber floors and roofs on light-frame wood bearing walls – Types III-A, III-B, IV-HT,* V-A, and V-B
  - If light-frame wood members are used in exterior bearing walls of Type III-A, III-B, or IV-HT construction, they must be FRTW.
- Mass timber floors and roofs on steel stud bearing walls – All of the construction types shown in Table 1
- Mass timber floors and roofs on post-and-beam framing – All of the construction types shown in Table 1

*Type IV-HT construction consists of exposed wood components meeting minimum cross-section sizes. Generally, no concealed spaces are permitted. However, they are permitted within 1-hour FRR wall assemblies, and the 2021 IBC introduced new allowances for concealed spaces in these projects. For additional information on this topic, see the WoodWorks publication *Concealed Spaces in Mass Timber and Heavy Timber Structures*.

Exceeding Prescriptive Height Limits

Construction type options for the different building size ranges are as follows:

Small – 1-3 stories – Type V
Medium – 4-8 stories – Types V, III, IV-HT, and IV-C
Large – 9+ stories – Types IV-B and IV-A

While the story limits shown in Table 1 are maximums for the mass timber or mass timber hybrid portions of an affordable housing project, there are several ways a building designer can exceed those limits. This is especially beneficial when seeking to maximize site density, create on-site parking, or otherwise leverage multiple uses within the same footprint.

Podium construction—also known as pedestal or platform construction—typically includes a multi-story building (Type III, IV, or V) over a podium of another construction style, which may include retail space and above- or below-grade parking. Concrete podiums are the most common, though steel podiums also exist. The upper slab of a podium typically acts as both fire separation and structural transfer for the framing above. This approach allows increased density with additional stories if built using the special provisions of IBC Section 510.2. It maximizes the potential of smaller urban lots and IBC building height allowances, and several of the mass timber housing projects shown in this paper feature a podium. The podium story or stories must be Type I-A construction and the lid of the podium requires a 3-hour FRR.

The primary benefit of a podium is that the structure is treated as two separate buildings (one above the podium, another below) for the purpose of determining allowable number of stories, area, construction type, and continuity of fire walls. Podiums can be one or multiple stories, with the caveat that the overall building height from grade plane to the average of the highest roof plane must not exceed the limits stated in IBC Chapter 5 for the more restrictive of the two buildings. For example, a five-story Type III-A building could be built on top of a two-story Type I-A podium if the overall building height does not

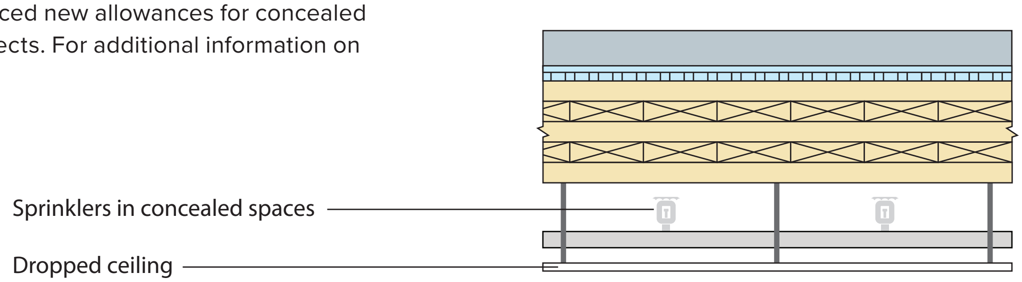


FIGURE 1: Example dropped ceiling; concealed space with sprinkler protection in Type IV-HT construction

TABLE 2: FRR requirements for building elements (hours)

Construction Type	I-A	I-B	II-A	II-B	III-A	III-B	IV-HT	IV-A	IV-B	IV-C	V-A	V-B
Primary structural frame[f] (see Section 202)	3[a,b]	2[a,b]	1[b]	0	1[b]	0	HT	3	2	2	1[b]	0
Bearing walls Exterior[e,f] Interior	3 3[a]	2 2[a]	1 1	0 0	2 1	2 0	2 1/HT	3 3	2 2	2 2	1 1	0 0
Nonbearing walls and partitions Exterior	See Table 705.5											
Nonbearing walls and partitions Interior[d]	0	0	0	0	0	0	See Section 2304.11.2	0	0	0	0	0
Floor construction and associated secondary members (see Section 202)	2	2	1	0	1	0	HT	2	2	2	1	0
Roof construction and associated secondary members (see Section 202)	1.5[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1.5	1	1	1[b,c]	0

Source: IBC Table 601 / See IBC for footnotes

exceed 85 feet. Similarly, a 12-story Type IV-B building could be built on top of a four-story podium if the overall building height does not exceed 180 feet.

For more information on the code provisions and design implications of tall mass timber projects using Types IV-A, IV-B, and IV-C construction, see the WoodWorks publication, *Tall Wood Buildings in the 2021 IBC – Up to 18 Stories of Mass Timber*. For additional information on the design of podium structures, see the WoodWorks expert tip, *Code Path and Requirements for Podium Projects*.

FRR Requirements and Design Impacts

Once the construction type has been selected, the FRR of structural elements and assemblies is dictated by IBC Table 601. Unique to multi-family occupancies, several additional FRR requirements for elements such as walls and floors separating dwelling units and corridor walls are specified elsewhere in the IBC, such as Sections 420, 708, 711, and 1020. In most instances, the FRR requirements in Table 601 will be as or more restrictive than the requirements in other sections. However, a few notable exceptions are corridor walls, unit separation walls, and floor assemblies that separate dwelling units in Type III-B and V-B construction. Type IV-HT typically does not require an FRR for exposed timber members that meet the minimum sizes specified in IBC Section 2304.11. However, when using Type IV-HT in a multi-family project, some assemblies such as corridor walls, unit separation walls, and floor assemblies that separate dwelling units must provide a 1-hour FRR. Table 601 indicates a 0-hour FRR requirement for these unique conditions in Types V-B, IV-HT, and III-B construction, but other sections of the code indicate a minimum 0.5-hour (V-B and III-B) or 1-hour (IV-HT) FRR.

