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# Fire Design of Mass Timber Members

## Code Applications, Construction Types and Fire Ratings

For many years, exposed heavy timber framing elements have been permitted in U.S. buildings due to their inherent fire-resistance properties. The predictability of wood's char rate has been well-established for decades and has long been recognized in building codes and standards.

Today, one of the exciting trends in building design is the growing use of mass timber—i.e., large solid wood panel products such as cross-laminated timber (CLT) and nail-laminated timber (NLT)—for floor, wall and roof construction. Like heavy timber, mass timber products have inherent fire resistance that allows them to be left exposed and still achieve a fire-resistance rating (FRR). Because of their strength and dimensional stability, these products also offer an alternative to steel, concrete, and masonry for many applications, but have a much lighter carbon footprint. It is this combination of exposed structure and strength that developers and designers across the country are leveraging to create innovative designs with a warm yet modern aesthetic, often for projects that go beyond traditional norms.

This paper has been written to support architects and engineers exploring the use of mass timber for commercial and multi-family construction. It focuses on how to meet fire-resistance requirements in the International Building Code (IBC), including calculation and testing-based methods. Unless otherwise noted, references refer to the 2021 IBC.

### Mass Timber & Construction Type

Before demonstrating FRRs of exposed mass timber elements, it's important to understand under what circumstances the code currently allows the use of mass timber in commercial and multi-family construction.

A building's assigned construction type is the main indicator of where and when all wood systems can be used. IBC Section 602 defines five main options (Type I through V); Types I, II, III and V have subcategories A and B, while Type IV has subcategories IV-HT, V-A, IV-B, and IV-C. Types III, IV and V permit the use of wood framing throughout much of the structure and are used extensively for modern mass timber buildings.

***Type III*** (IBC 602.3) – Timber elements can be used in floors, roofs and interior walls. Fire-retardant-treated wood (FRTW) framing is permitted in exterior walls required to have an FRR of 2 hours or less.

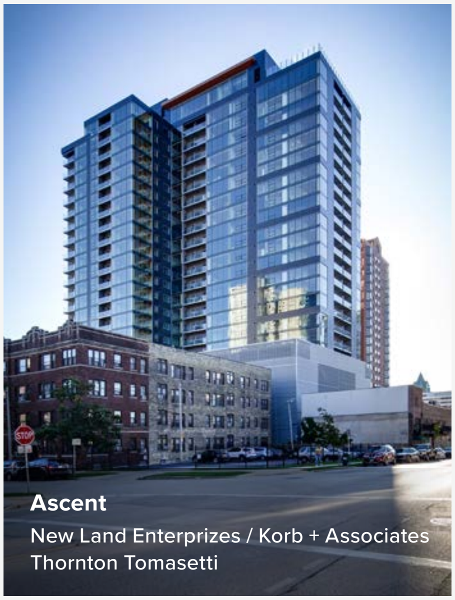
***Type V*** (IBC 602.5) – Timber elements can be used throughout the structure, including floors, roofs and both interior and exterior walls.


**University of Washington Founders Hall**
LMN Architects / Magnusson Klemencic Associates

Photo: Tim Griffith

## Common Mass Timber Products

Wood's potential from a carbon footprint perspective is much broader than many thought possible. Worldwide, mass timber buildings are now surpassing 20 stories, and the IBC allows up to 18 stories in the U.S. While innovative systems continue to be developed within the mass timber category, common products currently include:



**Ascent**
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***Cross-laminated timber*** *(CLT)* – CLT consists of layers of dimension lumber (typically three, five, or seven plies) oriented at right angles to one another and then glued to form structural panels with exceptional strength, dimensional stability, and rigidity. CLT can be used for walls, floors, and roofs—as a stand-alone system or with other structural products (e.g., post and beam)—and is often left exposed on the interior of buildings. Because of the cross-lamination, CLT offers two-way span capabilities.

***Glued-laminated timber*** *(glulam or, when used as panels, GLT)* – Glulam is composed of individual wood laminations (dimension lumber), selected and positioned based on their performance characteristics and bonded together with durable, moisture-resistant adhesives. These adhesives are applied to the wide face of each lamination. Glulam has excellent strength and stiffness properties, and is available in a range of appearance grades. It is typically used as beams and columns, but can be used in the plank orientation for floor or roof decking. It can also be curved and bent, lending itself to the creation of unique structural forms.

***Nail-laminated timber*** *(NLT)* – NLT is created from individual dimension lumber members (2-by-4, 2-by-6, etc.), stacked on edge and fastened with nails or screws to create a larger structural panel. Commonly used in floors and roofs, it offers the potential for a variety of textured appearances in exposed applications. Like glulam, NLT lends itself to the creation of unique forms, and wood structural panels (WSPs) can be added to provide a structural diaphragm.

***Dowel-laminated timber*** *(DLT)* – Common in Europe and gaining popularity in the U.S., DLT panels are made from softwood lumber boards (2-by-4, 2-by-6, etc.) stacked like the boards of NLT but friction-fit with hardwood dowels. The dowels hold each board side-by-side, while the friction fit adds dimensional stability.

***Structural composite lumber*** *(SCL)* – SCL is a family of wood products created by layering dried and graded wood veneers, strands, or flakes with moisture-resistant adhesive into blocks of material, which are subsequently re-sawn into specified sizes. Two SCL products—laminated veneer lumber (LVL) and laminated strand lumber (LSL)—are relevant to the mass timber category as they can be manufactured as panels in sizes up to 8 feet wide, with varying thicknesses and lengths. Parallel strand lumber (PSL) columns are also commonly used in conjunction with other mass timber products.

***Tongue and groove decking*** *(T&G)* – Structural T&G decking is made from lumber at least 1-1/2 inches thick, with the flat (wide) face laid over supports such as beams or purlins for floors and roofs. Available in a variety of species, thicknesses and lengths, it is used where the appearance of exposed wood decking is desired for aesthetics or where its mass is desired for fire resistance.

***Type IV*** (IBC 602.4) – Commonly 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 was renamed IV-HT and given three subcategories, IV-A, IV-B and IV-C. 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. Type IV-HT structural wood components are permitted in floors, roofs and interior walls when they meet minimum cross-section sizes. Per IBC Sections 602.4.4.1 and 602.4.4.2, walls in Type IV-HT projects required to have an FRR of 2 hours or less are also permitted to use FRTW framing, or CLT when covered with FRTW sheathing or noncombustible materials. In general, heavy timber components used in Type IV-HT construction can be exposed.

