

Early Design Decisions: Priming Mass Timber Projects for Success

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WoodWorks



Photo credit: Image: Trinity University Dicke Hall + Business and Humanities District, Lake Flato Architects, Datum Engineers, Robert

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Course Description

Mass timber is a unique, non-commodity building material and, to lay the groundwork for success, certain critical decisions must be made as early as possible. These decisions can have a big impact on cost and can either increase or limit opportunities later in design. There are many cases of project teams that want to realize the full benefits of mass timber, but, because they base their designs on traditional building practices instead of optimizing them for mass timber, end up with avoidable price premiums. This presentation will walk through early project decisions and design steps, focusing on how to optimize projects for mass timber and how one early decision can influence others. Topics will include construction types, fire ratings, column grids and beam/panel spans, acoustics and MEP integration. Completed mass timber projects will be used to illustrate the variety of viable options when navigating these key decisions.

Learning Objectives

1. Identify construction types within the International Building Code where a mass timber structure is permitted.
2. Discuss the impacts of construction type on required fire-resistance ratings of structural elements, noting the impacts that these ratings have on effective member spans and resulting grids.
3. Review code-compliance requirements for acoustics and primary frame connections, and provide solutions for meeting these requirements with tested mass timber assemblies.
4. Highlight effective methods of integrating MEP services in a mass timber building and discuss the relative impacts of each on cost, aesthetics, occupant comfort and future tenant renovations.

Outline

- » Key Early Design Decisions
- » Construction Types
- » Fire Design
- » Structural Grid
- » Connections
- » Penetrations & Firestopping
- » MEP Layout and Integration
- » Lateral Systems
- » Acoustics
- » Design Example

Outline

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 - » Design Example

Key Early Design Decisions

What is the Single Most Important Early Design Decision on a Mass Timber Project? Is it:

Construction Type

Fire-Resistance Ratings

Member Sizes

Grids & Spans

Exposed Timber (where & how much)

MEP Layout

Acoustics

Concealed Spaces

Connections

Penetrations

The Answer is...They All Need to Be Weighed (Plus Others)

Key Early Design Decisions

Significant Emphasis Placed on the Word **Early**

Early Because:

- » Avoids placing limitations due to construction norms or traditions that may not be efficient with mass timber
- » Allows greater integration of all building elements in 3D models, ultimately used throughout design, manufacturing and install



Key Early Design Decisions

Early = Efficient

Realize Efficiency in:

- » Cost reduction
- » Material use (optimize fiber use, minimize waste)
- » Construction speed
- » Trade coordination
- » Minimize RFIs

Commit to a mass timber design from the start

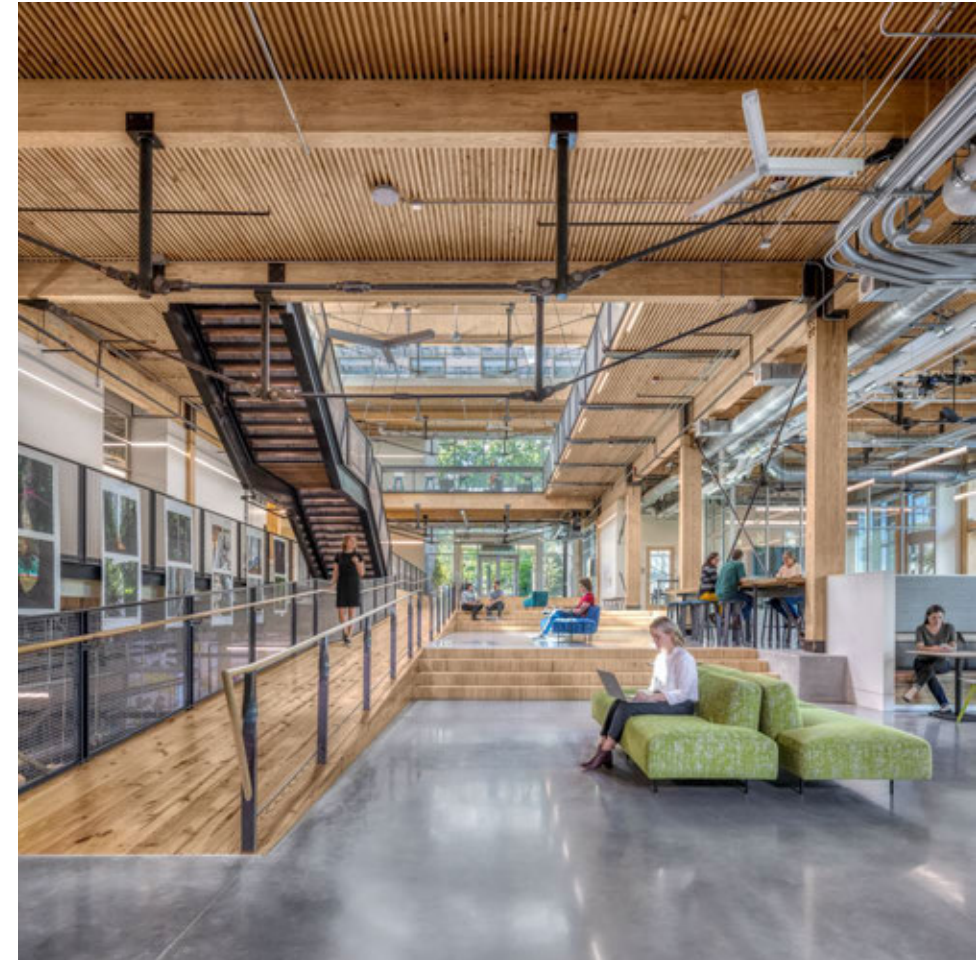


Key Early Design Decisions

One *potential* design route:

1. Building size & occupancy informs construction type & grid
2. Construction type informs fire resistance ratings
3. Grid & fire resistance ratings inform timber member sizes & MEP layout

But that's not all...



Architects: The Miller Hull Partnership with Lord Aeck Sargent
Engineer: Uzun + Case
Contractor: Skanska USA
Photo: Jonathan Hillyer

Key Early Design Decisions

Other impactful decisions:

- » **Acoustics** informs member sizes (and vice versa)
- » Fire-resistance ratings inform **connections & penetrations**
- » **MEP layout** informs use of concealed spaces



Key Early Design Decisions

Other impactful decisions:

- » **Grid** informs efficient spans, MEP layout
- » **Manufacturer capabilities** inform member sizes, grids & connections
- » **Lateral system** informs connections, construction sequencing

And more...



Key Early Design Decisions

Where do we start?



1 De Haro, Perkins & Will, photo Alex Nye



Key Early Design Decisions

Construction Type – Primarily based on building size & occupancy

	Construction Type (All Sprinklered Values)							
	IV-A	IV-B	IV-C	IV-HT	III-A	III-B	V-A	V-B
Occupancies	Allowable Building Height above Grade Plane, Feet (IBC Table 504.3)							
A, B, R	270	180	85	85	85	75	70	60
	Allowable Number of Stories above Grade Plane (IBC Table 505.4)							
A-2, A-3, A-4	18	12	6	4	4	3	3	2
B	18	12	9	6	6	4	4	3
R-2	18	12	8	5	5	5	4	3
	Allowable Area Factor (At) for SM, Feet ² (IBC Table 506.2)							
A-2, A-3, A-4	135,000	90,000	56,250	45,000	42,000	28,500	34,500	18,000
B	324,000	216,000	135,000	108,000	85,500	57,000	54,000	27,000
R-2	184,500	123,000	76,875	61,500	72,000	48,000	36,000	21,000

Key Early Design Decisions

Construction Type – Primarily based on building size & occupancy

	Construction Type (All Sprinklered Values)							
	IV-A	IV-B	IV-C	IV-HT	III-A	III-B	V-A	V-B
Occupancies	Allowable Building Height above Grade Plane, Feet (IBC Table 504.3)							
A, B, R	270	180	85	85	85	75	70	60
For low- to mid-rise mass timber buildings, there may be multiple options for construction type. There are pros and cons of each, don't assume that one type is always best.								
A-2, A-3, A-4	135,000	90,000	56,250	45,000	42,000	28,500	34,500	18,000
B	324,000	216,000	135,000	108,000	85,500	57,000	54,000	27,000
R-2	184,500	123,000	76,875	61,500	72,000	48,000	36,000	21,000
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R-2	184,500	123,000	76,875	61,500	72,000	48,000	36,000	21,000

Key Early Design Decisions

Fire-Resistance Ratings

- » Driven primarily by construction type
- » Rating achieved through timber alone or non-com protection required?

**TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)**

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
	A	B	A	B	A	B	A	B	C	HT	A	B
Primary structural frame ^f (see Section 202)	3 ^{a, b}	2 ^{a, b, c}	1 ^{b, c}	0 ^c	1 ^{b, c}	0	3 ^a	2 ^a	2 ^a	HT	1 ^{b, c}	0
Bearing walls												
Exterior ^{a, f}	3	2	1	0	2	2	3	2	2	2	1	0
Interior	3 ^a	2 ^a	1	0	1	0	3	2	2	1/HT ^g	1	0
Nonbearing walls and partitions Exterior					See Table 705.5							
Nonbearing walls and partitions Interior ^d	0	0	0	0	0	0	0	0	0	See Section 2304.11.2	0	0
Floor construction and associated secondary structural members (see Section 202)	2	2	1	0	1	0	2	2	2	HT	1	0
Roof construction and associated secondary structural members (see Section 202)	1 ^{1/2} ^b	1 ^{b, c}	1 ^{b, c}	0 ^c	1 ^{b, c}	0	1 ^{1/2}	1	1	HT	1 ^{b, c}	0

Key Early Design Decisions

Fire-Resistance Ratings (FRR)

- » Thinner panels (i.e. 3-ply) generally difficult to achieve a 1+ hour FRR
- » 5-ply CLT / 2x6 NLT & DLT panels can usually achieve a 1- or 2-hour FRR
- » Construction Type | FRR | Member Size | Grid (or re-arrange that process but follow how one impacts the others)

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



Photo: David Barber, ARUP

Outline

- » Key Early Design Decisions

- **Construction Types**

- » Fire Design

- » Structural Grid

- » Connections

- » Penetrations & Firestopping

- » MEP Layout and Integration

- » Lateral Systems

- » Acoustics

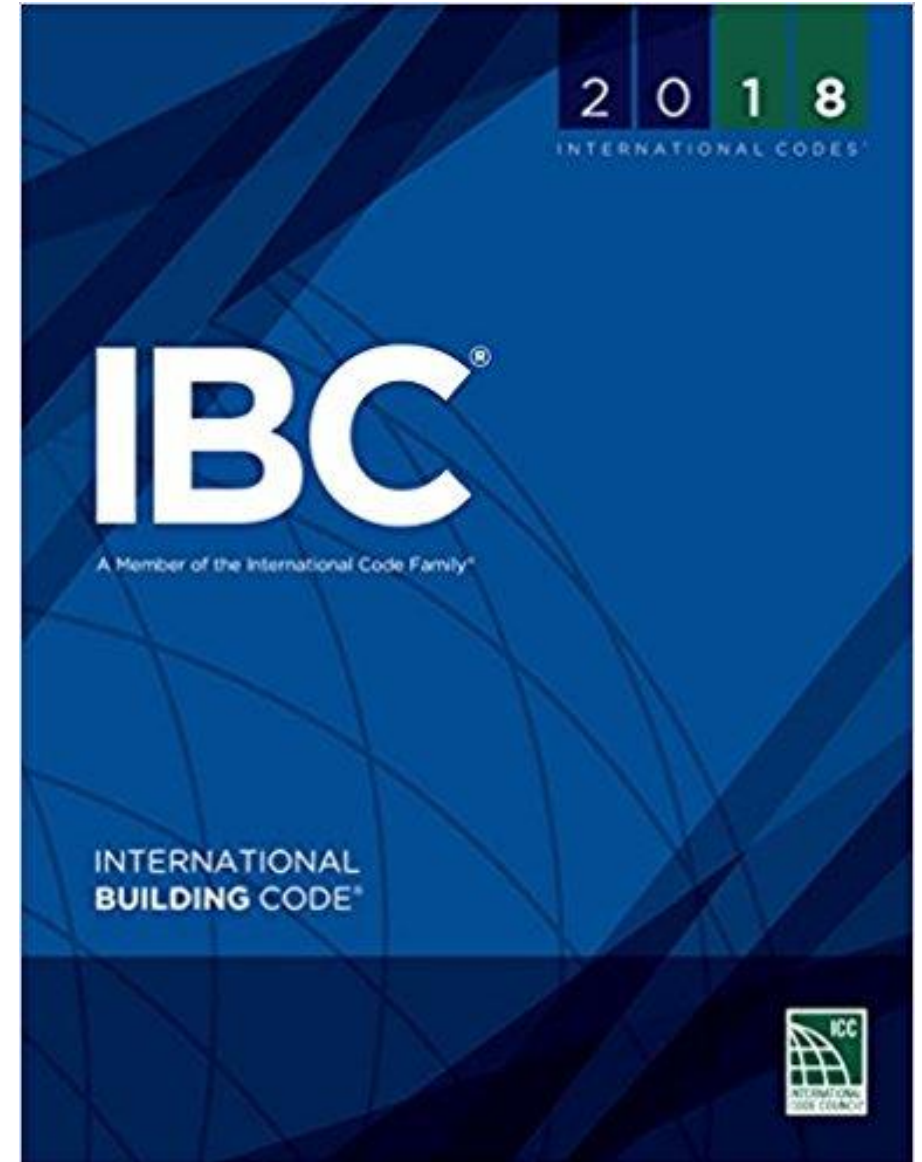
- » Design Example

Construction Types

When does the code allow mass timber to be used?