Table 2 shows FRR requirements in IBC Table 601, and Table 3 shows common requirements by building size.

These FRR requirements apply to all structural members and assemblies regardless of whether they are all mass timber, a hybrid of mass timber and other systems, or any other system. The following sections describe how the required FRRs are met using different material and assembly options.

TABLE 3: Common FRR requirements by building size

	Building Size	Construction Type(s)	FRR Requirements
Small	1-3 stories	V	0-1 hours
Medium	4-8 stories	V, III, IV-HT, and IV-C	1-2 hours
Large	9+ stories	IV-B and IV-A	2-3 hours

FRR Design of Mass Timber Elements

The fire resistance of mass timber construction is based on the size of the timber elements. In a fire, large wood members retain their load-carrying ability longer than members with small cross sections because a char layer forms on exposed surfaces while the interior remains undamaged, at ambient temperature, and therefore structurally sound. Although noncombustible protection (such as GWB) can be added to help achieve some or all of the FRR (required in some instances for Type IV-B and IV-C construction and all instances in IV-A), most building designers look to expose the mass timber elements to the maximum extent possible.

As highlighted in Table 3, exposed mass timber members and assemblies require an FRR of between 0 and 2 hours when used in affordable housing projects. Type IV-A construction requires a 3-hour FRR for primary frame members and bearing walls, and that all mass timber members be protected with noncombustible materials. These protecting materials must provide 2 hours of the 3-hour FRR. As such, there is no situation where the 2021 or 2024 IBC requires exposed mass timbers to demonstrate an FRR greater than 2 hours.

The two most common ways to demonstrate the FRR of mass timber elements are:

1. Citing an assembly that has been fire tested in accordance with ASTM E119
2. Calculations in accordance with Chapter 16 of the American Wood Council's National Design Specification® (NDS®) for Wood Construction or Fire Design Specification (FDS) for Wood Construction

The WoodWorks website includes a *Database of Fire-Tested Mass Timber Assemblies* for floor, roof and wall applications, including options for 1-, 2- and 3-hour FRRs. Calculations performed in accordance with the NDS

Where Wood Can Be Used in Each Construction Type

- **Type V** (IBC 602.5) – Mass timber and light-frame wood elements can be used alone or in combination with each other throughout the structure, including floors, roofs, interior walls, and exterior walls. Noncombustible materials permitted by code may also be used throughout these buildings.
- **Type III** (IBC 602.3) – Mass timber elements can be used in floors, roofs, and interior walls. FRTW framing is permitted in exterior walls required to have an FRR of 2 hours or less. Fire retardant-treated mass timber walls are not commercially available (with the possible exception of NLT or DLT) and, as such, mass timber is not used in Type III exterior walls unless approved under an alternative material request. Light-frame wood elements, as well as noncombustible materials permitted by code, may be used throughout Type III buildings, on their own or in combination with mass timber.
- **Type IV** (IBC 602.4) – Often referred to as 'heavy timber' construction, this option has been in the building code for over a hundred years in one form or another, but its use has increased along with renewed interest in exposed wood buildings. In the 2021 IBC, Type IV construction was renamed IV-HT and subcategories A, B, and C were added. These new construction types generally require 2- or 3-hour FRRs for structural elements and, in some cases, noncombustible protection of some or all of the mass timber elements.
- **Type IV-HT:** This construction type is unique in that fire-resistive behavior is based in part on the inherent and long-demonstrated fire resistance of large solid wood framing. Structural wood components must meet minimum sizes defined in IBC Section 2304.11 and are permitted in floors, roofs, and interior walls. Per IBC Section 602.4.4.2, exterior walls required to have an FRR of 2 hours or less are also permitted to use FRTW framing, or CLT when the exterior face is covered with FRTW sheathing or noncombustible materials. Heavy timber components used in Type IV-HT construction can be fully exposed.
- **Type IV-C:** This construction type can include mass timber elements that meet the minimum sizes specified in IBC Section 2304.11 (in addition to meeting the FRRs required in IBC Table 601) or noncombustible materials. No light-frame wood is permitted within building elements. Mass timber components used in Type IV-C construction can be fully exposed, except for shaft wall construction and within concealed spaces.
- **Type IV-B:** This construction type can include mass timber elements that meet the minimum sizes specified in IBC Section 2304.11 (in addition to meeting the FRRs required in IBC Table 601) or noncombustible materials. No light-frame wood is permitted. Mass timber components used in Type IV-B construction can be partially exposed; the amount of exposure permitted varies with the application (ceiling vs. wall) and the IBC edition.
- **Type IV-A:** This construction type can include mass timber elements that meet the minimum sizes specified in IBC Section 2304.11 (in addition to meeting the FRRs required in IBC Table 601) or noncombustible materials. No light-frame wood is permitted within building elements. All mass timber components used in Type IV-A construction are required to be protected with noncombustible materials such as GWB.

Heartwood – Seattle, WA
Community Roots Housing / atelierjones, LLC
Photo: Blanton Turner

allow up to a 2-hour FRR for mass timber products such as CLT, glulam, SCL, and heavy timber decking. For more information, including how to perform the calculation-based method, see the WoodWorks publication, *Fire Design of Mass Timber Members.*

When designing mass timber floor assemblies for affordable housing projects, it is important to consider the impact that FRR, span, and loading have on panel thickness, as this has a direct impact on cost. Consider the following:

A 3-ply CLT panel (often 4-1/8 inches thick) or 2x4 NLT/DLT/GLT panel will usually be the minimum thickness permitted by code. These panels can achieve a 0.5-hour or 1-hour FRR, but only when lightly loaded and with short spans. A typical span for a 3-ply CLT panel, considering structural loading, panel capacity, and particularly vibration performance, would be in the range of 10 to 12 feet. However, these spans would not be achievable if the panel was left exposed and had to achieve a 1-hour FRR. There are currently no ASTM E119 fire-tested, exposed 3-ply CLT systems, which means a designer would have to calculate the FRR in accordance with the NDS or FDS.