In Types IV-A, IV-B and IV-C buildings, mass timber components are permitted in floors, roofs, interior walls and exterior walls when they meet the minimum cross-section sizes, required FRRs, and timber exposure limits as noted in IBC Sections 602.4.1, 602.4.2 and 602.4.3. For additional information on the fire resistance and timber exposure limits of tall mass timber structures, see the WoodWorks publication, *Demonstrating Fire-Resistance Ratings for Mass Timber Elements in Tall Wood Structures.*

## Heavy Timber Requirements

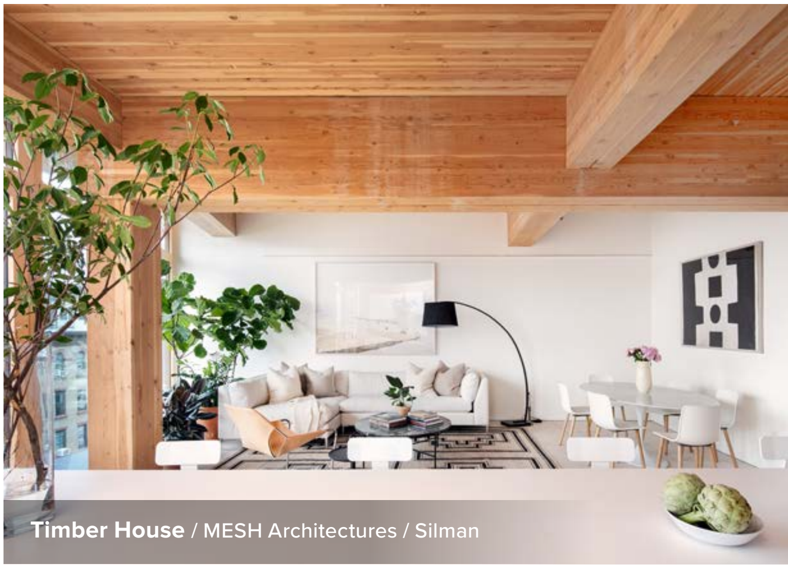
The fire resistance of heavy timber construction is based on the inherent size of large timber elements. In a fire, large members tend to retain their load-carrying ability longer than members with small cross-sections; this is because a char layer forms on the surface while the interior remains undamaged and structurally sound. IBC Section 2304.11 provides minimum heavy timber sizes for columns, floor framing and decking, roof framing and decking, and walls.

These minimum nominal sizes are applicable to solid sawn wood members. However, in consideration of engineered wood products, IBC Table 2304.11 provides equivalent glulam and SCL sizes that qualify as heavy timber.

**TABLE 1:** Heavy Timber Miniumum Member Sizes

| Application | Minimum Nominal Size |
|---|---|
| Floor decking | 3" decking planks w/ 15/32" WSP*; or 4" boards on edge (NLT) w/ 15/32" WSP; or 4" CLT |
| Roof decking | 2" decking planks; or 3" boards on edge (NLT); or 3" CLT |

*Source: IBC Section 2304.11*
**WSP = Wood Structural Panel*



**Timber House** / MESH Architectures / Silman

Photo: Travis Mark

**TABLE 2:** Minimum Dimensions of Heavy Timber Structural Members

| Supporting | Heavy Timber Structural Elements | Minimum Nominal Solid Sawn Size | | Minimum Glued-Laminated Net Size | | Minimum Structural Composite Lumber Net Size | |
|---|---|---|---|---|---|---|---|
| | | Width, inch | Depth, inch | Width, inch | Depth, inch | Width, inch | Depth, inch |
| Floor loads only or combined floor and roof loads | Columns | 8 | 8 | 6-3/4 | 8-1/4 | 7 | 7-1/2 |
| | Wood beams and girders | 6 | 10 | 5 | 10-1/2 | 5-1/4 | 9-1/2 |
| Roof loads only | Columns | 6 | 8 | 5 | 8-1/4 | 5-1/4 | 7-1/2 |
| | Framed timber trusses and other roof framing[a] | 4[b] | 6 | 3[b] | 6-7/8 | 3-1/2[b] | 5-1/2 |

*Source: IBC Table 2304.11 / See IBC for footnotes*

## Fire-Resistance Rating Requirements

The IBC defines FRR as *the period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by the tests, or the methods based on tests, prescribed in Section 703.*

## FRR based on Construction Type

The construction type of a building determines many of the minimum required FRRs for different building components, as shown in IBC Table 601.

A couple features of this table are relevant to mass timber.

Footnote c allows for timber components meeting the requirements of heavy timber to be used in the construction of all roofs having an FRR of 1 hour or less in lieu of the required FRR. This means that a mass timber roof meeting the minimum size requirement of heavy timber can be used in construction Types I-B, II-A and II-B, which otherwise prohibit the use of combustible framing.

Interior nonbearing walls and partitions generally do not have an FRR, except for Type IV construction.

## Other FRR Requirements

In addition to requirements related to construction type, there are other requirements for FRRs in the IBC. For multi-unit residential buildings, walls and floors between dwelling or sleeping units are required to have an FRR of 1/2 hour in Type II-B, III-B and V-B construction when sprinklered throughout with an NFPA 13 system, and 1 hour for all other construction types (IBC 420, 708 and 711). Multiple separated occupancies (IBC 508.4), incidental uses (IBC 509), and special provisions (IBC 510) also require FRRs of select components and assemblies.

## Selecting a Construction Type

Selection of construction type for mass timber projects is one of the more significant design considerations. While it's common to choose construction type based on structural material—i.e., to assume that steel and concrete structures should be Type II, light-frame wood should be Type V, and exposed heavy timber should be Type IV—this approach can lead to additional costs. While Type IV construction can be used for exposed mass timber projects, a full understanding of the allowable use of materials in all five construction types, as well as the unique allowances and limitations associated with each, will help to inform the most efficient design.