IBC defines mass timber systems in IBC Chapter 2 and notes their acceptance and manufacturing standards in IBC Chapter 23

Permitted anywhere that combustible materials and heavy timber are allowed, plus more



Construction Types

IBC defines 5 construction types: I, II, III, IV, V

A building must be classified as one of these

Construction Types I & II:

All elements required to be non-combustible materials

However, there are exceptions including several for mass timber

Construction Types

Where does the code allow MT to be used?

Type IB & II: Roof Decking



Image: DeStafano & Chamberlain, Inc, Robert Benson Photography



Image: StructureCraft Builders

Construction Types

All wood-framed building options:

Type III

Exterior walls non-combustible (may be FRTW)

Interior elements any allowed by code, including mass timber

Type V

All building elements are any allowed by code, including mass timber

Types III and V are subdivided to A (protected) and B (unprotected)

Type IV (Heavy Timber)

Exterior walls non-combustible (may be FRTW OR CLT)

Interior elements qualify as Heavy Timber (min. sizes, no concealed spaces except in 2021 IBC)

Construction Types

Where does the code allow MT to be used?

Type III: Interior elements (floors, roofs, partitions/shafts) and exterior walls if FRT

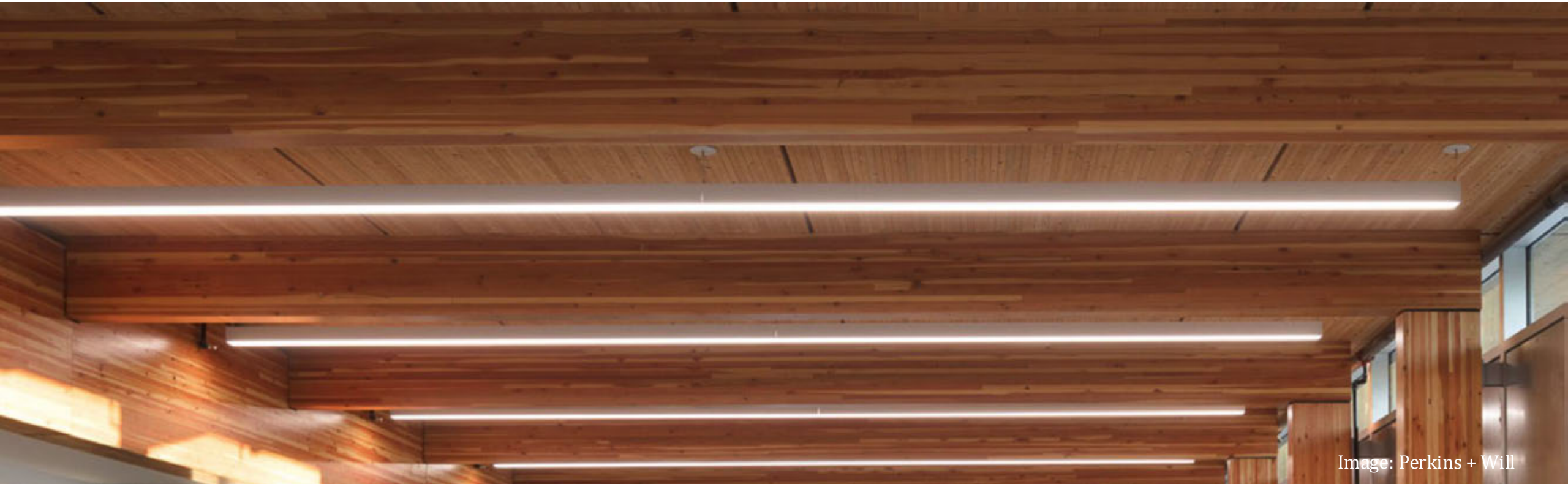


ICE Block I, RMW Architecture & Interiors, Buehler Engineering, Bernard André Photography

Construction Types

Where does the code allow MT to be used?

Type IV: Any exposed interior elements & roofs, must meet min. sizes; exterior walls if CLT or FRT. Concealed space limitations (varies by code version)



Construction Types

Type IV construction permits exposed heavy/mass timber elements of min. sizes.

Minimum Width by Depth in Inches

Framing		Solid Sawn (nominal)	Glulam (actual)	SCL (actual)
Floor	Columns	8 x 8	6 ³ / ₄ x 8 ¹ / ₄	7 x 7 ¹ / ₂
	Beams	6 x 10	5 x 10 ¹ / ₂	5 ¹ / ₄ x 9 ¹ / ₂
Roof	Columns	6 x 8	5 x 8 ¹ / ₄	5 ¹ / ₄ x 7 ¹ / ₂
	Beams*	4 x 6	3 X 6 ⁷ / ₈	3 ¹ / ₂ X 5 ¹ / ₂

*3” nominal width allowed where sprinklered
See IBC 2018 2304.11 or IBC 2015 602.4 for Details



Photo: WoodWorks

Construction Types

Type IV min. sizes:

Floor Panels/Decking:

- » 4" thick CLT (actual thickness)
- » 4" NLT/DLT/GLT (nominal thickness)
- » 3" thick (nominal) decking covered with: 1" decking or 15/32" WSP or ½" particleboard



Photo: StructureCraft



Photo: Aitor Sanchez/ Ewing Cole



Photo: WoodWorks

Construction Types

Type IV min. sizes:

Interior Walls:

- » Laminated construction 4" thick
- » Solid wood construction min. 2 layers of 1" matched boards
- » Wood stud wall (1 hr min)
- » Non-combustible (1 hr min)

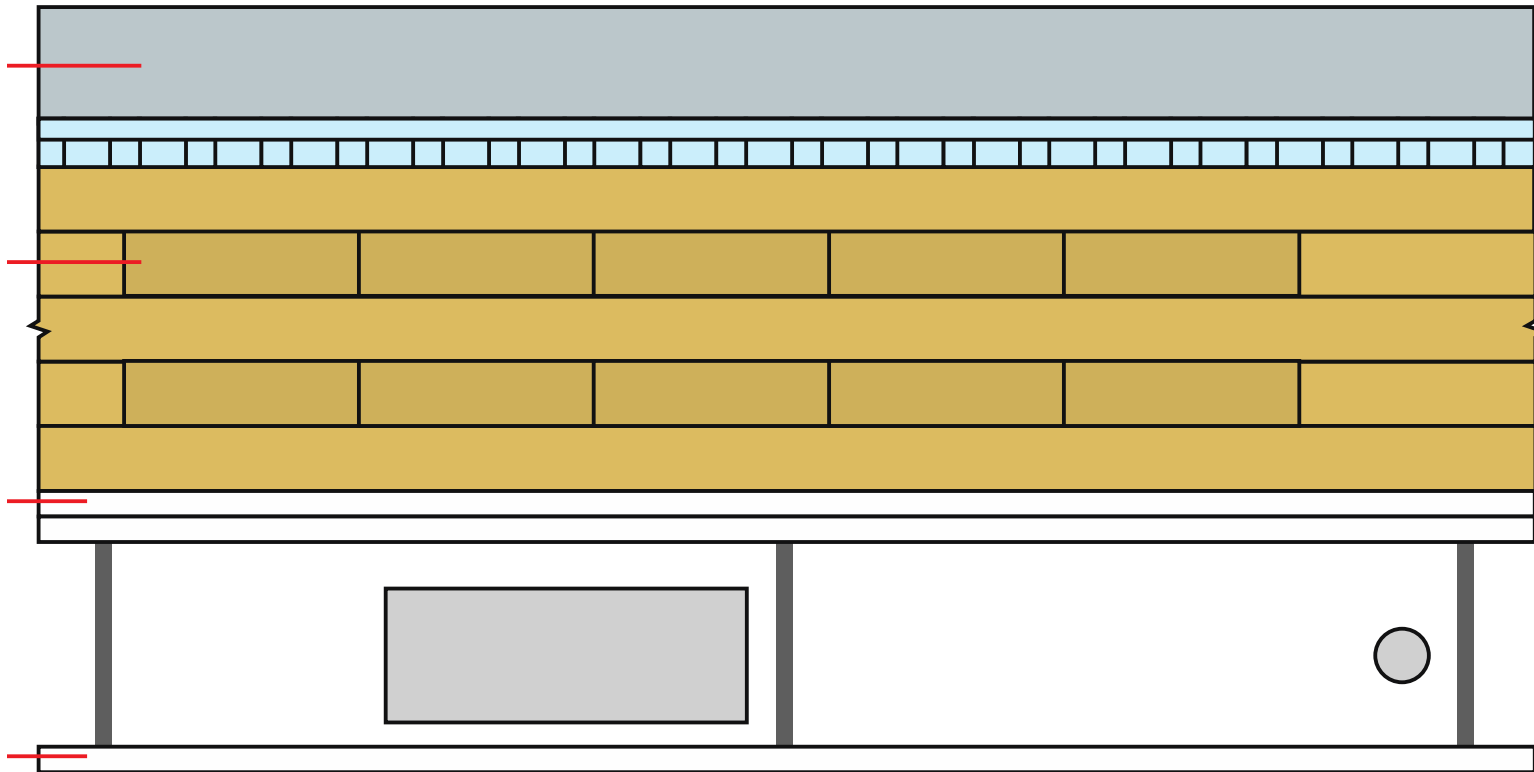
Verify other code requirements for FRR (eg. interior bearing wall; occupancy separation)



Construction Types

Type IV concealed spaces

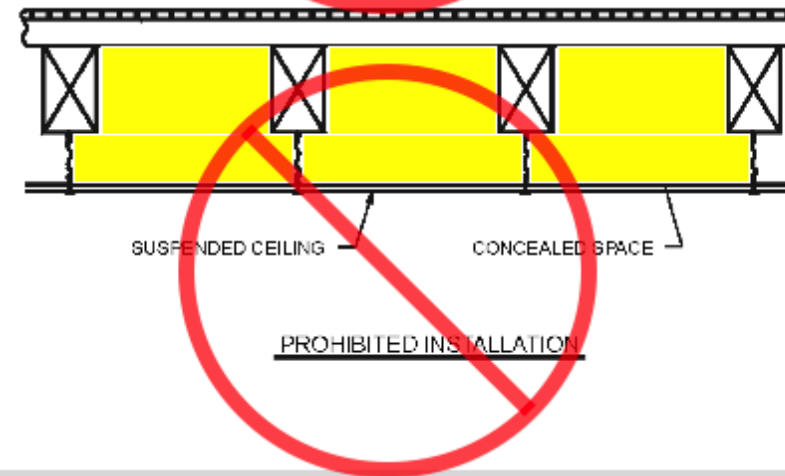
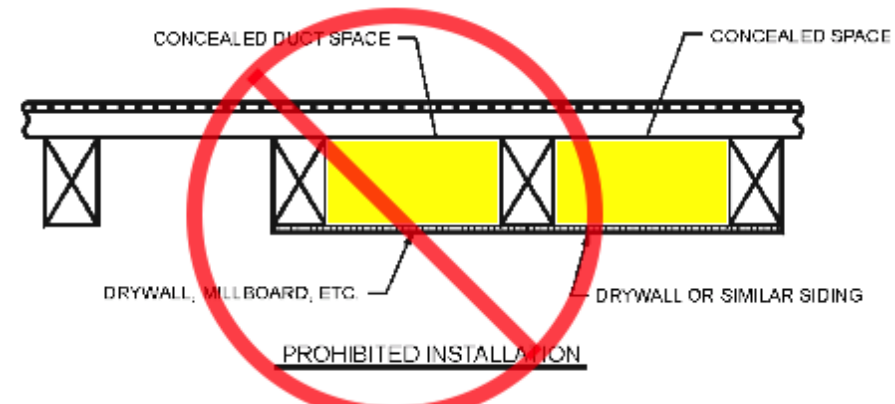
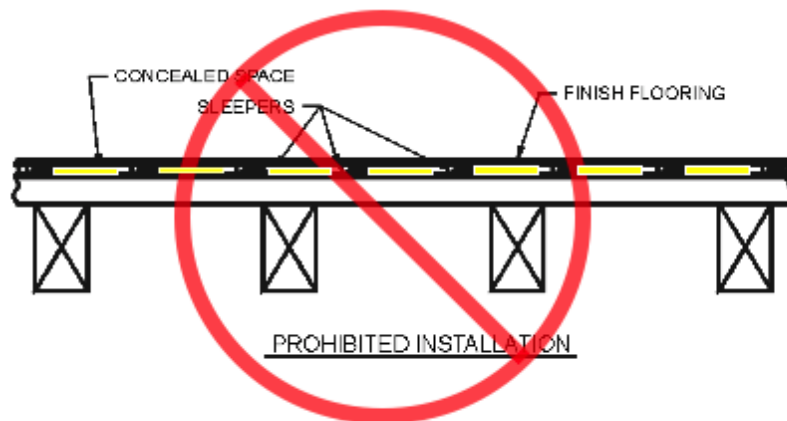
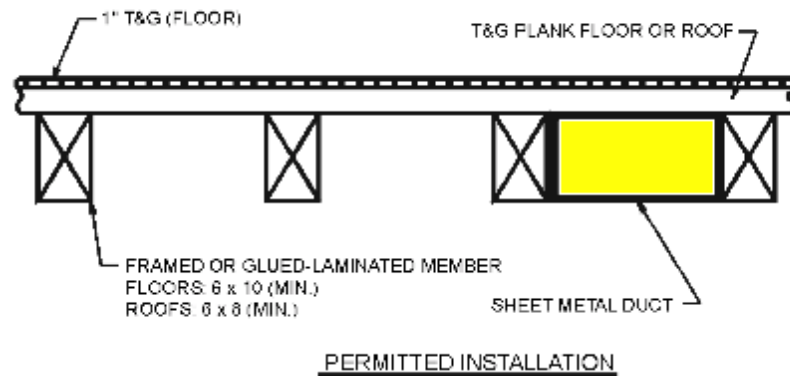
Can I have a dropped ceiling? Raised access floor?