For an exposed 3-ply CLT panel, the remaining section corresponding to a 1-hour FRR would leave only the uppermost lamination (essentially a 2x flat) to span and support the necessary loads. Such a structural condition will usually result in spans so short that they are either not practical or require too many framing pieces to be efficient in terms of material cost and installation labor. For these reasons, a 2-hour FRR on an exposed 3-ply CLT panel is not achievable, even if spans are very short. However, some designers have used 3-ply CLT for 1- or 2-hour rated conditions, where all of the CLT will be covered on the ceiling side with one or two layers of 5/8-inch Type X GWB. In this case, the GWB provides most or all of the FRR, allowing the mass timber to achieve its maximum spans. These projects utilize mass timber for its speed of installation, light weight, and/or thin structure depth. The designers decided to not expose the mass timber in these cases.

1510 Webster in Oakland is one such project. It is Type IV-A construction, meaning that all of the mass timber is concealed under GWB. Despite this, using mass timber on the project contributed to savings of nearly $30 million. For more information, read the **case study** on this project at woodworks.org.

A 5-ply CLT panel (often 6-7/8 inches thick) or 2x6 NLT/DLT/GLT panel can usually achieve a 1-hour FRR, and *sometimes* a 2-hour FRR with no noncombustible protection. For common spans of approximately 15 feet and common residential or office occupancies, many stronger panels (made from E-rated lumber) can achieve a 2-hour FRR; however, more economical CLT panels (made from V-rated lumber) would have more limiting spans under a 2-hour FRR design scenario. See Figure 2 for an assembly commonly used to achieve a 1-hour or 2-hour rating.

Photo: Flor Projects, courtesy oWOW

GWB installation nearly complete at 1510 Webster in Oakland, CA

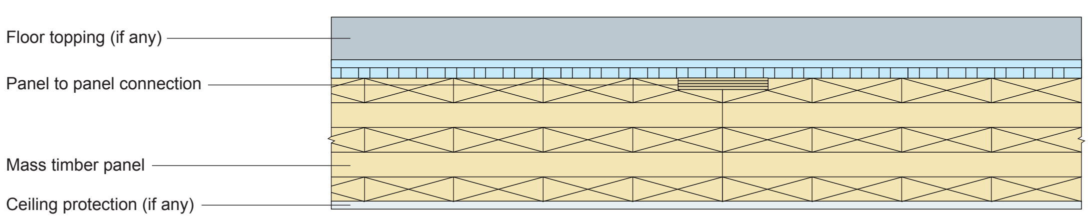


FIGURE 2: Common mass timber floor assembly to achieve a 1-hour or 2-hour FRR

FRR Design of Light-Frame Wall Assemblies

As noted, the use of light-frame wood wall assemblies is permitted in Types III, IV-HT, and V construction, which in the case of multi-family construction requires a 1-hour FRR. (Types III and IV-HT require a 2-hour FRR for load-bearing exterior walls). Light-frame wood wall assemblies have long been used in FRR applications and there are many tested wall options available. Unit separation walls and corridor walls will typically take one of three forms:

1. Single-stud wall with resilient channels (e.g., UL U327 and GA WP 3241)
2. Staggered-stud wall (e.g., GA WP 3910)
3. Double-stud wall (e.g., GA WP 3820)

One or two layers of Type X GWB will cover both faces of the wood stud wall assembly.

Acoustic Performance

Acoustic performance is critical in multi-family buildings, perhaps more than any other building type. However, this is also just one aspect of building performance and must be considered in combination with other requirements such as fire protection and structural systems. To determine an optimal design solution, it is important to understand how the design and detailing of each individual system affects the others—especially when using a newer system such as a mass timber floor assembly. Determining the required acoustic performance in conjunction with the owner is another best practice that should not be overlooked. Affordable housing projects are typically designed to meet code minimums for acoustics while other multi-family project types often exceed them (see Table 4).

TABLE 4: Acoustical isolation between units – airborne (STC) and impact (IIC)

Class Designation	Airborne Sound Isolation (STC)	Floor Ceiling Impact Isolation (IIC)
Entry level	50	50
Market rate	55	55
Luxury	60	60

IBC Section 1206 lists requirements for acoustic performance of walls, partitions, and floor/ceiling assemblies in multi-family buildings. These assemblies, which separate one dwelling unit from another or from public areas, must have a sound transmission class (STC) rating of 50 and, in the case of floor/ceiling assemblies, an impact insulation class (IIC) rating of 50. (These ratings can be reduced to 45 when field tested.) STC measures how effectively a wall or floor/ceiling assembly isolates airborne sound—such as conversation or music—and reduces the level that passes from one side to the other. IIC measures how effectively a floor/ceiling assembly blocks impact sound—like that resulting from an object dropped on the floor—from passing through a floor/ceiling and only applies to those assemblies.

Designing Mass Timber Floor Panels for Acoustics

Since mass timber floor assemblies typically leave the panel exposed on the ceiling side, asymmetric assemblies are necessary. A bare 5-ply CLT floor panel has an STC of about 40 and an IIC of about 25, so to meet or exceed code minimums, additional mass, decouplers, and/or noise barriers are added on top of the panels. A common floor build-up includes a mass timber panel, covered by an acoustic mat and then a poured concrete or gypsum-based topping, which is usually in the range of 1 to 3.5 inches thick. Considering the variables of mass timber panel types and thicknesses, acoustic mat types and thickness, topping density and thickness, and types of floor finish, this floor assembly can result in STC and IIC ratings up to the mid 50s. This net built-up assembly is usually in the range of 8-12 inches thick.

As an example, a common assembly would include a 5-ply CLT floor panel, acoustic mat product, two inches of gypsum poured topping, and finish flooring of luxury vinyl tile (LVT), as shown in Figure 3. Depending on the products used, this can result in STC and IIC values in the low 50s.