**TABLE 3:** FRR Requirements for Building Elements (Hours)

| Building Element | Type I | | Type II | | Type III | | Type IV | | | | Type V | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | HT | IV-A | IV-B | IV-C | A | 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<br>Exterior[e,f]<br>Interior | 3<br>3[a] | 2<br>2[a] | 1<br>1 | 0<br>0 | 2<br>1 | 2<br>0 | 2<br>1/HT | 3<br>3 | 2<br>2 | 2<br>2 | 1<br>1 | 0<br>0 |
| Nonbearing walls and partitions Exterior | See Table 602 | | | | | | | | | | | |
| Nonbearing walls and partitions Interior[d] | 0 | 0 | 0 | 0 | 0 | 0 | See Section 2304.11.2 | 3 | 2 | 2 | 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) | 1-1/2[b] | 1[b,c] | 1[b,c] | 0[c] | 1[b,c] | 0 | HT | 1-1/2 | 1 | 1 | 1[b,c] | 0 |

*Source: IBC Table 601 / See IBC for footnotes*

**TABLE 4:** Comparison of Construction Types III, IV-HT and V

| Construction Type | III-A | III-B | IV-HT | IV-A | IV-B | IV-C | V-A | V-B |
|---|---|---|---|---|---|---|---|---|
| Exterior wall materials | FRTW | FRTW | FRTW or CLT | CLT | CLT | CLT | Any wood including mass timber | Any wood including mass timber |
| Exterior bearing wall FRR | 2-hour | 2-hour | 2-hour | 3-hour | 2-hour | 2-hour | 1-hour | 0-hour |
| Interior framing materials | Any wood including mass timber | Any wood including mass timber | Heavy timber including mass timber | Heavy timber including mass timber | Heavy timber including mass timber | Heavy timber including mass timber | Any wood including mass timber | Any wood including mass timber |

*Sources: IBC Section 602, Table 601 and Section 2304.11*

To optimize a building design from a construction type perspective, it is best to start with Type V-B construction and work up toward higher construction types. This avoids unnecessary defaults or assumptions—and unnecessary costs. The fact that certain materials are being used doesn't mean there is only one option for construction type. Similarly, a mix of occupancy groups doesn't dictate that certain materials, construction types or building configurations are required. For example, a mass timber building may have isolated steel, concrete or masonry structural elements, but this doesn't mean that Type I or II construction is necessary, nor does it mean that some or all of the building can't be framed with mass timber. Likewise, a building with mass timber elements has options other than Type IV construction. Note IBC Section 602.1.1:

> ***602.1.1 Minimum requirements.*** *A building or portion thereof shall not be required to conform to the details of a type of construction higher than that type which meets the minimum requirements based on occupancy even though certain features of such a building actually conform to a higher type of construction.*

This section permits the use of elements commonly used in a higher construction type without requiring that the entire building meet all of the provisions of that construction type. For example, if a building's size permitted the use of Type V-B construction, it could still be completely framed with noncombustible materials while being classified as V-B. Similarly, a Type III or V building could be framed with a combination of combustible and noncombustible materials.

As noted, from a cost efficiency perspective, it is usually best to start a building analysis with Type V-B construction as this provides the most flexibility in terms of allowable use of materials throughout the building while minimizing requirements for fire resistance-rated assemblies and structural elements. However, Type V-B is also the most restrictive in terms of allowable building size. All three of these factors—allowable building size, allowable use of structural materials, and required fire-resistance levels—are interconnected.

Construction type, which is a direct function of the types of materials used in a building (and vice versa) looks at limiting the size of the building based on fire and life safety risks. In other words, how much of a building's contents and structure are combustible has an impact on presumed risk, which in turn affects the code's allowances for building size. Fire-resistant measures required of the building's structure dictate the length of passive fire endurance (i.e., 1 hour, 2 hours).

If Type V-B construction doesn't allow as large a building as desired, the next step is to check Type V-A. The main differences between V-B and V-A are FRR requirements and allowable building size. If Type V-A doesn't allow the desired size, Type III-B is the next choice, with Type III-A following. Type IV construction has similar allowable building size limits as Type III-A; however, there are nuances to the selection of one or the other as discussed below.

Table 4 summarizes the main differences between construction Types III, IV and V, as well as the different types of wood systems permitted in each. These allowances are shown in IBC Section 602, Table 601 and Section 2304.11.

**TABLE 5:** Comparison of Construction Types III and IV-HT: Group B Occupancy

| | Type III-A | Type IV-HT | IBC 2021 Reference |
|---|---|---|---|
| **Allowable Height/Area** | | | |
| Base allowable area per story[1, 2] | 85,500 | 108,000 | Table 506.2 |
| Allowable stories[1] | 6 | 6 | Table 504.4 |
| Allowable building height[1] | 85' | 85' | Table 504.3 |

*[1]NFPA 13 sprinklered throughout building per IBC Section 903.3.1.1*
*[2]No frontage increase included*

| | | | |
|---|---|---|---|
| **Rating Requirements** | | | |
| Primary structural frame | 1-hour | HT | Table 601 |
| Exterior bearing walls | 2-hours | 2-hours | |
| Interior bearing walls | 1-hour | 1-hour/HT | |
| Nonbearing exterior walls | Table 602 | Table 602 | |
| Nonbearing interior walls | 0-hour | 1-hour or per 2304.11.2.2 | |
| Floor construction & associated secondary members | 1-hour | HT | |
| Roof construction & associated secondary members | 1-hour[3] | HT | |
| *[3]Note ability to use heavy timber in Type III-A roof construction in lieu of FRR*<br>*HT = Heavy Timber – See minimum wood member sizes per IBC 2304.11* | | | Table 601 footnote c |
| **Other Considerations** | | | |
| FRTW required in exterior walls | Yes | Yes (except CLT) | Sections 602.3 & 602.4.4.1 |
| CLT allowed in exterior walls | No | Yes with stipulations | Section 602.4.4.2 |
| Concealed spaces in floor systems allowed | Yes | Yes | Sections 602.3 & 602.4.4.3 |
| Exterior wall projections | Any approved material | Any approved material | Section 705.2.2 |
| Interior finish requirements | Table 803.11 | Exempt | Section 803.3 |
| Minimum roof covering classification | B | B | Section 1505.1 |

## Concealed Spaces in Type IV Construction

As of the 2021 IBC, concealed spaces are permitted in Type IV-HT heavy timber construction provided one or more of the following measures are in place:

- The building is sprinklered throughout and sprinkler protection is provided in the concealed space
- Combustible surfaces framing the concealed space are protected with 5/8-inch Type X gypsum board
- The concealed space is completely filled with a noncombustible material such as mineral wool insulation

For more information, see the WoodWorks publication, *Concealed Spaces in Mass Timber and Heavy Timber Structures.*

When looking to maximize the code's current allowances in terms of building size for mass timber structures, considering the differences between Type III-A and IV-HT construction is important. For example:

- Types III-A and IV-HT permit concealed spaces, but protection requirements vary. For Type III-A, protection of concealed spaces is not prescriptively addressed. Concealed spaces in IV-HT construction are addressed in IBC 602.4.4.3.
- Except for exterior bearing walls, Type IV does not require demonstration of FRRs for structural elements. This is a requirement for all other construction types, including III-A (but only when an FRR is required).
- Type IV-HT construction allows the use of CLT in exterior walls; Type III does not.