Construction Types

Type IV concealed spaces

Until 2021 IBC, Type IV-HT provisions



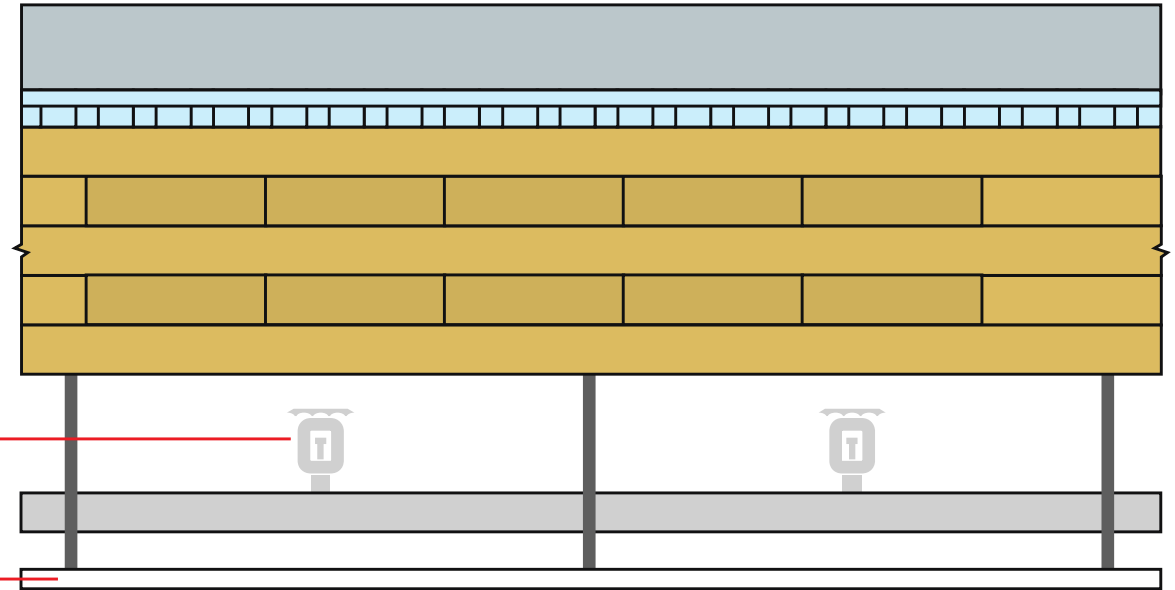
Construction Types

Type IV concealed space options within 2021 IBC

Option 1:

Sprinklers in concealed spaces

Dropped ceiling



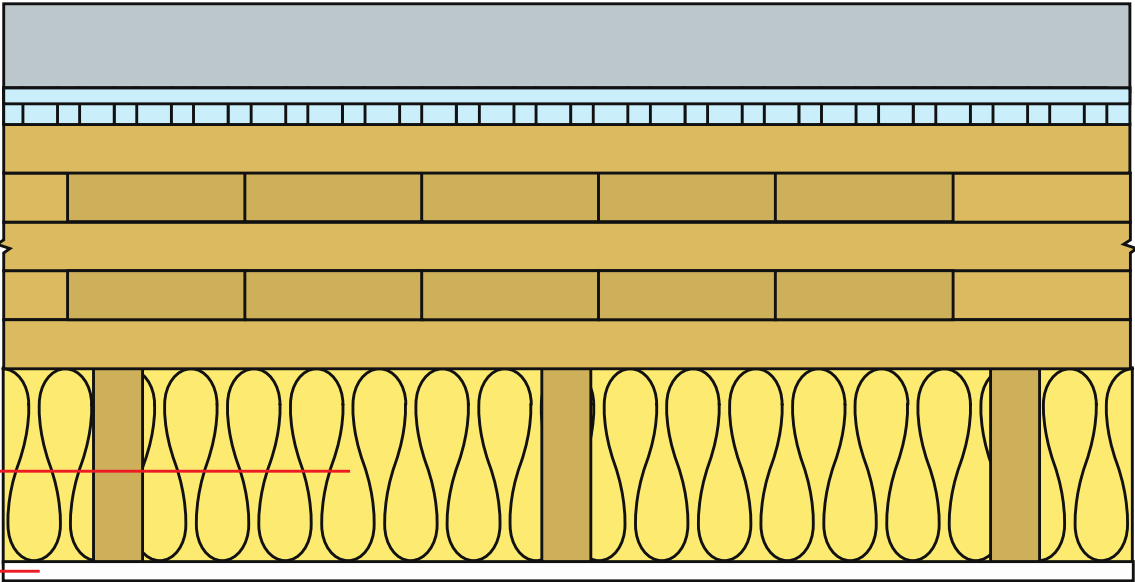
Construction Types

Type IV concealed space options within 2021 IBC

Option 2:

Noncombustible insulation

Dropped ceiling



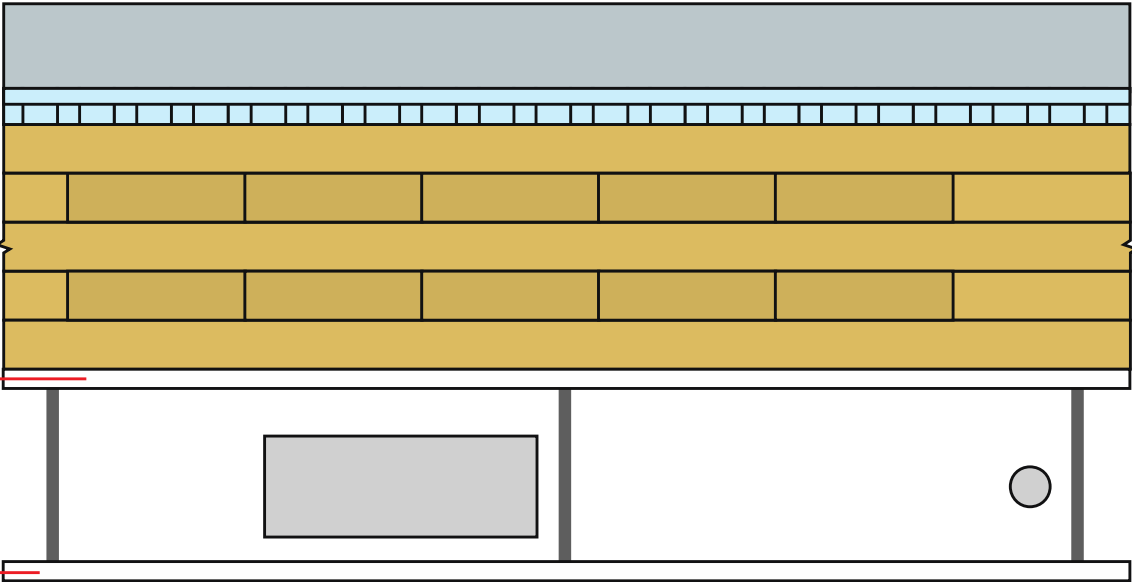
Construction Types

Type IV concealed space options within 2021 IBC

Option 3:

5/8" Type X gypsum on all mass timber surfaces within concealed space

Dropped ceiling



Construction Types

Concealed spaces solutions paper



Concealed Spaces in Mass Timber and Heavy Timber Structures

Concealed spaces, such as those created by a dropped ceiling in a floor/ceiling assembly or by a stud wall assembly, have unique requirements in the International Building Code (IBC) to address the potential of fire spread in non-visible areas of a building. Section 718 of the 2018 IBC includes prescriptive requirements for protection and/or compartmentalization of concealed spaces through the use of draft stopping, fire blocking, sprinklers and other means. For information on these requirements, see the WoodWorks Q&A, *Are sprinklers required in concealed spaces such as floor and roof cavities in multi-family wood-frame buildings?*¹

For mass timber building elements, the choice of construction type can have a significant impact on concealed space requirements. Because mass timber products such as cross-laminated timber (CLT) are prescriptively recognized for Type IV construction, there is a common misperception that exposed mass timber building elements cannot be used or exposed in other construction types. This is not the case.

In addition to Type IV buildings, structural mass timber elements—including CLT, glue-laminated timber (glulam), nail-laminated timber (NLT), structural composite lumber (SCL), and tongue-and-groove (T&G) decking—can be utilized and exposed in the following construction types, whether or not a fire-resistance rating is required:

- **Type III** – Floors, roofs and interior walls may be any material permitted by code, including mass timber; exterior walls are required to be noncombustible or fire retardant-treated wood.
- **Type V** – Floors, roofs, interior walls and exterior walls (i.e., the entire structure) may be constructed of mass timber.
- **Types I and II** – Mass timber may be used in select circumstances such as roof construction—including the primary frame in the 2021 IBC—in Types I-B, II-A or II-B; exterior columns and arches when 20 feet or more of horizontal separation is provided; and balconies, canopies and similar projections.



The John W. Olver Design Building at UMass Amherst includes exposed wood structure in some areas and dropped ceilings in others. Architect: Leers Weinzapfel Associates



https://www.woodworks.org/wp-content/uploads/wood_solution_paper-Concealed_Spaces_Timber_Structures.pdf

Construction Types

Where does the code allow MT to be used?

Type V: All interior elements, roofs & exterior walls



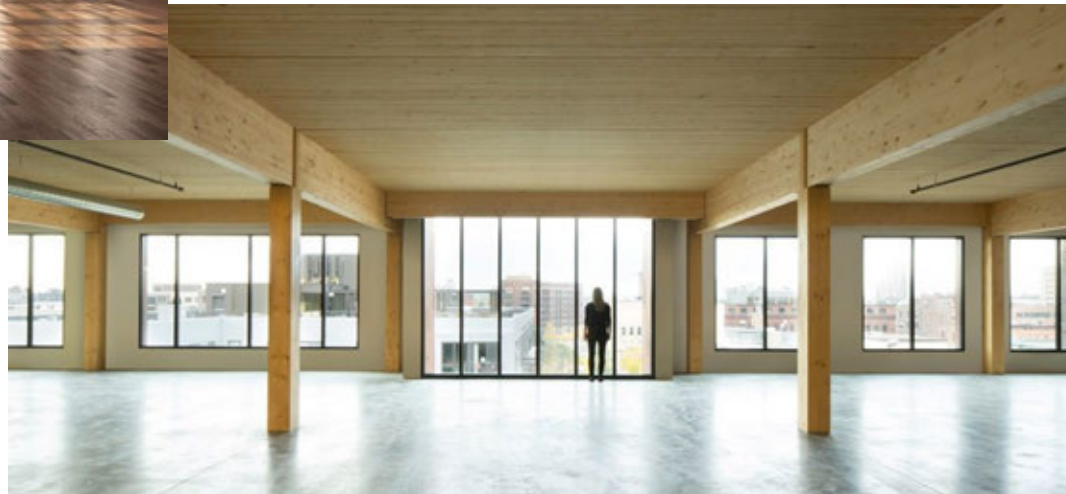
Image: Christian Columbres Photography

Construction Types



Type III: 6 stories

Allowable mass timber
building size for group B
occupancy with NFPA 13
Sprinkler



Type IV: 6 stories

Credit: Ema Peter



Credit: Christian Columbres Photography

Type V: 4 stories

Construction Types

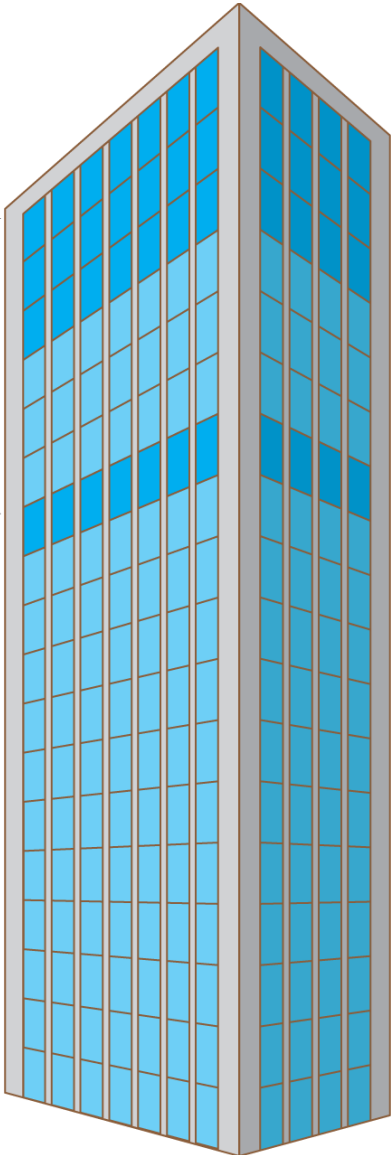
New Options in 2021 IBC
Allowable mass timber building size for
group B occupancy with NFPA 13
Sprinkler