For additional information on the acoustic design of mass timber floor panels, see the WoodWorks publication, *Acoustics in Mass Timber: Room-to-Room Noise Control.* For data from acoustic tests performed on mass timber assemblies, see WoodWorks' *Database of Acoustically-Tested Mass Timber Assemblies.*

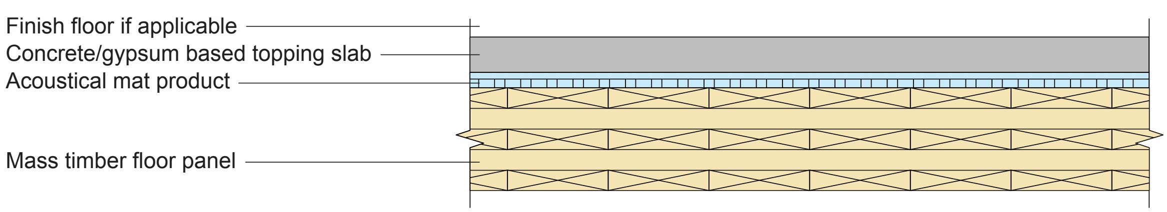


FIGURE 3: Example mass timber floor assembly with topping and acoustic mat

While most multi-family building designers aim to maximize the amount of exposed wood ceiling for aesthetics, others have different priorities. In these cases, an applied or dropped ceiling can significantly improve the acoustic performance of the floor/ceiling assembly. This in turn significantly reduces, or eliminates, the need for topping materials. An example of a mass timber floor assembly with a dropped ceiling includes a dropped ceiling with 3-1/2-inch batt insulation in a 4-inch-deep cavity, 3-ply CLT, an acoustical mat, a 1-inch-thick gypsum poured topping, and applied finish floor such as LVT. Depending on the products used, this can result in STC and IIC values in the upper 50s to low 60s.

Designing Mass Timber Wall Panels for Acoustic Performance

When mass timber unit demising walls or corridor walls are being used, they also require application of applied finishes on one or both sides to meet code minimums for STC. For example, a 5-ply CLT wall panel, exposed on one face and covered on the opposite face with 2x2 wood studs at 24 inches o.c. and 2 layers of 1/2-inch Type X GWB has an STC of 50. The furred-out wood stud cavity also provides an opportunity to route electrical wiring and plumbing lines. Other designers may choose to cover both faces of the mass timber wall panel as shown in Figure 4.

Acoustic Design of Light-Frame Wood Wall Assemblies

Several decisions factor into the design of light-frame wood wall assemblies in affordable housing projects. Thinner walls (single-stud walls) take up the least amount of rentable space, but can make it more challenging to meet acoustic performance criteria. Single-stud walls typically require resilient channels on one side of the wall, which can be more challenging to install and coordinate with blocking for shear walls and hung elements like cabinets. Staggered-stud walls and double-stud walls alleviate some of these challenges but the added materials can add cost while taking up some of the rentable floor area. For a full discussion on the design of light-frame wood wall assemblies in multi-family projects, see the WoodWorks expert tip, *Hybrid Design: Mass Timber Floor and Roof Panels Over Light-Frame Wood Walls.*

Detailing Floor-to-Wall Intersections

In addition to selecting the proper floor and wall assemblies for acoustic control, it is important to consider the details used at the intersection of two assemblies. For mass timber floor panels to interior light-frame wood wall intersections, one approach is to break each floor panel over each unit demising wall. This will create acoustic isolation and prevent sound from travelling between units by way of a continuous panel, as shown in Figure 5.

Another option is to use an isolated topping slab as shown in Figure 6.

For these intersections, additional considerations include the construction type, materials allowed within the exterior wall, and respective FRRs of the exterior wall and floor.

For examples of mass timber floor to light-frame wood wall intersection details, see the WoodWorks publication, *Index of Mass Timber Connections.*

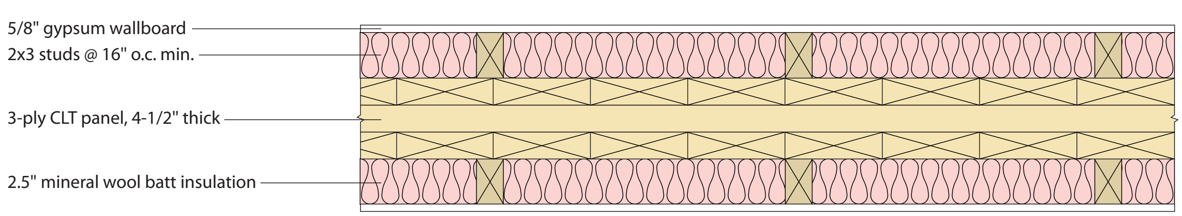


FIGURE 4: Example mass timber wall assembly with furred-out stud walls on each side, STC 58

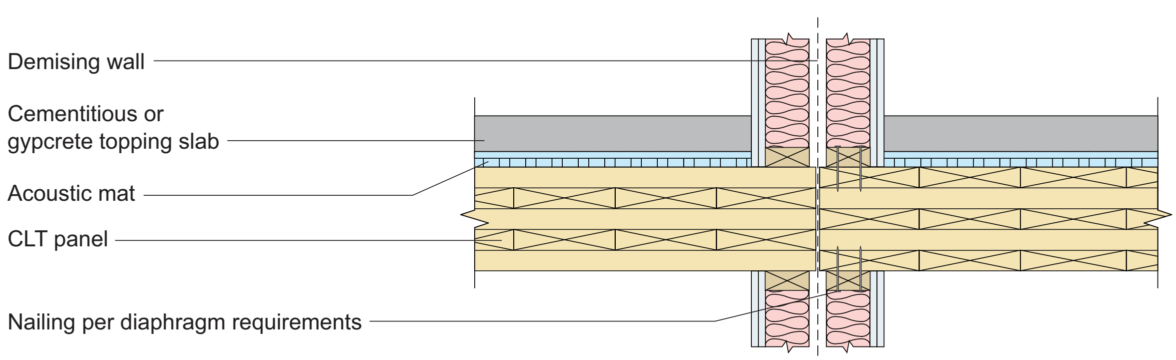


FIGURE 5: Isolated mass timber floor panels at intersection of floor and wall assemblies