Table 5 illustrates these differences and others for a Group B occupancy building.

The requirements of Type IV-HT construction for all interior partition walls to be solid wood or 1-hour rated can significantly impact its utility for some applications. The alternative of using Type III construction (or Type V where building size permits) avoids this limitation; however, the processes for demonstrating FRRs also vary between Type IV-HT and Types III and V. Methods for meeting FRR requirements for mass timber elements in buildings other than Type IV-HT construction are the focus of the rest of this paper.

## Methods to Demonstrate FRRs of Mass Timber

When a mass timber building element or assembly is required to have an FRR, IBC Section 703.2 requires the rating to be determined by testing in accordance with ASTM E 119 (or UL 263) or via one of six alternatives listed in IBC Section 703.2.2:

> *The required fire resistance of a building element, component or assembly shall be permitted to be established by any of the following methods or procedures:*
>
> 1. *Fire-resistance designs documented in approved sources*
> 2. *Prescriptive designs of fire resistance-rated building elements, components or assemblies as prescribed in Section 721*
> 3. *Calculations in accordance with Section 722*
> 4. *Engineering analysis based on a comparison of building element, component or assemblies designs having fire-resistance ratings as determined by the test procedures set forth in ASTM E119 or UL 263*
> 5. *Fire-resistance designs certified by an approved agency*

These alternatives are options when the exact assembly has not been tested per ASTM E 119 and a test report is therefore not available. They are all founded on ASTM E 119 testing.

There are currently limited options for fire resistance-rated mass timber assemblies from approved sources (e.g., Gypsum Association GA-600, American Wood Council's *Design for Code Acceptance 3 – Fire Resistance-Rated Wood Floor and Wall Assemblies*, [DCA 3]) or certification agencies (e.g., UL listings). However, an increasing number of assemblies have been tested according to the ASTM E119 standard and are available publicly or on request from manufacturers. The number of available tested assemblies can also be expanded using comparative engineering analysis described in Item 4 of IBC Section 703.2.2. Such an analysis, which seeks to justify the FRR of an assembly or component similar to one that has passed an E119 test, can be performed by a fire protection engineer.

Item 3 of IBC Section 703.2.2, which permits the use of calculations in accordance with Section 722, is also frequently used to demonstrate the FRR of exposed mass timber. IBC Section 722.1 states: *The calculated fire resistance of exposed wood members and wood decking shall be permitted in accordance with Chapter 16 of ANSI/AWC National Design Specification® for Wood Construction (NDS®).* Chapter 16 of the NDS can be used to calculate up to a 2-hour FRR for a variety of exposed wood members, including solid sawn, glulam, SCL, and CLT.

## ASTM E119 Testing Method

According to Section 4.2 of ASTM E119-18, the fire test procedure is intended to do the following:

> *The test exposes a test specimen to a standard fire controlled to achieve specified temperatures throughout a specified time period. When required, the fire exposure is followed by the application of a specified standard fire hose stream applied in accordance with Practice E2226. The test provides a relative measure of the fire-test-response of comparable building elements under these fire exposure conditions. The exposure is not representative of all fire conditions because conditions vary with changes in the amount, nature and distribution of fire loading, ventilation, compartment size and configuration, and heat sink characteristics of the compartment. Variation from the test conditions or test specimen construction, such as size, materials, method of assembly, also affects the fire-test-response. For these reasons, evaluation of the variation is required for application to construction in the field.*

Successful fire tests have been completed on numerous mass timber elements and assemblies, achieving FRRs of 3 hours or more. Additional tests by manufacturers and others are ongoing. Most tests are conducted according to ASTM E119 or its Canadian equivalent, ULC S101. Both utilize the same time-temperature curve and performance criteria and, as such, ULC S101 fire tests are usually acceptable to U.S. building officials. However, each project's building official should be consulted if choosing this design route.

To help building designers compare options, WoodWorks has compiled a web-based inventory of completed mass timber fire tests. The *Inventory of Fire Resistance-Tested Mass Timber Assemblies & Penetrations* is updated as new tests become available, and is available at woodworks.org.

**FIGURE 1:** Code Path for Exposed Wood Fire-Resistance Calculations

**IBC 703.2.2**
**Methods for determining fire resistance**

- Prescriptive designs per IBC 721.1
- ***Calculations in accordance with IBC 722***
- Fire-resistance designs documented in sources
- Engineering analysis based on a comparison

**IBC 722**
**Calculated Fire Resistance**

"The calculated *fire resistance* of exposed wood members and wood decking shall be permitted in accordance with **Chapter 16 of ANSI/AWC National Design Specification for Wood Construction (NDS)**

**NDS Chapter 16**
**Fire Design of Wood Members**

- Limited to calculating fire resistance up to 2 hours
- Char depth varies based on exposure time (i.e., fire-resistance rating), product type and lamination thickness. Equations and tables are provided.
- TR 10 and NDS commentary are helpful in implementing permitted calculations.

## Calculation-Based Method

As referenced in IBC Section 722.1, NDS Chapter 16 can be used to calculate the structural FRR of various wood products, including solid sawn, glulam, SCL, and CLT.

As noted by Douglas and Smart in *Structure* magazine,[1] "The design procedure allows calculation of the capacity of exposed wood members using basic wood engineering mechanics. Actual mechanical and physical properties of the wood are used, and member capacity is directly calculated for a given period of time—up to 2 hours. Section properties are computed using an effective char depth, $a_{eff}$, at a given time, t. Reductions of strength and stiffness of wood directly adjacent to the char layer are addressed by accelerating the char rate by 20 percent. Average member strength properties are approximated from existing accepted procedures used to calculate design properties. Finally, wood members are designed using accepted engineering procedures found in NDS for allowable stress design."

The American Wood Council's (AWC's) *Technical Report 10 – Calculating the Fire Resistance of Wood Members and Assemblies* (TR 10) provides an in-depth explanation of the concepts and background associated with exposed wood fire design. This document also includes a number of design examples for exposed structural wood members utilizing the provisions of NDS Chapter 16.