Office
Assembly
Residential

270 ft.
(18 stories)

Mercantile
(12 stories)

Type IV-A

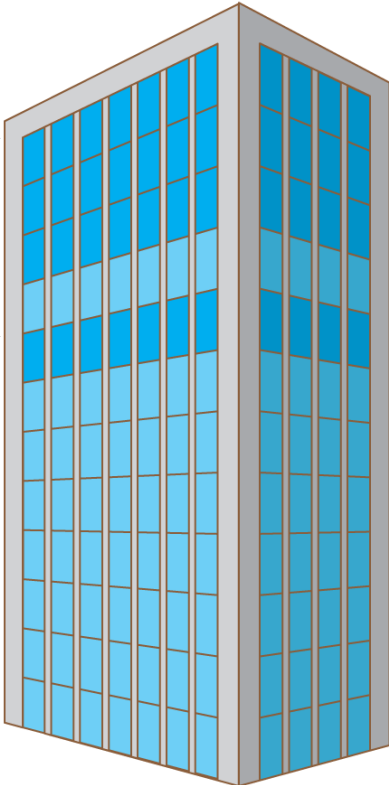


Office
Assembly
Residential

180 ft.
(12 stories)

Mercantile
(8 stories)

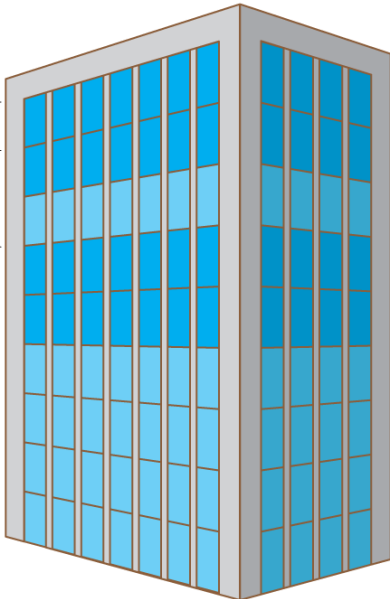
Type IV-B



Office
(9 stories)
Residential
(8 stories)
Assembly
Mercantile
(6 stories)

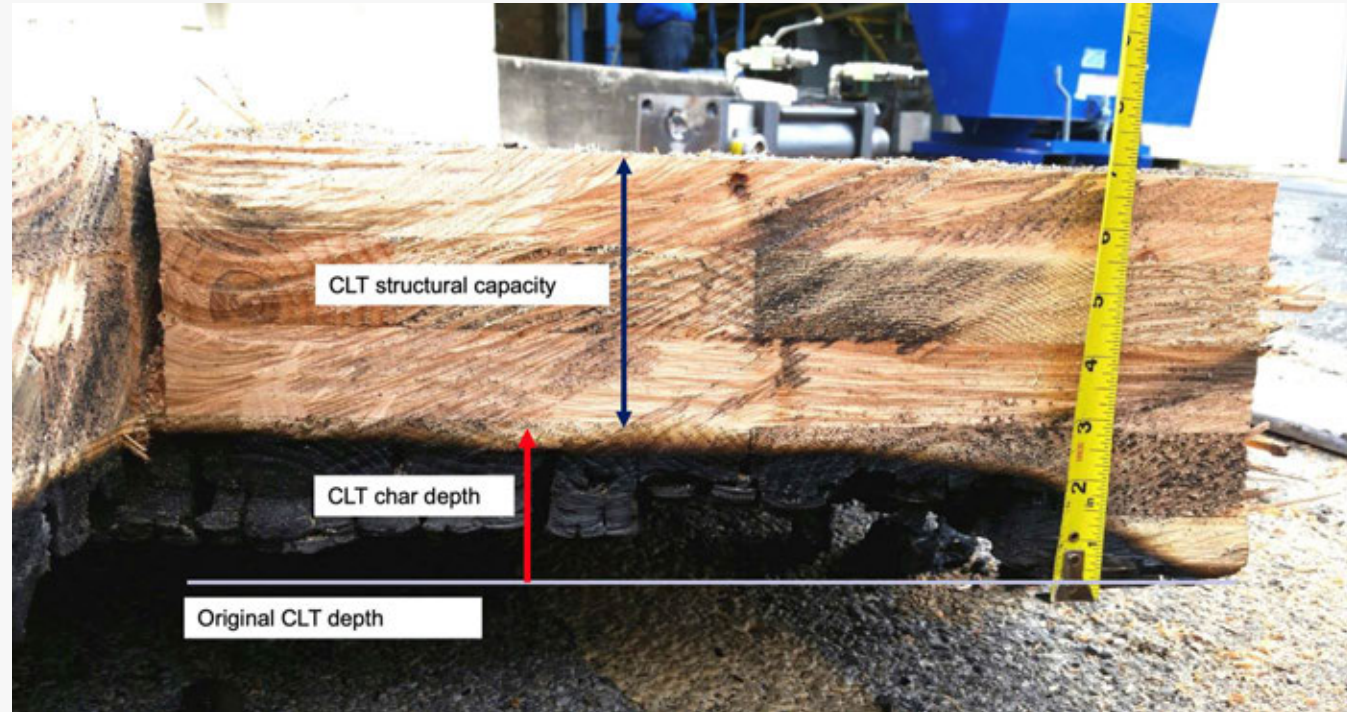
85 ft.
(9 stories)

Type IV-C



Outline

- » Key Early Design Decisions
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- » Fire Design
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Key Early Design Decisions

Construction type influences FRR

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
	A	B	A	B	A	B	A	B	C	HT	A	B
Primary structural frame ^f (see Section 202)	3 ^{a, b}	2 ^{a, b, c}	1 ^{b, c}	0 ^c	1 ^{b, c}	0	3 ^a	2 ^a	2 ^a	HT	1 ^{b, c}	0
Bearing walls												
Exterior ^{e, f}	3	2	1	0	2	2	3	2	2	2	1	0
Interior	3 ^a	2 ^a	1	0	1	0	3	2	2	1/HT ^g	1	0
Nonbearing walls and partitions Exterior					See Table 705.5							
Nonbearing walls and partitions Interior ^d	0	0	0	0	0	0	0	0	0	See Section 2304.11.2	0	0
Floor construction and associated secondary structural members (see Section 202)	2	2	1	0	1	0	2	2	2	HT	1	0
Roof construction and associated secondary structural members (see Section 202)	1 ^{1/2} ^b	1 ^{b, c}	1 ^{b, c}	0 ^c	1 ^{b, c}	0	1 ^{1/2}	1	1	HT	1 ^{b, c}	0

Construction type influences FRR

- » Type IV-HT Construction (minimum sizes)
- » Other than type IV-HT: Demonstrated fire resistance

Method of demonstrating FRR (calculations or testing) can impact member sizing



Member Sizing

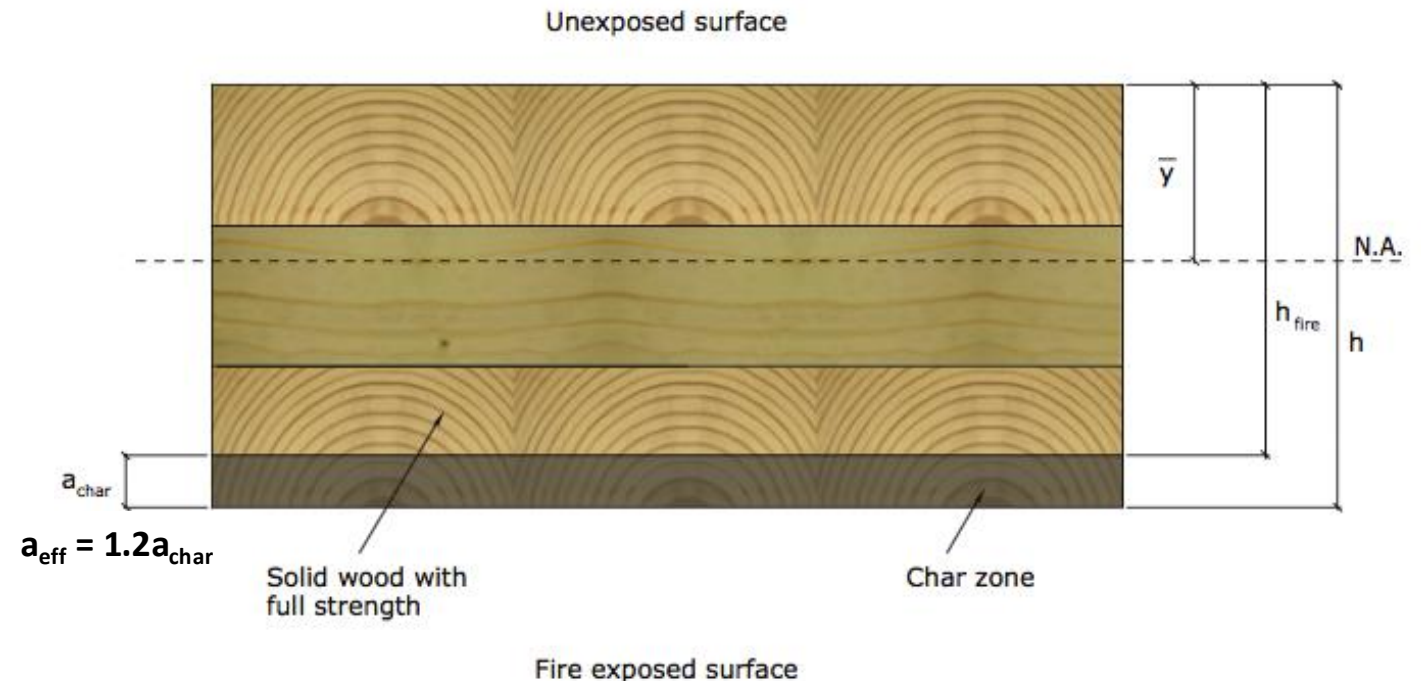
- » Impact of FRR on sizing
- » Impact of sizing on efficient spans
- » Consider connections – can drive member sizing



Construction type influences FRR

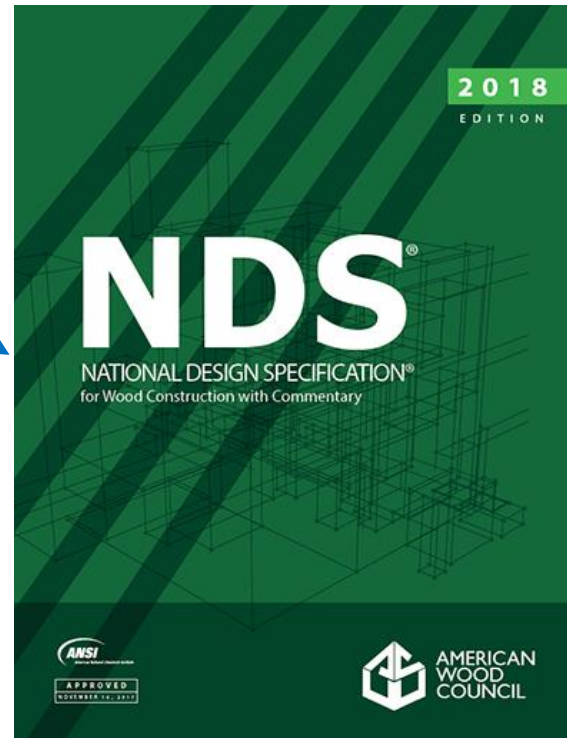
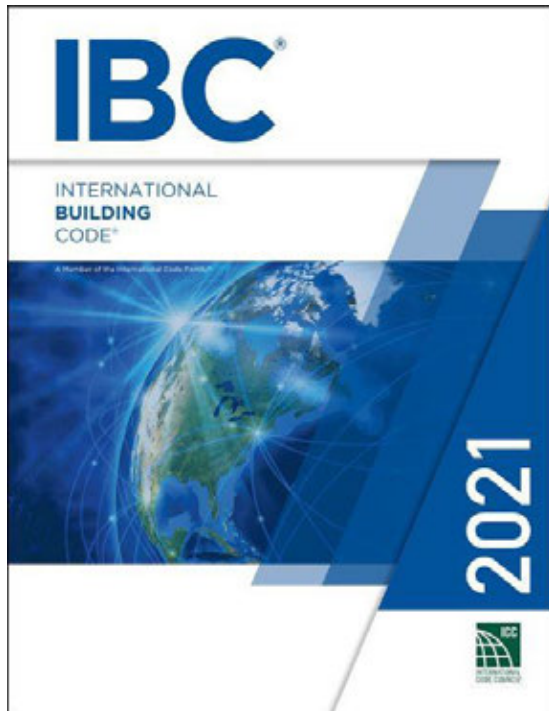
Which Method of Demonstrating FRR of MT is Being Used?