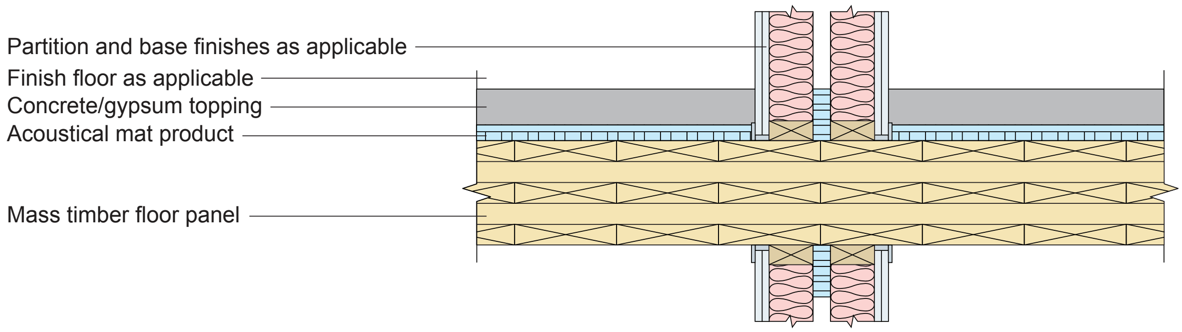


FIGURE 6: CLT floor panel at unit separation wall

Structural Design of Mass Timber Floor Panels

The structural design of mass timber walls, beams, and columns, and light-frame wood bearing walls and shear walls, is covered extensively elsewhere and not addressed in detail here. For examples of those resources, see the sidebar on page 17.

In addition to the calculations and detailing process associated with structural design of mass timber, it is important to coordinate design efforts with other aspects of the building design such as FRR, acoustics, and MEPF integration.

Regardless of whether the mass timber floor panels are being supported on beams or bearing walls, one of the first structural design decisions is the direction of panel span/orientation. Figure 7 shows a typical multi-family floor plan and unit layout for a 15x32-foot unit.

TABLE 5: Example mass timber floor panel span options

Panel	Example Floor Span Ranges
3-ply CLT (4-1/8 in. thick)	Up to 12 ft
5-ply CLT (6-7/8 in. thick)	14-17 ft
7-ply CLT (9-5/8 in. thick)	17-21 ft
5-in. SCL CLT	10-15 ft
2x4 NLT	Up to 12 ft
2x6 NLT	10-17 ft
2x8 NLT	14-21 ft

To determine efficient panel span and orientation for the floor plan in Figure 7, the first things to consider are construction type and associated FRR. The most efficient construction type will be a function of building size. For this example, assume a four-story, 48-foot-tall building. The area per floor is 16,800 square feet and the total building area is 67,200 square feet. Using the descending order of construction types, and the allowable building sizes within IBC Chapter 5 for an R-2 occupancy, we can eliminate Type V-B construction as an option since it only allows up to three stories. For the rest of the example, we will assume that Type V-A will be used. However, Type III-B could also be explored for this project. (Note that a Type V-A building with this area per story would require an NFPA 13 sprinkler system vs. 13R.)

As noted, mass timber floors in Type V-A construction require a 1-hour FRR. Choosing a floor panel thickness capable of achieving this FRR will then help to inform efficient panel spans and layout.

Due to mass timber's relative light weight, allowable spans for floor panels are often governed by vibration and deflection rather than bending or shear capacity. In addition to panel vibration design, vibration performance of the framing system as a whole, including beams, should be taken into account. Table 5 illustrates example span ranges based on panel size, assuming stiff supports. (Each project's specific span, loading and support conditions, and manufacturer-specific design properties, should also be accounted for when selecting panel thickness.) It is also worth noting that the thickness options for CLT in

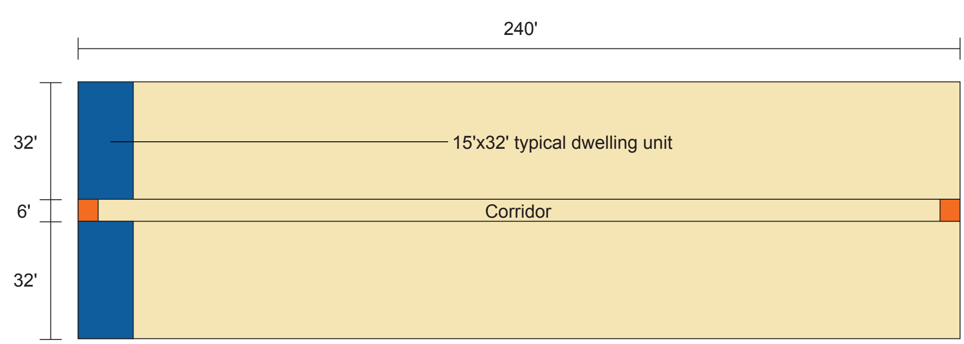


FIGURE 7: Example multi-family floor plan

Table 5 are based on 2x laminations planed to 1-3/8-inch thickness, which is the most common and widely available option from North American CLT manufacturers. Alternative lamination thicknesses (and therefore panel thicknesses) are also available from some manufacturers —such as 5-ply panels that are thinner or thicker than 6-7/8 inches. Each manufacturer should be consulted for their range of products and associated costs.

Continuing the design example, a 5-ply CLT floor panel will be the basis of design to meet the required 1-hour FRR. Its efficient span range is 14-17 feet as noted in Table 5. The panels could be oriented in either direction as shown in Figures 8 and 9.

With Option 2, an intermediate support member such as a beam or bearing wall will be necessary due to the size of the unit (15x32 feet) and efficient panel span (14-17 feet). (See photo lower right.) In Option 1, the unit demising walls could also function as bearing walls to limit panel spans to 15 feet. Or a beam, aligned with or just offset from the unit demising wall, could limit the panel span to almost the same. In Option 2, interior partition walls would generally not be running across the unit, indicating that a beam spanning from unit wall to unit wall would be necessary to reduce the panel span to about 16 feet.

When considering the panel layout options in Figures 8 and 9, it is also prudent to consider the impacts of structural layout on MEPF integration. In a common MEPF layout for the floor plan in Figure 9, main lines would run in the corridor with branches into each unit. Option 1 would significantly simplify the MEPF coordination with structural elements, specifically by reducing the number of MEPF penetrations through the interior unit beams as shown in Figures 10 and 11. In addition to the structural impacts of penetrations on the beams, the holes through the beams must also account for fire exposure around the holes, resulting in a larger net section loss after a 1- or 2-hour fire as shown in Figure 12.