***Structural Design Calculations under Fire Conditions***

When utilizing the char calculation option of NDS Chapter 16 to demonstrate FRRs, a structural design check must also be done to determine structural adequacy of framing members under fire conditions. One of the main benefits of the char calculation method is that it accounts for the ability that heavy and mass timber have to form a char zone, which insulates the remaining wood cross-section, allowing it to retain structural capacity.

NDS Section 16.2.2 states that, under fire design conditions, the average member strength can be approximated by multiplying reference design values such as $F_b$ by the adjustment factors specified in Table 16.2.2. As indicated in Table 7, an increase in allowable design stresses by a factor ranging from 2.03 to 2.85 is allowed, depending on the stress under consideration.

For example, a 6-3/4-inch x 13-1/2-inch glulam beam with an unadjusted allowable bending stress of 2,400 psi would first be checked for all structural loading conditions and limit states (bending, shear, deflection, vibration and others as applicable) using the full cross-sectional dimensions and adjustment factors per NDS Chapter 5. If this beam were required to have a 1-hour FRR (perhaps as a floor beam in a Type V-A structure) then its effective char depth on all three exposed sides would be 1.8 inches (per NDS Table 16.2.1A). Its cross-sectional dimensions under fire conditions would be:

Width = 6.75" – (2)(1.8") = 3.15"

Depth = 13.5" – 1.8" = 11.7"

This reduced cross-section would then be checked under fire conditions, with allowable design stresses increased by the factors given in NDS Table 16.2.2. For example, a 2.85 increase factor could be applied to allowable bending stresses. AWC's TR 10 provides design examples for a number of exposed timber applications under fire conditions.

The stress adjustment factor, K, to increase the reference design stress is for use when performing a structural capacity check under the fire load condition with allowable stress design (ASD) load combinations (e.g., D + L, etc.). This stress adjustment factor is not intended to be used with load and resistance factor design (LRFD) load combinations, including those intended for extraordinary events such as in ASCE 7-16 Section 2.5.

**FIGURE 2:** Reduction in Member Width and Depth over Time
*Source: TR 10, AWC*

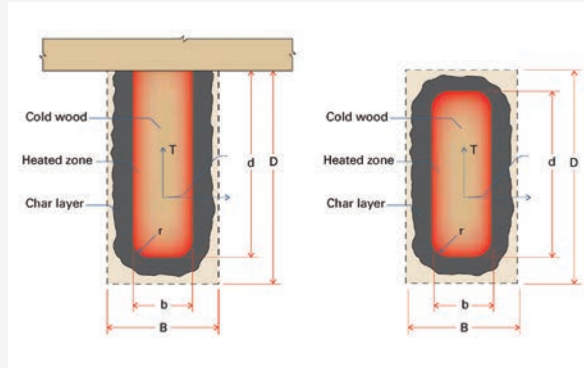



**TABLE 6:** Effective Char Rates and Char Depths (for $ß_n$ = 1.5 inches/hour)

| Required Fire Endurance (hours) | Char Depth, $a_{char}$ (inches) | Effective Char Depth $a_{eff}$ (inches) |
|---|---|---|
| 1<br>1-1/2<br>2 | 1.5<br>2.1<br>2.6 | 1.8<br>2.5<br>3.2 |

*Source: NDS Table 16.2.1A, AWC*

**TABLE 7:** Member Strength Adjustment Factors

| Member Strength | Adjustment Factor, K, for Fire Design |
|---|---|
| Bending strength | 2.85 |
| Beam bucking strength | 2.03 |
| Tensile strength | 2.85 |
| Compressive strength | 2.58 |
| Shear strength | 2.75* |
| Column buckling strength | 2.03 |

*Source: NDS Table 16.2.2, AWC*
**From TR 10 Table 4.1.2, not the NDS*

Appendix A of TR 10 provides design tools for beams and columns of solid sawn, glulam or SCL materials under fire design scenarios using the char calculation provisions of NDS Chapter 16. Table A1 provides a method to quickly check if a beam exposed on three sides passes the structural fire condition check provided the designer knows the beam's size and maximum demand to capacity ratio ($R_s$) under the required non-fire condition using ASD load combinations. Table A2 provides a similar design table for columns exposed on all four sides.

***Thermal Separation***

In addition to establishing structural capacity of exposed wood members under fire conditions, a thermal separation check should be done when using the char depth calculation method. ASTM E119 requires wall and floor/roof assemblies to be checked for thermal separation wherein transmission of heat through the test specimen during the fire exposure period does not raise the average temperature on the unexposed surface more than 250°F (139°C) above its initial temperature. AWC's TR 10 provides further discussion on this as well as design equations for calculating thermal separation ratings for exposed timber assemblies.

## Fire Performance of Glued-Laminated Timber

Mass timber projects often utilize exposed glulam columns and beams. These members are typically considered either part of the building's primary structural frame or its floor/roof construction, and require FRRs per IBC Table 601. Glulam is recognized as a permitted building material in IBC Section 2303.1.3 when manufactured in accordance with ANSI/AITC A 190.1 and ASTM D3737. When required to have an FRR, glulam bending members are unique in that they require core laminations to be substituted for additional tension laminations in order to account for the loss of the lowest lamination(s) due to charring in a fire. NDS Section 16.2.4 requires the following:

> *For structural glued-laminated timber bending members given in Table 5A and rated for 1-hour fire endurance, an outer tension lamination shall be substituted for a core lamination on the tension side for un-balanced beams and on both sides for balanced beams. For structural glued-laminated timber bending members given in Table 5A and rated for 1 1⁄2- or 2-hour fire endurance, two outer tension laminations shall be substituted for two core laminations on the tension side for unbalanced beams and on both sides for balanced beams.*