- » Calculations in Accordance with IBC 722 → NDS Chapter 16
- » Tests in Accordance with ASTM E119



FRR Design of MT

Calculated FRR of Exposed MT:
IBC to NDS code compliance path



IBC 703.3

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
- Alternate protection methods as allowed by 104.11



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.

FRR Design of MT

NDS Chapter 16 includes calculation of fire resistance of NLT, CLT, Glulam, Solid Sawn and SCL wood products

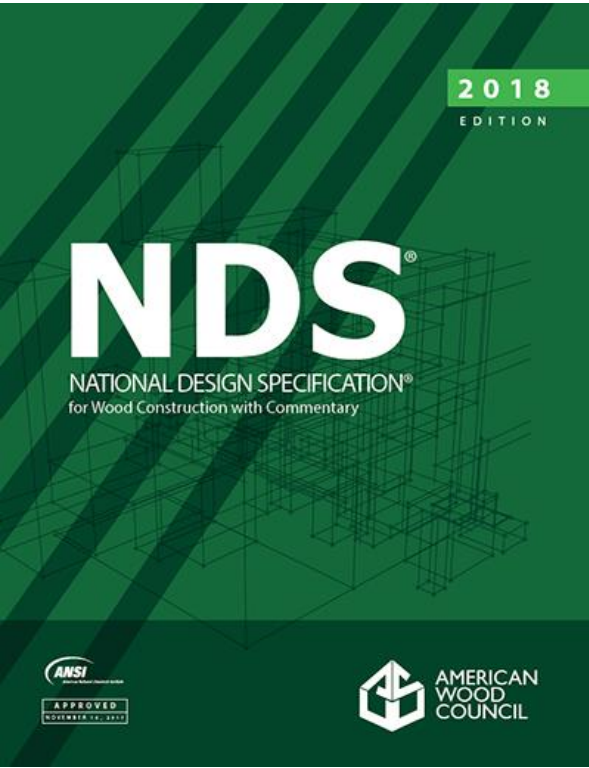


Table 16.2.1B Effective Char Depths (for CLT with $\beta_n=1.5\text{in./hr.}$)

Required Fire Endurance (hr.)	Effective Char Depths, a_{char} (in.)								
	lamination thicknesses, h_{lam} (in.)								
	5/8	3/4	7/8	1	1-1/4	1-3/8	1-1/2	1-3/4	2
1-Hour	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.8
1½-Hour	3.4	3.2	3.1	3.0	2.9	2.8	2.8	2.8	2.6
2-Hour	4.4	4.3	4.1	4.0	3.9	3.8	3.6	3.6	3.6

FRR Design of MT

Nominal char rate of 1.5”/HR is recognized in NDS. Effective char depth calculated to account for duration, structural reduction in heat-affected zone



Credit: ARUP

Table 16.2.1A Char Depth and Effective Char Depth (for $\beta_n = 1.5$ in./hr.)

Required Fire Resistance (hr.)	Char Depth, a_{char} (in.)	Effective Char Depth, a_{eff} (in.)
1-Hour	1.5	1.8
1½-Hour	2.1	2.5
2-Hour	2.6	3.2

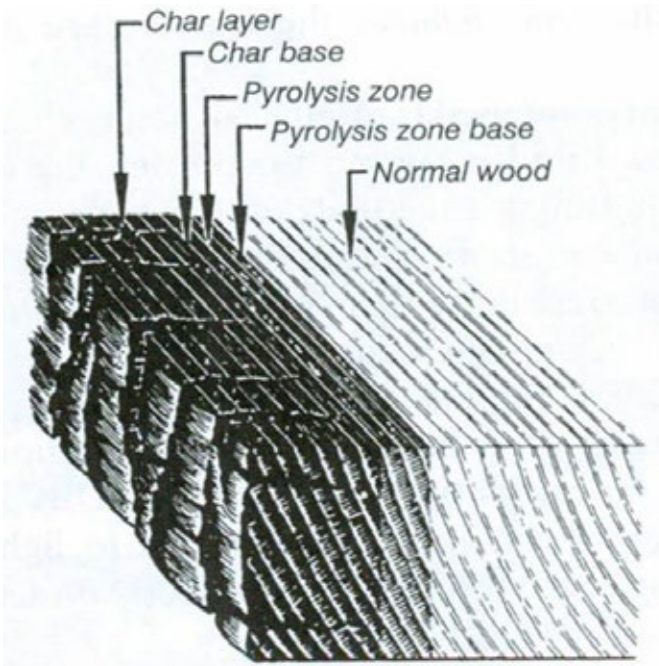
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	5/8	3/4	7/8	1	1-1/4	1-3/8	1-1/2	1-3/4	2
1-Hour	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.8
1½-Hour	3.4	3.2	3.1	3.0	2.9	2.8	2.8	2.8	2.6
2-Hour	4.4	4.3	4.1	4.0	3.9	3.8	3.6	3.6	3.6

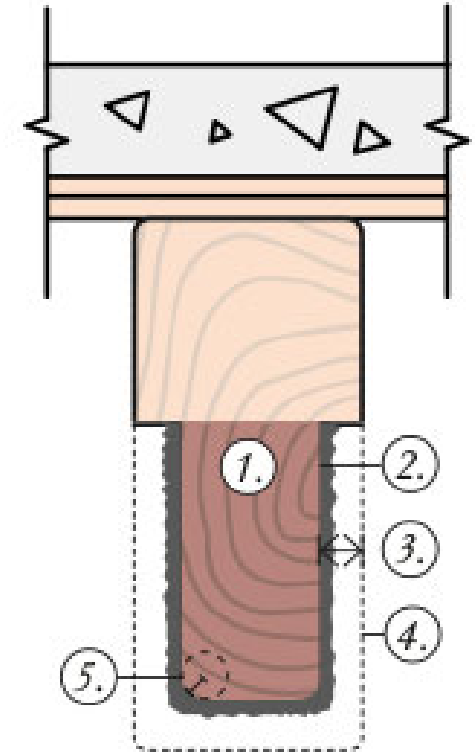
FRR Design of MT

Two structural capacity checks performed:

1. On entire cross section neglecting fire effects
2. On post-fire remaining section, with stress increases



Credit: Forest Products Laboratory



$$a_{\text{char}} = \beta_t t^{0.813}$$

Solid Sawn, Glulam, SCL

$$a_{\text{char}} = n_{\text{lam}} h_{\text{lam}} + \beta_t \left(t - (n_{\text{lam}} t_{\text{gl}}) \right)^{0.813}$$

CLT

$$a_{\text{eff}} = 1.2 a_{\text{char}}$$

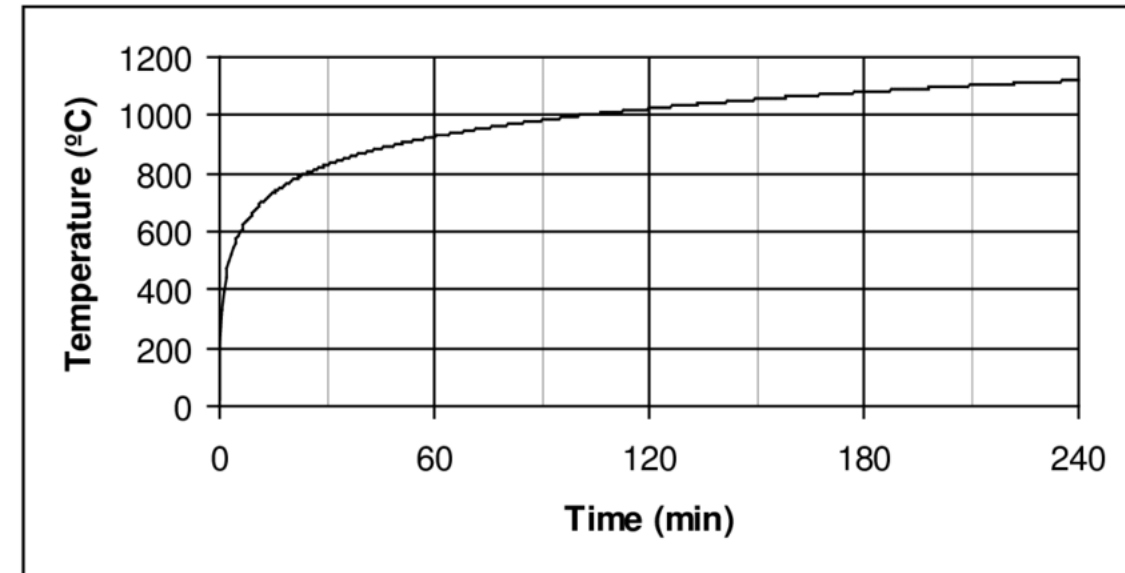
Effective Char Depth

FRR Design of MT

Tested FRR of Exposed MT:

IBC 703.2 notes the acceptance of FRR demonstration via testing in accordance with ASTM E119

703.2 Fire-resistance ratings. The *fire-resistance rating* of building elements, components or assemblies shall be determined in accordance with the test procedures set forth in ASTM E119 or UL 263 or in accordance with Section 703.3. The *fire-resistance rating* of penetrations and *fire-resistant joint systems* shall be determined in accordance Sections 714 and 715, respectively.



Standard ASTM E119 test time-temperature curve

FRR Design of MT

Tested FRR of Exposed MT:

Many successful Mass Timber ASTM E119 fire tests have been completed by industry & manufacturers

 **Fire Testing Laboratory** 

TEST REPORT Page 1 of 53
for
American Wood Council
222 Catoctin Circle SE, Suite 201
Leesburg, VA 20175

**Standard Methods of
Fire Tests of Building Construction and Materials
ASTM E 119 – 11a**

Test Report No: WP-1950
Assignment No: K-1089
Subject Material: Cross-Laminated Timber and Gypsum Board Wall Assembly (Load-Bearing)
Test Date: October 4, 2012
Report Date: October 15, 2012

Prepared by: 
Michael J. Pizzo
Test Engineer

Reviewed by: 
Robert J. Menchetti
Director, Laboratory Facilities and Testing Services

The results reported in this document apply to specific samples submitted for measurement. No responsibility is assumed for performance of any other specimen. This report may not be reproduced, except in full, without the written approval of the laboratory. The laboratory's test report in no way constitutes or implies product certification, approval or endorsement by this laboratory.

Intertek

REPORT NUMBER: 102891256SAT-001
ORIGINAL ISSUE DATE: February 27, 2017
REVISED DATE: N/A

EVALUATION CENTER
16015 Shady Falls Road
Elmendorf, TX 78112
Phone: (210) 635-8100
Fax: (210) 635-8101
www.intertek.com

TEST REPORT

RENDERED TO
Structurlam Products LP
2176 Government Street
Penticton, BC V2A 8B5
Canada

PRODUCT EVALUATED: CrossLam® CLT Un-restrained Load-Bearing Floor/Ceiling Assembly
EVALUATION PROPERTY: Fire Resistance

Report of Testing a CrossLam® CLT Un-restrained Load-Bearing Floor/Ceiling Assembly for compliance with the applicable requirements of the following criteria: ASTM E119–16a, Standard Test Methods for Fire Tests of Building Construction and

FPInnovations 
NRC-CNRC

Project No. 301006155
Final Report 2012/13

Preliminary CLT Fire Resistance Testing Report

by
Lindsay Osborne, M.A.Sc.
Christian Dagenais, Eng., M.Sc.
Scientists
Advanced Building Systems – Serviceability and Fire Group

and
Noureddine Bénichou, Ph.D.
Senior Research Officer
National Research Council of Canada – Fire Research Resource Centre

July 2012

WoodWorks Inventory of Fire Tested MT Assemblies

Table 1: North American Fire Resistance Tests of Mass Timber Floor / Roof Assemblies