Photo: Jeremy Bittermann courtesy Hacker

One-way mass timber post-and-beam framing scheme

Photo: KL&A Engineers and Builders

Mass timber floor panel supported on light-frame bearing wall and wood beam within multi-family dwelling unit

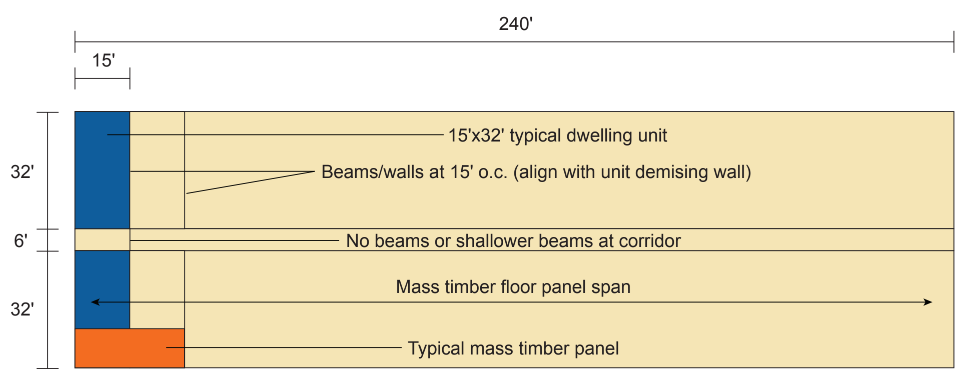


FIGURE 8: Option 1 panel and structure layout

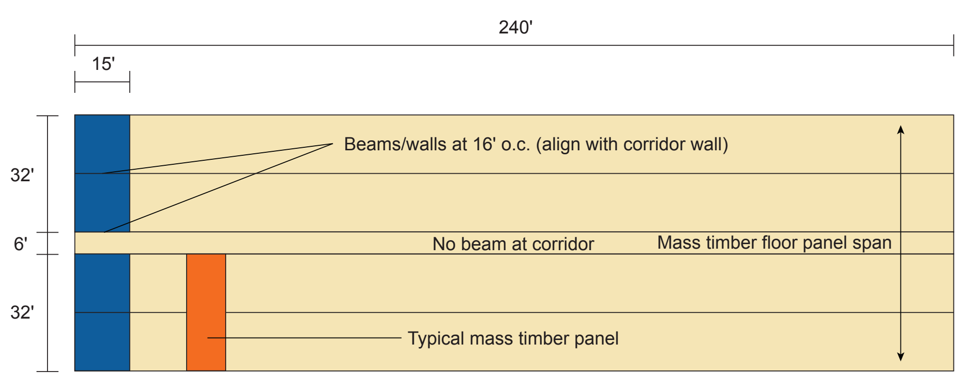


FIGURE 9: Option 2 panel and structure layout

Photo: Engberg Anderson Architects

CLT floor/ceiling panels in a corridor with intermediate beams at Timber Lofts / Engberg Anderson Architects

In Option 1, the floor panels over the corridor may be supported on shallow beams that align with adjacent beams/walls, or span in their weak axis direction with no supplemental support (see photo top left). When using Option 1, the columns could be located at or near the corridor and exterior walls—particularly when the main framing system is beams and columns (vs. bearing walls). (See Figure 13.)

An alternative would be to locate the corridor side columns further into the unit space such that it creates three equal beam spans as shown in Figure 14. This requires beams framing across the corridor, but also allows a reduction in the beam depths within the units. One potential downside with this option is that the beams spanning across the corridor are deeper and therefore have a greater impact on routing main MEPF lines within the corridor.

Adohi Hall, a student residence at the University of Arkansas in Fayetteville, AR, utilized this concept. A 20-foot grid increment was used to form three equal bays in the 60-foot-wide building. The CLT manufacturer provided 40-foot-long panels, resulting in the use of one full-length and one half-length panel to achieve the full 60-foot building width. Because each 20-foot panel was simply a full-length panel cut in half, this was a highly efficient approach that minimized waste.

For more information on the grid design and panel layout in mass timber buildings, see the WoodWorks Expert Tip, *Creating Efficient Structural Grids in Mass Timber Buildings.*