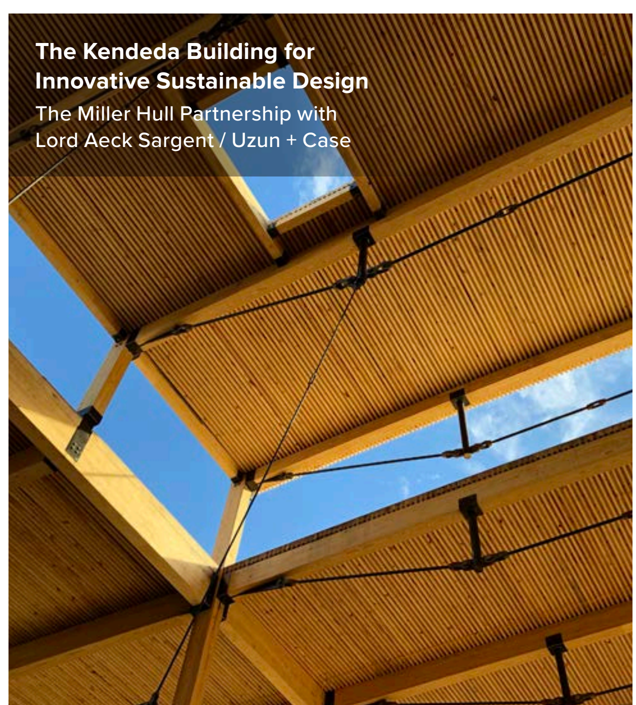
When used as a flat floor or roof panel, the fire-resistance provisions for glulam would match those for NLT, noted in the next section.

Photo: David Barber, ARUP

*Partially charred glulam column pre (left image) and post (right image) 2-hour fire test*

## Fire Performance of Nail-Laminated Timber

Although it has been used in North American buildings for many years, there has been a recent surge of interest in NLT panels for floors, roofs and walls in mass timber buildings. NLT is recognized in IBC Section 2304.9.3 as a permitted building material under the name *mechanically-laminated decking*. Its allowable use is similar to that for exposed, fire resistance-rated glulam. Chapter 16 of the NDS is a valid option for calculating fire resistance of exposed NLT. However, consideration should be given to the entire NLT assembly; it is often combined with a monolithic topping layer to justify uni-directional char behavior, and recent fire testing has demonstrated the validity of this approach. Recent E119 tests of NLT assemblies have shown FRRs determined by testing to be significantly longer than the three-sided char method for timber decking in NDS Chapter 16 applied to NLT. For further discussion, see the *Nail-Laminated Timber Design & Construction Guide*, available at: https://www.thinkwood.com/products-and-systems/mass-timber/nltguide



**The Kendeda Building for Innovative Sustainable Design**
The Miller Hull Partnership with Lord Aeck Sargent / Uzun + Case

Photo: The Miller Hull Partnership

## Fire Performance of Tongue & Groove Decking

T&G decking is recognized in IBC Section 2304.9 as a permitted building material under the name *lumber decking.* Its allowable use is similar to exposed, fire resistance-rated glulam and NLT, and Chapter 16 of the NDS is a valid option for calculating structural fire resistance. In NDS Section 16.2.5, the calculated structural fire resistance of T&G decking is permitted assuming only the underside of the deck is exposed to fire and charring. In contrast, the calculated structural FRR of butt-jointed decking is required to be analyzed with additional charring occurring on the sides; 33% of the effective char depth is used on each side of each plank.

## Fire Performance of Structural Composite Lumber

SCL includes a variety of engineered wood products such as laminated veneer lumber (LVL), laminated strand lumber (LSL) and parallel strand lumber (PSL). These products have been used for years in both residential and commercial light-frame wood construction, but, again, there has been an increase in interest due to their applicability for mass timber buildings. SCL products are recognized as accepted building materials in IBC Section 2303.1.10 when manufactured in accordance with ASTM D5456. As noted in NDS Section 16.2.1, the nominal char rate of 1.5 inches per hour used for solid sawn and glulam members is also applicable to SCL members.

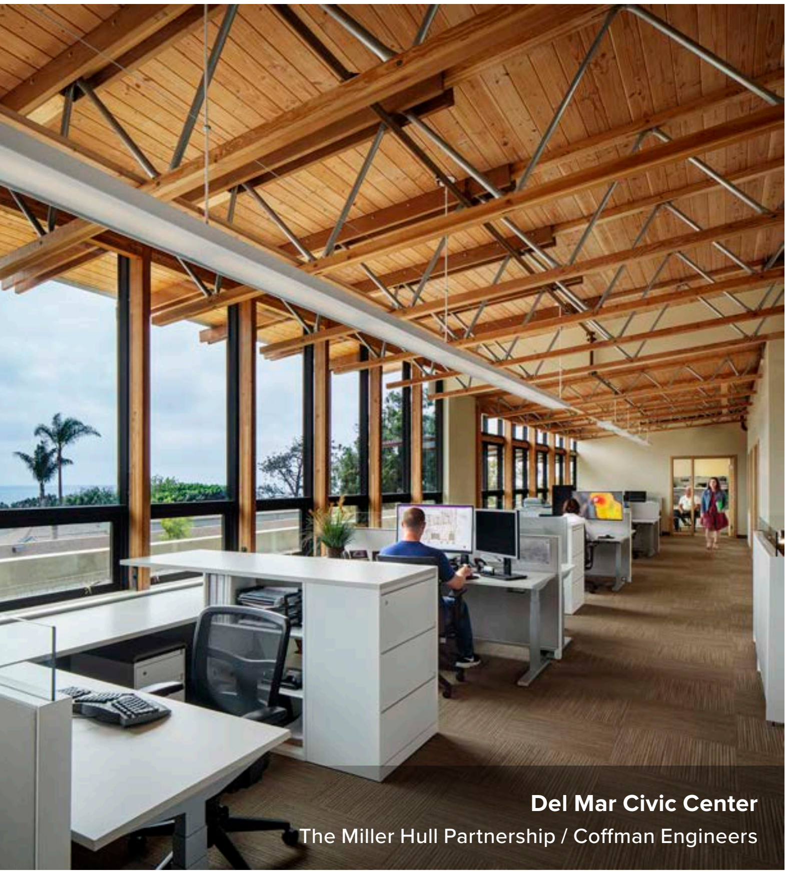


Photo: Chipper Hatter

**Del Mar Civic Center**
The Miller Hull Partnership / Coffman Engineers

**Winthrop Library**
Johnston Architects with Prentice Balance Wickline / Methow Engineering

Photo: Benjamin Drummond, courtesy Johnston Architects

## Fire Performance of Cross-Laminated Timber

CLT has been at the forefront of the mass timber revolution worldwide, including in North America. It is a dimensionally stable solid timber panel that performs well structurally and under fire conditions. CLT was first recognized in the 2015 IBC, Section 2303.1.4, when manufactured in accordance with ANSI/APA PRG 320 – Standard for Performance-Rated Cross-Laminated Timber.