CLT Panel	Manufacturer	CLT Grade or Major x Minor Grade	Ceiling Protection	Panel Connection in Test	Floor Topping	Load Rating	Fire Resistance Achieved (Hours)	Source	Testing Lab
3-ply CLT (114mm 4.488 in)	Nordic	SPF 1650 Fb 1.5 EMSR x SPF #3	2 layers 1/2" Type X gypsum	Half-Lap	None	Reduced 36% Moment Capacity	1	1 (Test 1)	NRC Fire Laboratory
3-ply CLT (105mm 4.133 in)	Structurlam	SPF #1/#2 x SPF #1/#2	1 layer 5/8" Type X gypsum	Half-Lap	None	Reduced 75% Moment Capacity	1	1 (Test 5)	NRC Fire Laboratory
5-ply CLT (175mm 6.875")	Nordic	EI	None	Topside Spline	2 staggered layers of 1/2" cement boards	Loaded, See Manufacturer	2	2	NRC Fire Laboratory March 2016
5-ply CLT (175mm 6.875")	Nordic	EI	1 layer of 5/8" Type X gypsum under Z-channels and furring strips with 3 5/8" fiberglass batts	Topside Spline	2 staggered layers of 1/2" cement boards	Loaded, See Manufacturer	2	5	NRC Fire Laboratory Nov 2014
5-ply CLT (175mm 6.875")	Nordic	EI	None	Topside Spline	3/4 in. proprietary gypcrete over Maxxon acoustical mat	Reduced 50% Moment Capacity	1.5	3	UL
5-ply CLT (175mm 6.875")	Nordic	EI	1 layer 5/8" normal gypsum	Topside Spline	3/4 in. proprietary gypcrete over Maxxon acoustical mat or proprietary sound board	Reduced 50% Moment Capacity	2	4	UL
5-ply CLT (175mm 6.875")	Nordic	EI	1 layer 5/8" Type X Gyp under Resilient Channel under 7 7/8" I-Joints with 3 1/2" Mineral Wool between Joints	Half-Lap	None	Loaded, See Manufacturer	2	21	Intertek 8/24/2012
5-ply CLT (175mm 6.875")	Structurlam	EI M5 MSR 2100 x SPF #2	None	Topside Spline	1-1/2" Maxxon Cyp-Grete 2000 over Maxxon Reinforcing Mesh	Loaded, See Manufacturer	2.5	6	Intertek, 2/22/2016
5-ply CLT (175mm 6.875")	DR Johnson	VI	None	Half-Lap & Topside Spline	2" gypsum topping	Loaded, See Manufacturer	2	7	SwRI (May 2016)
5-ply CLT (175mm 6.875")	Nordic	SPF 1950 Fb MSR x SPF #3	None	Half-Lap	None	Reduced 59% Moment Capacity	1.5	1 (Test 3)	NRC Fire Laboratory
5-ply CLT (175mm 6.875")	Structurlam	SPF #1/#2 x SPF #1/#2	1 layer 5/8" Type X gypsum	Half-Lap	None	Unreduced 101% Moment Capacity	2	1 (Test 6)	NRC Fire Laboratory
7-ply CLT (245mm 9.65")	Structurlam	SPF #1/#2 x SPF #1/#2	None	Half-Lap	None	Unreduced 101% Moment Capacity	2.5	1 (Test 7)	NRC Fire Laboratory
5-ply CLT (175mm 6.875")	SmartLam	SL-V4	None	Half-Lap	nominal 1/2" plywood with 8d nails	Loaded, See Manufacturer	2	12 (Test 4)	Western Fire Center 10/26/2016
5-ply CLT (175mm 6.875")	SmartLam	VI	None	Half-Lap	nominal 1/2" plywood with 8d nails	Loaded, See Manufacturer	2	12 (Test 5)	Western Fire Center 10/28/2016
5-ply CLT (175mm 6.875")	DR Johnson	VI	None	Half-Lap	nominal 1/2" plywood with 8d nails	Loaded, See Manufacturer	2	12 (Test 6)	Western Fire Center 11/01/2016
5-ply CLT (175mm 6.875")	KLH	CV3M1	None	Half-Lap & Topside Spline	None	Loaded, See Manufacturer	1	18	SwRI 11/10/2016

FRR Design of MT

Method of demonstrating FRR (calculations or testing) can impact member sizing

Each has unique benefits:

- » **Testing:**

- » Can result in higher FRR for some assemblies when compared to calculations (i.e. 2-hr FRR with 5-ply CLT panel).
- » Seen as more acceptable by some building officials

- » **Calculations:**

- » Can provide more design flexibility
- » Allows for project span and loading specific analysis

FRR Design of MT

Mass Timber Fire Design Resource

- » Code compliance options for demonstrating FRR
- » Free download at woodworks.org



Richard McLain, PE, SE
Senior Technical Director
Scott Breneman, PhD, PE, SE
Senior Technical Director
WoodWorks – Wood Products Council

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 Gentry

Outline

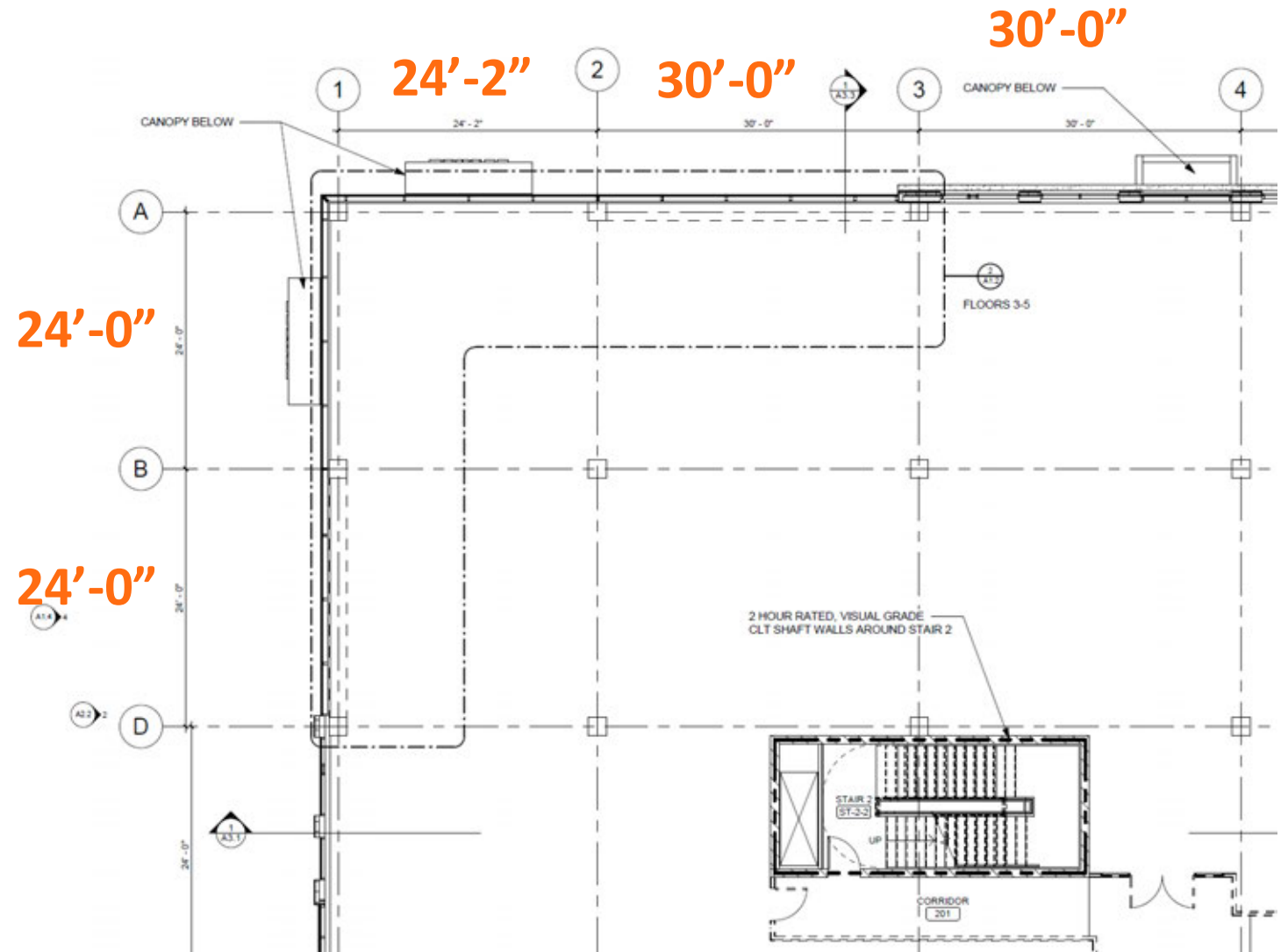
- » Key Early Design Decisions
- » Construction Types
- » Fire Design
- **Structural Grid**
- » Connections
- » Penetrations & Firestopping
- » MEP Layout and Integration
- » Lateral Systems
- » Acoustics
- » Design Example



Structural Grid

Grids & Spans

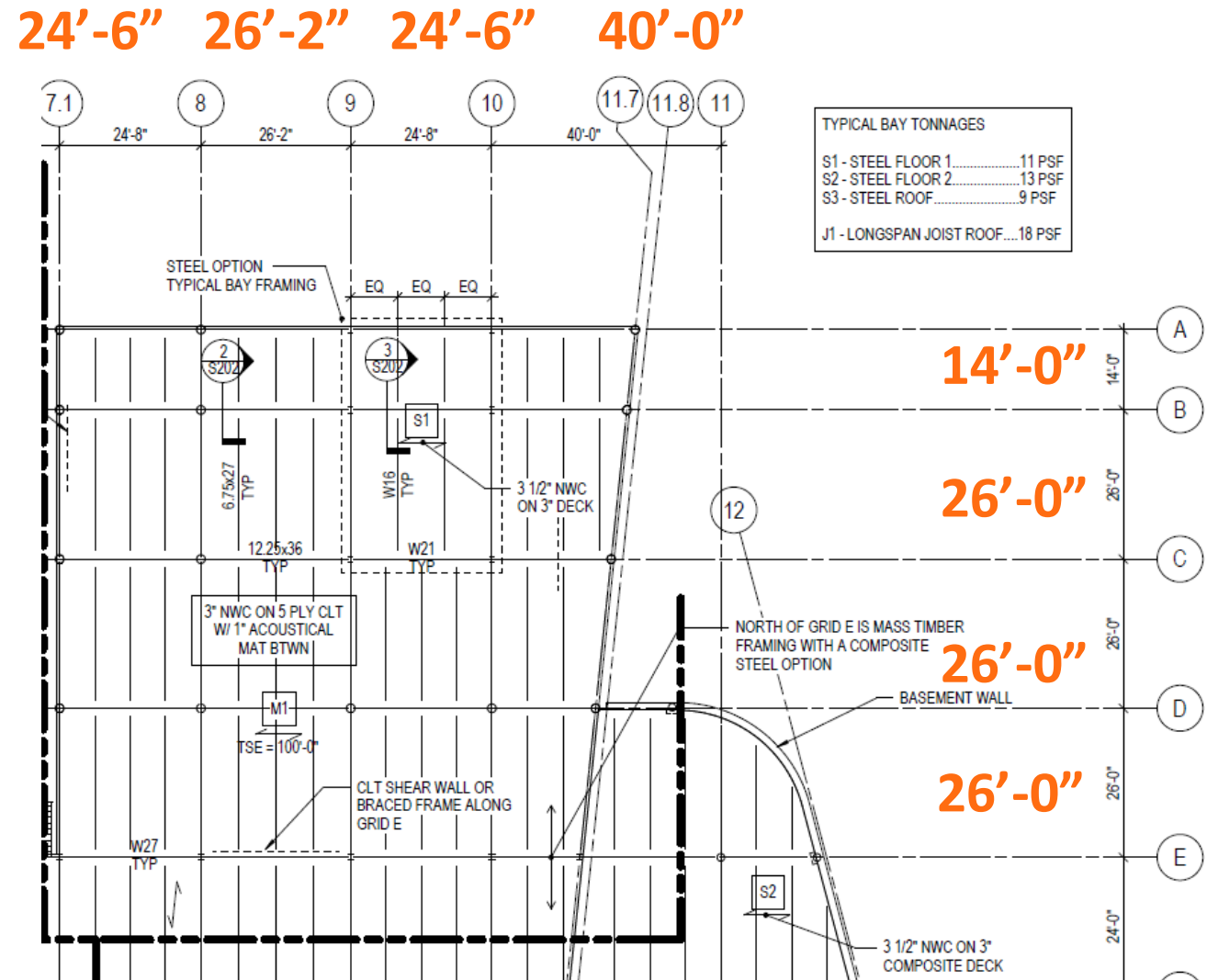
- » Consider Efficient Layouts
- » Repetition & Scale
- » Manufacturer Panel Sizing
- » Transportation



Structural Grid

Grids & Spans

- » Consider Efficient Layouts
- » Repetition & Scale
- » Manufacturer Panel Sizing
- » Transportation



Structural Grid

Member Sizes

- » Impact of FRR on Sizing
- » Impact of Sizing on Efficient Spans
- » Consider connections – can drive member sizing

0 HR FRR: Consider 3-ply Panel

- » Efficient Spans of 10-12 ft
- » Grids of 20x20 (1 purlin) to 30x30 (2 purlins) may be efficient



Platte Fifteen, Denver, CO
30x30 Grid, 2 purlins per bay
3-ply CLT
Image: JC Buck

Structural Grid

Member Sizes

- » Impact of FRR on Sizing
- » Impact of Sizing on Efficient Spans
- » Consider connections – can drive member sizing

1 or 2 HR FRR: Likely 5-ply Panel

- » Efficient spans of 14-17 ft
- » Grids of 15x30 (no purlins) to 30x30 (1 purlin) may be efficient



First Tech Credit Union, Hillsboro, OR
12x32 Grid, One-Way Beams
5-ply (5.5") CLT
Image: Swinerton

Construction Type Early Decision Example

7-story building on health campus

- » Group B occupancy, NFPA 13 sprinklers throughout
- » Floor plate = 22,300 SF
- » Total Building Area = 156,100 SF

MT Construction Type Options:

- » If Building is < 85 ft
 - » 7 stories of IV-C
 - » 6 stories of IIIA or IV-HT over 1 story IA podium
- » If Building is > 85 ft
 - » 7 stories of IV-B



Construction Type Early Decision Example

MT Construction Type Options:

- » If Building is < 85 ft
 - » 7 stories of IV-C
 - » 6 stories of IIIA or IV-HT over 1 story IA
- » If Building is > 85 ft
 - » 7 stories of IV-B

Implications of construction type choice in this example:

- » FRR (2 hr vs 1 hr vs min sizes)
- » Efficient spans & grid
- » Exposed timber limitations
- » Concealed spaces
- » Cost
- » And more...