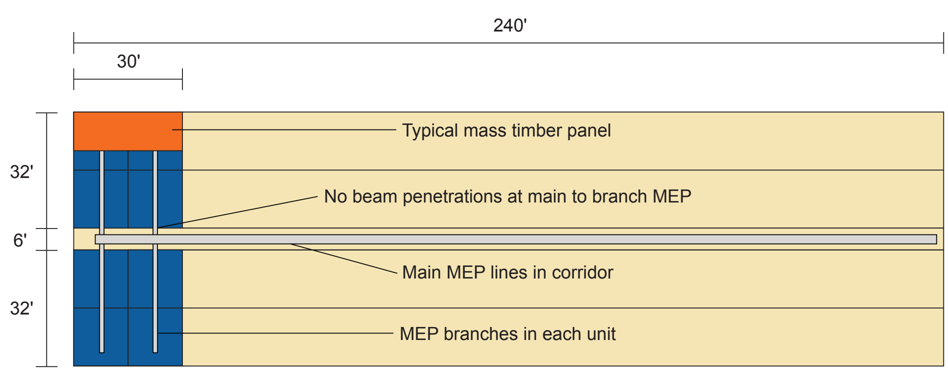


FIGURE 10: Option 1 MEPF layout

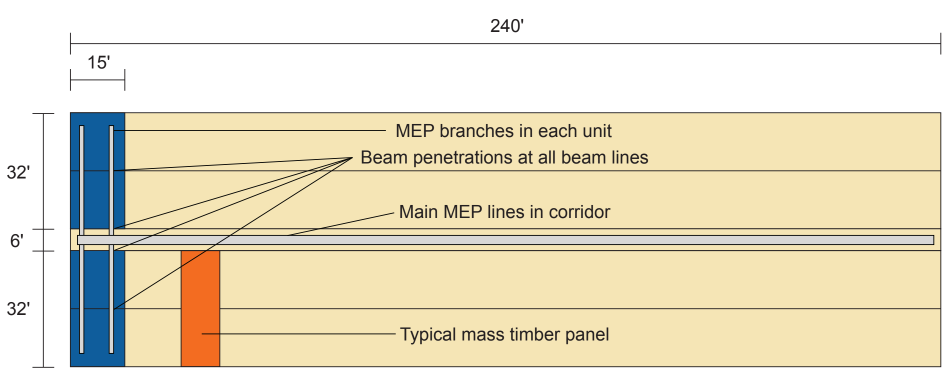


FIGURE 11: Option 2 MEPF layout

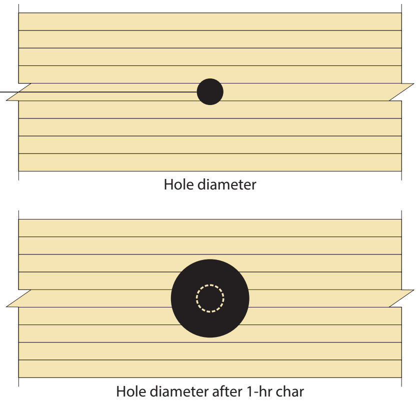


FIGURE 12: Impact of fire on glulam beam penetrations.

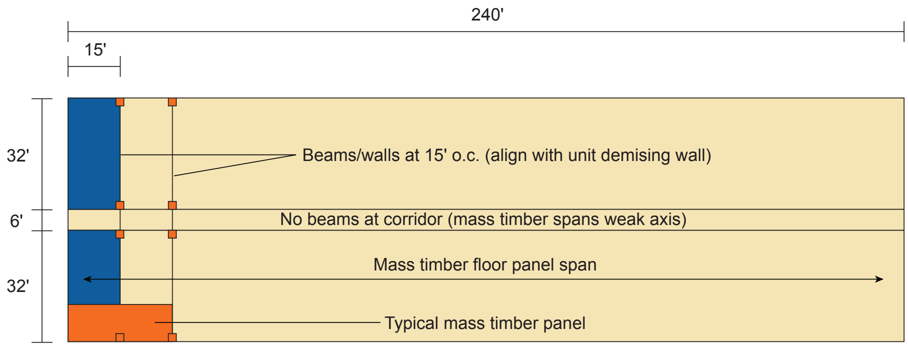


FIGURE 13: Option 1 layout with columns located along corridor walls and exterior walls

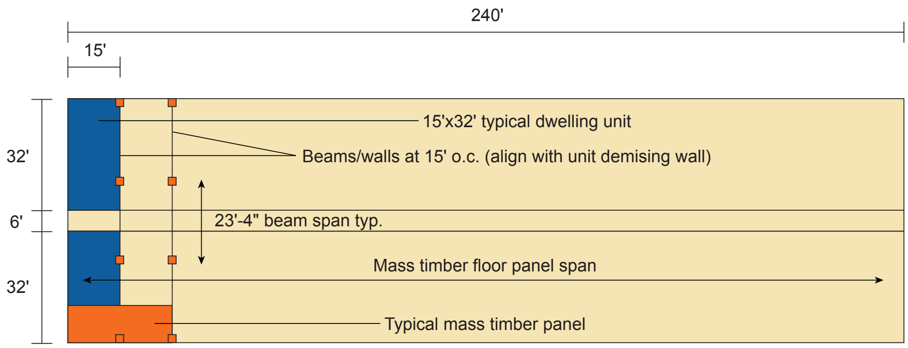


FIGURE 14: Option 1 layout with columns located within unit demising walls to create three equal beam spans

Additional resources on mass timber structural design:

- *U.S. Mass Timber Floor Vibration Design Guide* – WoodWorks
- *Cross-Laminated Timber Structural Floor and Roof Design* – STRUCTURE magazine
- *CLT Diaphragm Design Guide* – WoodWorks
- *CLT Layups and Basis of Design for Gravity Load Applications* – WoodWorks
- *Creating Efficient Structural Grids in Mass Timber Buildings* – WoodWorks
- *Cross-Laminated Timber Shear Wall* – American Wood Council

Browse a wide range of technical resources, including those highlighted throughout this paper, at woodworks.org.

Other MEPF Integration Options

Although more commonly used for office buildings than affordable multi-family housing, there are other MEPF integration options that could be evaluated for applicability. The first is a raised access floor system, where a cavity is created on top of the floor. This type of system can be shallow to accommodate data and electric, or deeper to accommodate air distribution.

Photo: Global IFS

Raised access floor being installed in a mass timber building

Another option is routing electrical and fire suppression systems in chases or gaps between mass timber floor panels. In this scenario, the chases should not run continuously from one unit to the next due to concerns with noise spread, smoke migration, and other potential issues.

Photo: KPFF

Gapped mass timber panels with electrical routed in chases at the PAE Living Building

A concrete topping slab is commonly added on top of mass timber floor panels to improve acoustic performance. The topping slab can also house electrical conduit or radiant heat tubing.

Photo: Alex Schreyer

Electrical conduit placed above mass timber floor panel prior to topping slab pour at the John W. Olver Design Building at UMass Amherst / Leers Weinzapfel Associates

In mass timber multi-family buildings, it is usually desirable to maximize timber ceiling exposure—which goes hand in hand with minimizing MEPF exposure. Knowing that the heaviest concentrations of MEPF services will be in bathrooms and kitchens, a dropped ceiling may be employed in these areas of a dwelling unit, leading to more exposure (no dropped ceilings) in living areas and bedrooms. Dropped ceilings below mass timber floor panels do create combustible concealed spaces, and applicable IBC and National Fire Protection Association (NFPA) requirements need to be met. See the WoodWorks publication, ***Concealed Spaces in Mass Timber and Heavy Timber Structures***, for an explanation of these requirements and design routes for compliance.

Photo: Nick Johnson, Tour D Space

Dropped ceiling over kitchen area at INTRO Cleveland / Hartshorne Plunkard Architecture

Alternatively, designers of some affordable housing projects have chosen to expose both the mass timber and MEPF services. This was the case at Sonrisa as shown in the photo below.