2015 and newer versions of the NDS give char depth calculations for exposed CLT members. These provisions differ from those of solid sawn, glulam and SCL members in that the lamination thicknesses in combination with the required fire-endurance rating determine the effective char depth. The effective char depth for CLT panels is given in NDS Table 16.2.1B.

The calculated fire-resistance method for CLT presented in the 2015 NDS was developed based on full scale ASTM E119 fire tests. Additional discussion on these fire tests and how the CLT fire-resistance calculations presented in NDS Chapter 16 were derived is available in TR 10.

**1 De Haro** / SKS Partners / Perkins&Will / DCI Engineers

Photo: David Wakely

## Fire Protection of Penetrations

It is often necessary to penetrate a fire resistance-rated floor, roof or wall assembly to accommodate mechanical, electrical or plumbing (MEP) service members. These members can range from combustible pipe or tubing, to noncombustible wiring with combustible coverings, to noncombustible members such as pipe, conduit and ductwork. To maintain the continuity and integrity of rated assemblies, penetrations must be properly sealed and protected in accordance with IBC Section 714. Note that Sections 708.7, 707.7, 713.8, and 712.1.4, which cover penetrations in fire partitions, fire barriers, shaft enclosures and horizontal assemblies (respectively), all point to section 714 for their protection.

Section 714.4.1 addresses penetrations in wall assemblies, and gives the following options for demonstrating acceptable protection measures:

1. *Penetrations shall be installed as tested in an approved fire resistance-rated assembly (i.e., incorporated during the conduct of an ASTM E119 test of the wall assembly, per Section 714.4.1.1) or, more commonly,*
2. *Protected by an approved penetration firestop system installed as tested in accordance with ASTM E 814 or UL 1479, with a minimum positive pressure differential of 0.01 inch of water and shall have an F (flame) rating of not less than the required fire-resistance rating of the wall penetrated (per Section 714.4.1.2).*

The requirements for penetration protection in floor/roof assemblies are given in IBC Section 714.5.1 and are similar to those for walls. The main difference is that, when using a tested and approved firestop system, a T (temperature) rating is required for floors, in addition to an F (flame) rating. This requirement is noted in IBC Section 714.5.1.2.

The purpose and construction of common firestop systems are described in the commentary to Section 714.4.1.2:

*A through-penetration firestop system consists of specific materials or an assembly of materials that are designed to restrict the passage of fire and hot gases for a prescribed period of time through openings made*

**TABLE 8:** Effective Char Depths for CLT (for $ß_n$ = 1.5 inches/hour)

| Required Fire Endurance (hour) | Effective Char Depths, $a_{eff}$ (inches) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Lamination thicknesses, $h_{lam}$ (inches) | | | | | | | | |
| | 5/8 | 3/4 | 7/8 | 1 | 1-1/4 | 1-3/8 | 1-1/2 | 1-3/4 | 2 |
| 1 | 2.2 | 2.2 | 2.1 | 2.0 | 2.0 | 1.9 | 1.8 | 1.8 | 1.8 |
| 1-1/2 | 3.4 | 3.2 | 3.1 | 3.0 | 2.9 | 2.8 | 2.8 | 2.8 | 2.6 |
| 2 | 4.4 | 4.3 | 4.1 | 4.0 | 3.9 | 3.8 | 3.6 | 3.6 | 3.6 |

*Source: NDS Table 16.2.1B*

*in fire resistance-rated walls or horizontal assemblies. In certain instances, the through-penetration firestop system is also required to limit the transfer of heat from the fire side to the unexposed side. In order to determine the effectiveness of a through penetration firestop system in restricting the passage of fire and the transfer of heat, firestop systems are required to be subjected to fire testing. ASTM E814 and UL 1479 are the test methods developed specifically for the evaluation of a firestop system's ability to resist the passage of flame and hot gases, withstand thermal stresses and restrict transfer of heat through the penetrated assembly.*

As noted, the more common route for demonstrating protection of penetrations for MEP members through mass timber assemblies is the use of firestop systems tested in accordance with ASTM E814 or UL 1479. Several tests have been conducted for these conditions on mass timber assemblies, which have achieved F and T ratings up to 2 hours. A summary of these tests is included in the *WoodWorks Inventory of Fire Resistance-Tested Mass Timber Assemblies & Penetrations.*

FPInnovations[2]

*Exposed side of an assembly prior to a fire test*

## Fire Protection of Connections

In addition to FRR requirements for structural wood members such as beams, columns and floor/roof panels, connections between members (e.g., beam-to-column connections) must have sufficient protection to provide the same FRR. Section 16.3 of the NDS states:

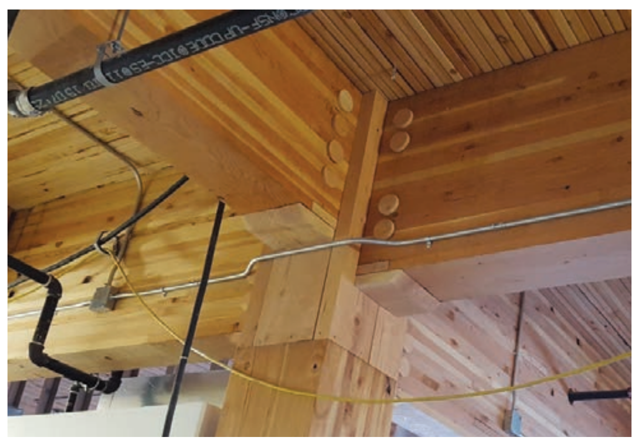
*Wood connections, including connectors, fasteners, and portions of wood members included in the connection design, shall be protected from fire exposure for the required fire-resistance time. Protection shall be provided by wood, fire-rated gypsum board, other approved materials, or a combination thereof.*

*Unprotected exposed connections*

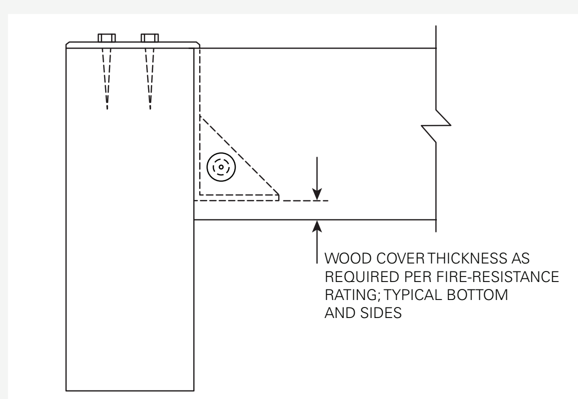
As noted in NDS Section 16.3, options for protecting connections include:

- Concealed connections protected by charring of wood
- Fire-rated gypsum board
- Other materials or methods approved by the Authority Having Jurisdiction

TR 10 provides discussion on connection protection options, including unique design considerations associated with wood as a covering material for connections.