Construction Type Early Decision Example

MT Construction Type Options:

- » If Building is < 85 ft
 - » 7 stories of IV-C
 - » 6 stories of IIIA or IV-HT over 1 story IA
- » If Building is > 85 ft
 - » 7 stories of IV-B

Implications of Type IV-C:

- » 2 hr FRR, all exposed floor panels, beams, columns
- » Likely will need at least 5-ply CLT / 2x6 NLT/DLT
- » Efficient spans in the 14-17 ft range
- » Efficient grids of that or multiples of that (i.e. 30x25, etc)
- » No podium required



Construction Type Early Decision Example

MT Construction Type Options:

- » If Building is < 85 ft
 - » 7 stories of IV-C
 - » 6 stories of IIIA or IV-HT over 1 story IA
- » If Building is > 85 ft
 - » 7 stories of IV-B

Implications of Type IIIA or IV-HT:

- » 1 hr FRR or min. sizes
- » Potential to use 3-ply or thin 5-ply CLT
- » Efficient spans in the 10-12 ft range
- » Efficient grids of that or multiples of that (i.e. 20x25, etc)
- » 1 story Type IA podium required



Construction Type Early Decision Example

MT Construction Type Options:

- » If Building is < 85 ft
 - » 7 stories of IV-C
 - » 6 stories of IIIA or IV-HT over 1 story IA
- » If Building is > 85 ft
 - » 7 stories of IV-B

Implications of Type IV-B (2021 IBC):

- » 2 hr FRR, mostly protected floor panels, beams, columns
- » Exposed areas: likely 5-ply / 2x6 NLT/DLT
- » Protected areas: potential for thinner panels
- » Choose 1 system throughout or multiple systems?
- » Does grid vary or consistent throughout?
- » No podium required



Construction Type Early Decision Example

MT Construction Type Options:

- » If Building is < 85 ft
 - » 7 stories of IV-C
 - » 6 stories of IIIA or IV-HT over 1 story IA
- » If Building is > 85 ft
 - » 7 stories of IV-B

Implications of Type IV-B (2024 IBC):

- » 2 hr FRR, **up to 100% exposed panels, beams, columns**
- » Exposed areas: likely 5-ply / 2x6 NLT/DLT
- » Protected areas: potential for thinner panels
- » Choose 1 system throughout or multiple systems?
- » Does grid vary or consistent throughout?
- » No podium required



Code Updates to Type IV-B

602.4.2.2.2 Protected Area

Interior faces of mass timber elements, including the inside face of exterior mass timber walls and mass timber roofs, shall be protected in accordance with Section 602.4.2.2.1.

2021 IBC

Exceptions: Unprotected portions of mass timber ceilings and walls complying with Section 602.4.2.2.4 and the following:

- 1. Unprotected portions of mass timber ceilings and walls comply with one of the following:
 - 1.1 Unprotected portions of mass timber ceilings, including attached beams, shall be permitted and shall be limited to an area equal to **20 percent** of the floor area in any dwelling unit or fire area.
 - 1.2 ...

2024 IBC

Exceptions: Unprotected portions of mass timber ceilings and walls complying with Section 602.4.2.2.4 and the following:

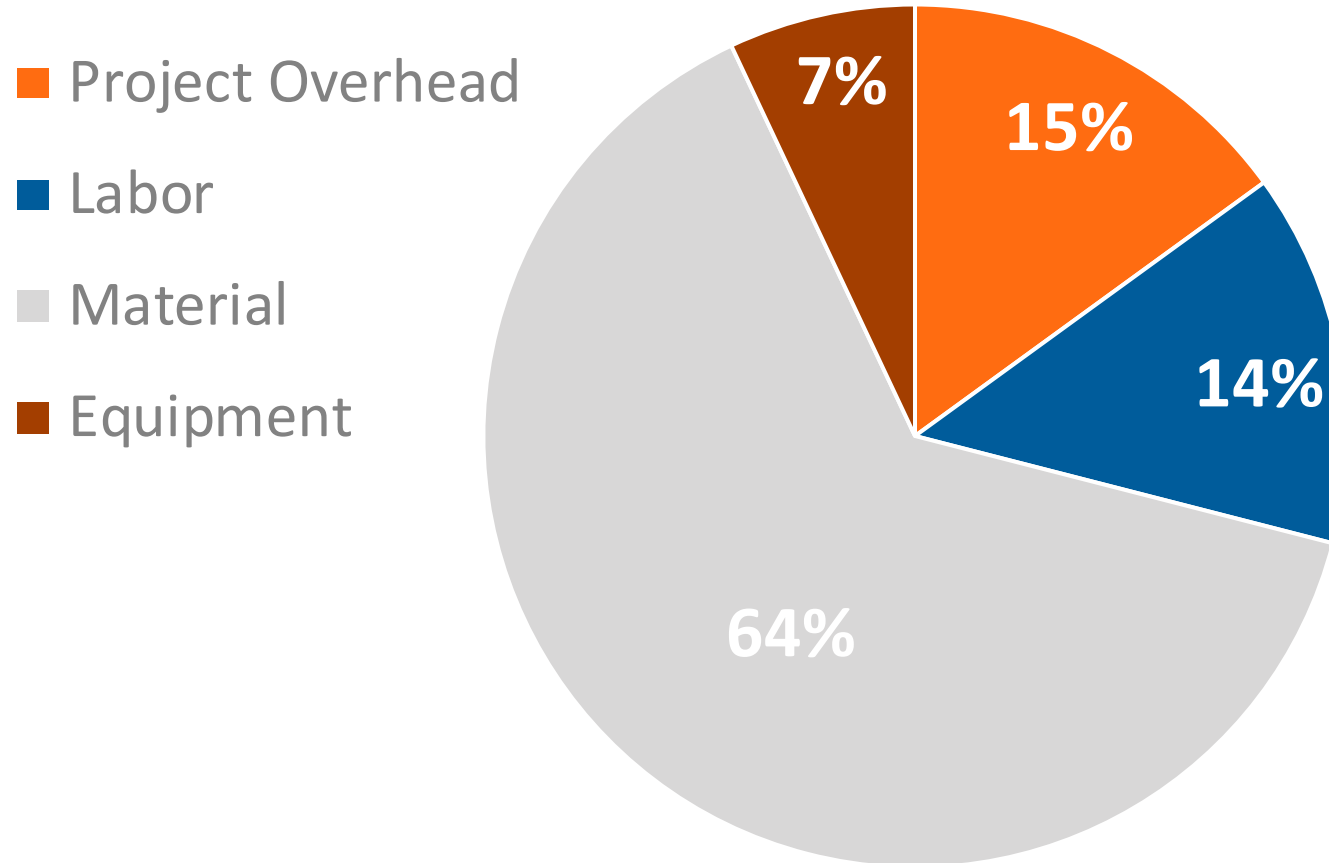
- 1. Unprotected portions of mass timber ceilings and walls comply with one of the following:
 - 1.1 Unprotected portions of mass timber ceilings, including attached beams, limited to an area less than or equal to **100 percent** of the floor area in any dwelling unit within a story or fire area within a story.
 - 1.2 ...

Key Early Design Decisions

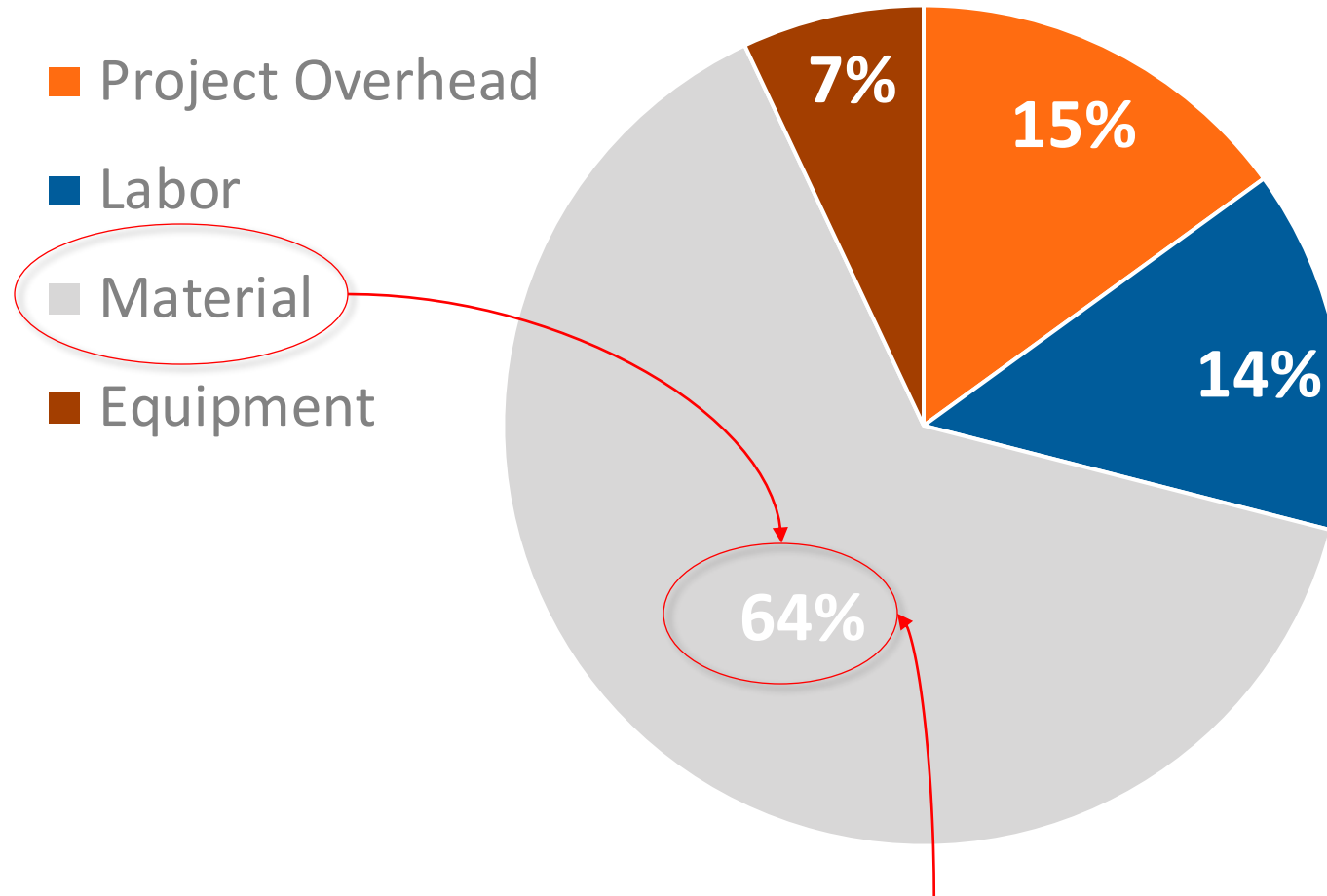
Why so much focus on panel thickness?



Typical MT Package Costs



Typical MT Package Costs



Panels are the biggest part of the biggest piece of the cost pie

Panel volume usually 65-80% of MT package volume

Type IIIA option 1

1-hr FRR

Purlin: 5.5"x28.5"

Girder: 8.75"x33"

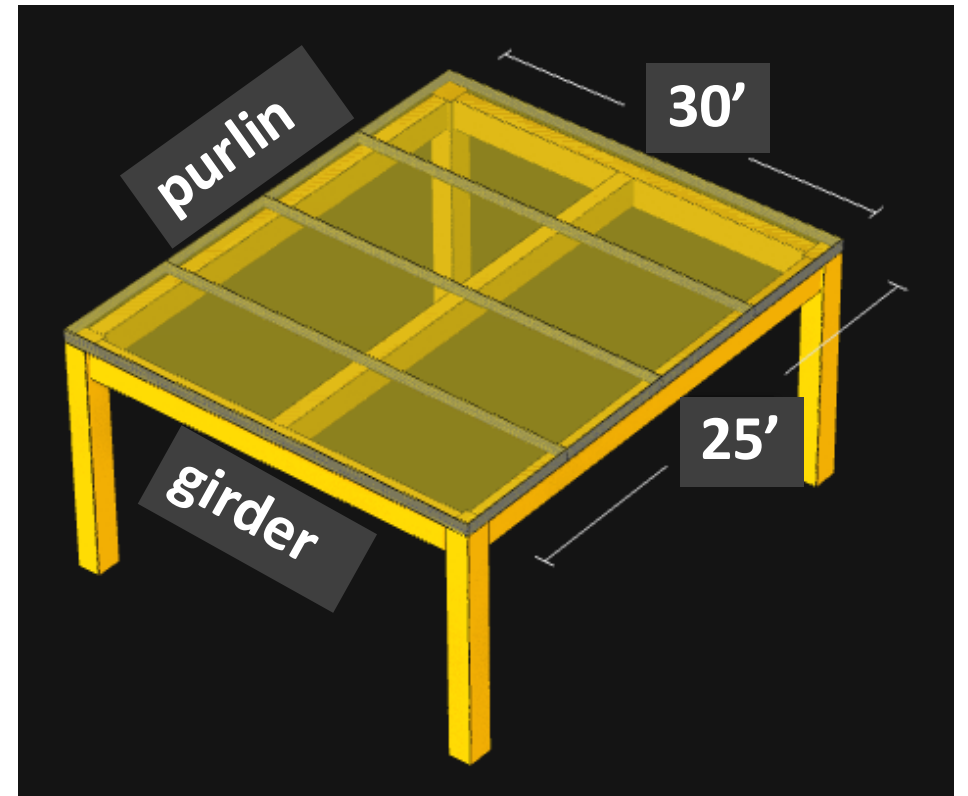
Column: 10.5"x10.75"