Photo: Capitol Area Development Authority

Exposed MEPF at Sonrisa / 19six Architects

Lateral System Options

Common lateral force-resisting systems used in the mass timber structural typologies discussed earlier are as follows:

- Mass timber floors and roofs on mass timber bearing walls – Lateral system is typically mass timber shear walls
- Mass timber floors and roofs on light-frame bearing walls – Lateral system is typically light-frame wood shear walls (wood structural panels added to some or all interior and exterior walls) or steel stud shear walls
- Mass timber floors and roofs on post and beam framing – Lateral system is commonly concrete core shear walls or structural steel braced frames

CLT shear walls have been used on some U.S. projects. The 2021 SDPWS now includes narrative on their construction, and ASCE 7-22 contains the following seismic response coefficients for two types:

- CLT shear walls, R=3
- CLT shear walls with shear resistance provided by high-aspect-ratio panels only, R=4

It is important to note that these options rely on a platform-framed floor-to-wall detail.

In 2023, a 10-story mass timber structure was successfully tested on the University of California, San Diego's Natural Hazards Engineering Research Infrastructure (NHERI) shake table. The evaluations were designed to simulate the most destructive earthquakes ever recorded. The structure included a full-height rocking CLT shear wall and researchers determined that the building sustained no damage from the series of tests. This has potential implications for eventual inclusion of rocking CLT shear walls in the building code as a prescriptive seismic force-resisting system for high-rise structures.

Light-frame wood shear walls have been widely used on many projects for many years. The nuances of wood stud shear wall design in common mid-rise multi-family projects (e.g., lack of solid exterior walls, the need to assess flexible vs. semi-rigid vs. rigid diaphragms) are also applicable to mass timber and light-frame hybrid projects. Wind and seismic design forces for these shear walls and diaphragms are obtained from ASCE 7, and design values for light-frame shear walls and diaphragms can be found in the SDPWS. The 2021 SDPWS was the first version to include narrative on the design of CLT diaphragms, and WoodWorks' ***CLT Diaphragm Design Guide*** offers extensive information on this topic.

Photo: SA+R Architects

CLT shear walls at the University of Denver Burwell Center

The design of non-wood vertical lateral force-resisting systems in mass timber projects is largely the same as it would be in a building framed entirely with those non-wood systems. The primary differences exist at the mass timber (panels and/or beams) to non-wood connections, usually concrete cores or steel braced frames. For example:

- Mass timber structures can experience vertical movement due to shrinkage and column axial shortening.
- Masonry shaft walls expand due to moisture or thermal changes.
- Structural steel framing does not shrink due to moisture change but may move with thermal changes.
- Concrete core walls shrink, but much less than mass timber.

This differential movement can create issues with the function and performance of structural connections, finishes, openings, enclosures, MEPF systems, and more. One of the primary means of addressing potential issues is to limit vertical movements of the timber structure while also using detailing strategies that can accommodate horizontal and vertical adjustability.

One option is to cast a steel embed plate with the concrete core shear wall, making it oversized relative to the steel ledger angle that will ultimately be attached. The connecting CLT panel or glulam beam are fabricated to allow a small gap to exist between the end of the panel/beam and face of the wall, sized as a function of the tolerance limits for the face of wall location and length of the panel/beam. Vertical adjustability is provided by the oversized embed plate, allowing the steel angle to be field welded to the plate once final elevations are determined (and ideally once some shrinkage and settlement has occurred). For more information on the vertical movement of timber structures relative to other materials, see the WoodWorks publication, *Differential Material Movement in Tall Mass Timber Structures.*

Steel braced frames have also been used as lateral force-resisting systems in affordable housing projects, such as Heartwood in Seattle. Sequencing of construction is a consideration in this scenario, as timber and steel are commonly installed in tandem whereas concrete core walls are installed prior to the timber.

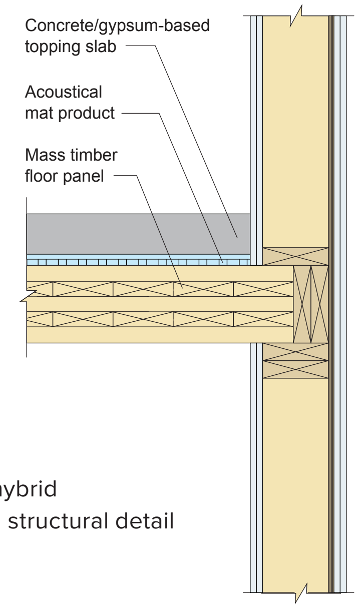


FIGURE 15: Typical hybrid floor-to-exterior wall structural detail

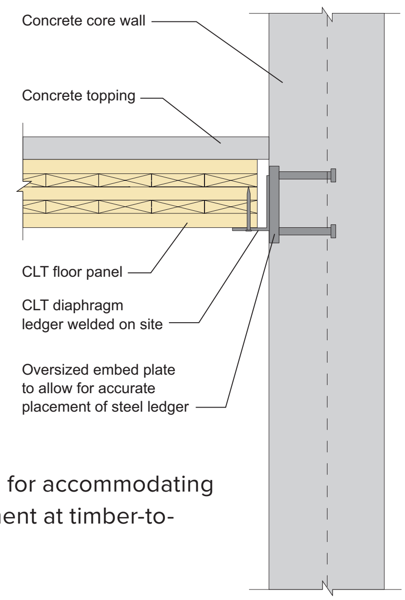


FIGURE 16: Option for accommodating differential movement at timber-to-concrete wall

Conclusion

Mass timber's use in affordable, multi-family projects has increased over the past few years, and new provisions for taller timber buildings in the 2021 and 2024 IBC are accelerating that growth. Mass timber systems can be cost competitive in this building typology, either alone or in hybrid configurations. The key to efficient design is understanding what the code allows while optimizing unit layouts, timber spans, and assemblies to match these allowances.

For more information on projects featured in this paper (and many others), visit the WoodWorks Innovation Network (WIN). *woodworksinnovationnetwork.org*

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