*Exposed connections protected with wood coverings*




Concealed beam-to-column connection
*Source: AITC 7*

Where unconcealed connections are desired, justification of the FRR through other means acceptable to the jurisdiction shall be provided. Some projects have used intumescent paints to provide protection for exposed connections.

In 2017, three different configurations of glulam beam-to-column connection fire tests were conducted using the ASTM E 119 time-temperature curve. The completed fire tests and supporting reports allow engineers and architects to specify these tested connection assemblies and satisfy the requirements noted above. All three tests consisted of a glulam beam and column connected with one or two prefabricated hangers. Each connection was also structurally loaded. Ratings of 1 hour and 1.5 hours were achieved. The full report and fire test documents are available in the Think Wood Research Library,[3] which includes mass timber research from around the world.

A qualified professional can also be retained to perform an engineering analysis on a proposed connection detail in order to evaluate its performance under fire conditions.

*Connection protected and approved using other means acceptable to the jurisdiction*

## Interior Finish Requirements

When using exposed mass timber framing, structure also functions as finish making it necessary to consider interior finish provisions of the code. IBC Chapter 8 provides requirements and limitations for items such as flame spread index, heat release and flashover, and flame propagation limitations for interior finishes. Section 803 covers wall and ceiling finishes which are the most common applications of exposed mass timber. Exposed heavy timber elements complying with the requirements of Type IV construction are not subject to interior finish requirements, except in specific egress passages, per IBC Section 803.3. Due to this, an argument could be made that any exposed mass timber elements, even those in construction types other than IV, would not be subject to interior finish requirements. However, if a jurisdiction is applying these requirements to exposed mass timber elements used in Types I, II, III or V, the following provisions exist.

IBC Section 803.1.2 defines how materials are classified for flame spread smoke-developed index performance. It states:

> *Interior wall and ceiling finish materials shall be classified in accordance with ASTM E84 or UL 723. Such interior finish materials shall be grouped in the following classes in accordance with their flame spread and smoke-developed indexes.*
>
> *Class A: Flame spread index 0-25; smoke-developed index 0-450*
>
> *Class B: Flame spread index 26-75; smoke-developed index 0-450*
>
> *Class C: Flame spread index 76-200; smoke-developed index 0-450*

IBC Table 802.1.3 provides the requirements for interior finish class (A, B or C), which is a function of the building's occupancy, whether or not it is sprinklered, and where in the building the finish is located. For sprinklered buildings, most occupancies and building areas require a class B or class C finish per Table 9.

AWC's *Design for Code Acceptance 1 – Flame Spread Performance of Wood Products Used for Interior Finish* (DCA 1) lists flame spread values for a number of wood species and wood panel products. Table 10 shows values for common species used in softwood mass timber framing members. Mass timber product manufacturers have conducted ASTM E 84 tests on their products and have found results matching or exceeding those presented in DCA 1.

**TABLE 9:** Interior Wall and Ceiling Finish Requirements by Occupancy

| Group | Sprinklered[1] | | | Nonsprinklered | | |
|---|---|---|---|---|---|---|
| | Interior exit stairways and ramps and exit passageways[a,b] | Corridors and enclosure for exit access stairways and ramps | Rooms and enclosed spaces[c] | Interior exit stairways and ramps and exit passageways[a,b] | Corridors and enclosure for exit access stairways and ramps | Rooms and enclosed spaces[c] |
| A-1 & A-2 | B | B | C | A | A[d] | B[e] |
| A-3[f], A-4, A-5 | B | B | C | A | A[d] | C |
| B, E, M, R-1 | B | C | C | A | B | C |
| R-4 | B | C | C | A | B | B |
| F | C | C | C | B | C | C |
| H | B | B | C[g] | A | A | B |
| I-1 | B | C | C | A | B | B |
| I-2 | B | B | B[h,i] | A | A | B |
| I-3 | A | A[j] | C | A | A | B |
| I-4 | B | B | B[h,i] | A | A | B |
| R-2 | C | C | C | B | B | C |
| R-3 | C | C | C | C | C | C |
| S | C | C | C | B | B | C |
| U | No restrictions | | | No restrictions | | |

*Source: IBC Table 803.11 / See IBC for footnotes*

**TABLE 10:** Flame Spread Values for Common Mass Timber Species

| Species | Flame Spread Index | Smoke Developed Index | Flame Spread Class |
|---|---|---|---|
| Douglas-fir | 70 | 80 | B |
| Hem-fir species group | 60 | 70 | B |
| Pine, eastern white | 70 | 110 | B |
| Pine, southern yellow | 70 | 165 | B |
| Spruce, black (4"-thick, 3 layers of cross laminations) | 35 | 55 | B |

*Source: DCA 1, AWC*

## Conclusion

The increased use of exposed mass timber in multi-family and commercial buildings has created a need for greater understanding of the fire design procedures of these types of structures. Under the 2021 IBC, many mass timber products are permitted and multiple design routes exist for demonstrating compliance with fire-related provisions of the building code. As wood members are exposed to fire and the wood begins to burn, a char layer is formed. The char layer acts as an insulator and protects the core of the wood section. Mass timber elements can be designed so a sufficient cross-section of wood remains to sustain the design loads for the required duration of fire exposure. This sets mass timber apart as a unique building material—one that is able to achieve structural performance and passive fire-resistance objectives for larger and taller wood buildings than ever before, while offering enhanced aesthetic value and environmental responsibility.

For more information, including other resources noted in this paper, visit woodworks.org.

## End Notes:

[1] Douglas, B., PE, Smart, J., PE, Design of Fire-Resistive Exposed Wood Members, Structure magazine, July 2014

[2] Ranger, L., Dagenais, C., Lum, C., Thomas, T., Fire Performance of Firestops, Penetrations, and Fire Doors in Mass Timber Assemblies, World Conference on Timber Engineering, FPInnovations, August 2018

[3] Softwood Lumber Board Glulam Connection Fire Test Summary Report, 2017, https://research.thinkwood.com

*Updated February 2023*



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