Floor panel: 5-ply

Glulam volume = 118 CF (22% of MT)

CLT volume = 430 CF (78% of MT)

Total volume = 0.73 CF / SF



Source: Fast + Epp, Timber Bay Design Tool

Panel volume usually 65-80% of MT package volume

Type IIIA option 2

1-hr FRR

Purlin: 5.5"x24"

Girder: 8.75"x33"

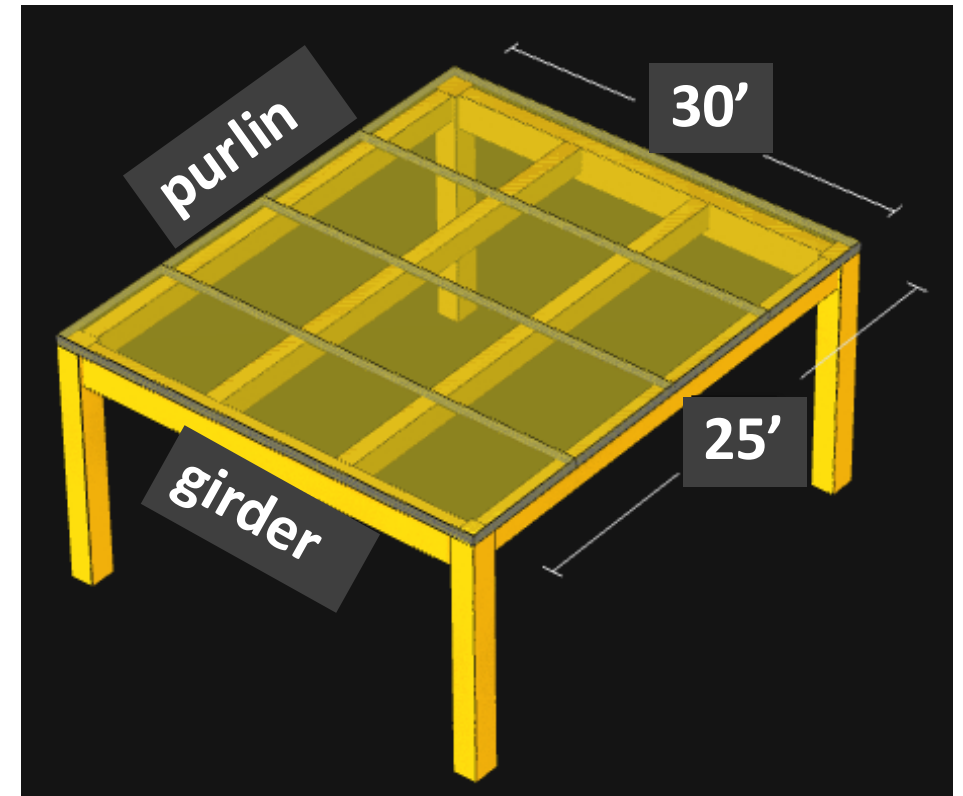
Column: 10.5"x10.75"

Floor panel: 5-ply

Glulam volume = 123 CF (22% of MT)

CLT volume = 430 CF (78% of MT)

Total volume = 0.74 CF / SF



Source: Fast + Epp, Timber Bay Design Tool

Cost considerations: One additional beam (one additional erection pick), 2 more connections

Panel volume usually 65-80% of MT package volume

Type IV-HT

0-hr FRR (min sizes per IBC)

Purlin: 5.5"x24" (IBC min = 5"x10.5")

Girder: 8.75"x33" (IBC min = 5"x10.5")

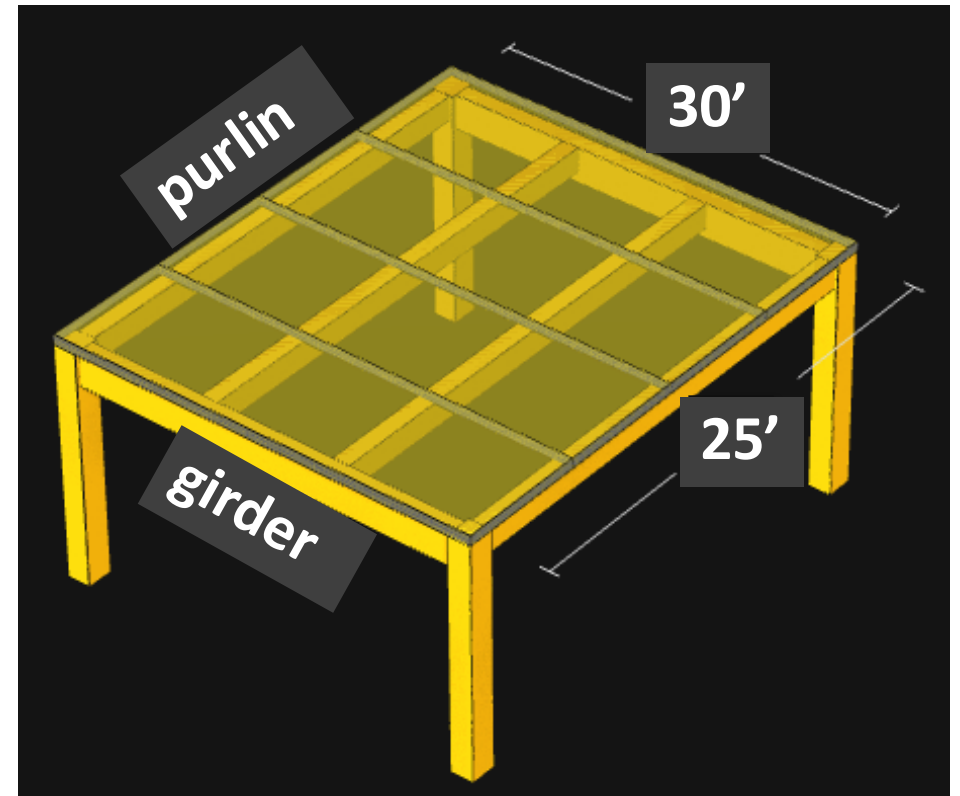
Column: 10.5"x10.75" (IBC min = 6.75"x8.25")

Floor panel: 3-ply (IBC min = 4" CLT)

Glulam volume = 120 CF (32% of MT)

CLT volume = 258 CF (68% of MT)

Total volume = 0.51 CF / SF



Source: Fast + Epp, Timber Bay Design Tool

Panel volume usually 65-80% of MT package volume

Type IV-HT

0-hr FRR (min sizes per IBC)

Purlin: 5.5"x24" (IBC min = 5"x10.5")

Note that if size of building had permitted Type IIIB, member sizing would essentially be the same as IV-HT.

Glulam volume = 120 CF (32% of MT)

CLT volume = 258 CF (68% of MT)

Total volume = 0.51 CF / SF



Source: Fast + Epp, Timber Bay Design Tool

Panel volume usually 65-80% of MT package volume

Type IV-C

2-hr FRR

Purlin: 8.75"x28.5"

Girder: 10.75"x33"

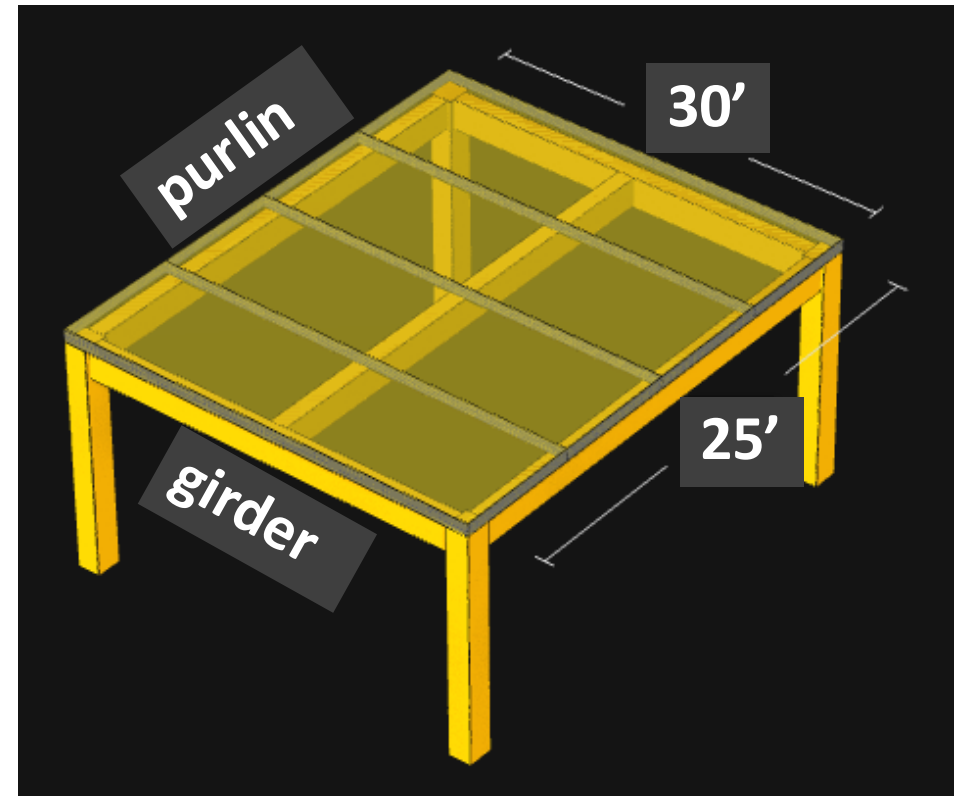
Column: 13.5"x21.5"

Floor panel: 5-ply

Glulam volume = 183 CF (30% of MT)

CLT volume = 430 CF (70% of MT)

Total volume = 0.82 CF / SF

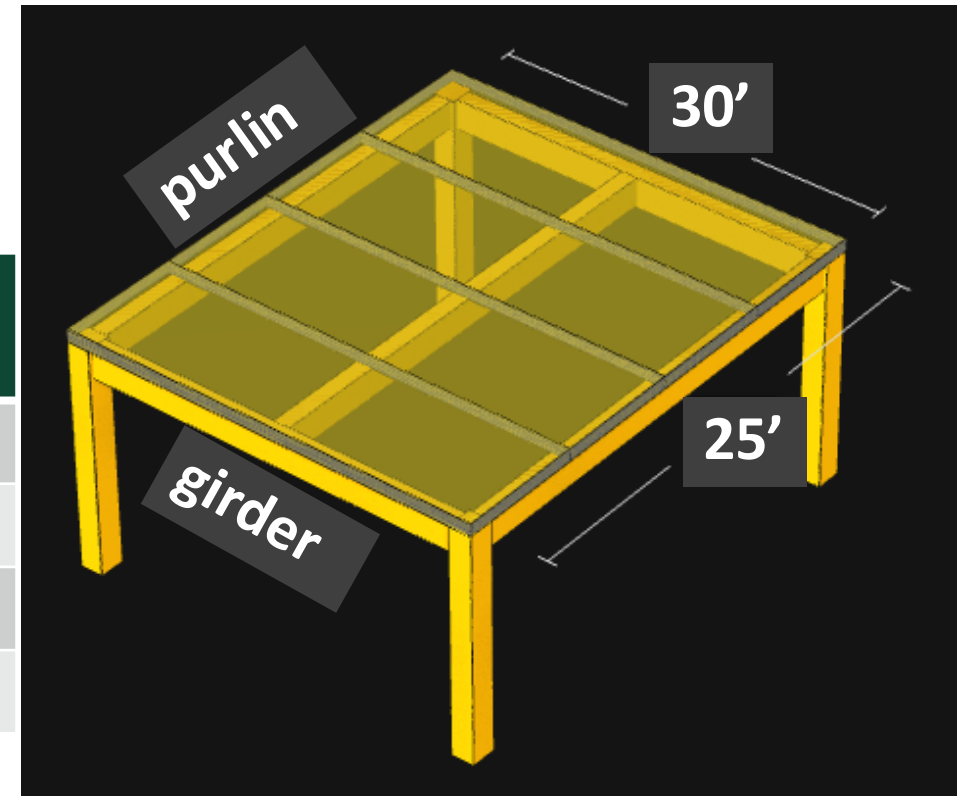


Source: Fast + Epp, Timber Bay Design Tool

Which is the most efficient option?

A general rule of thumb for efficient mass timber fiber volume is no higher than 0.75 CF per SF. Ratios in the 0.85 to 1.0 CF / SF range tend to become cost prohibitive.

	Timber Volume Ratio	Podium on 1 st Floor?
IIIA – Option 1	0.73 CF / SF	Yes
IIIA – Option 2	0.74 CF / SF	Yes
IV-HT	0.51 CF / SF	Yes
IV-C	0.82 CF / SF	No



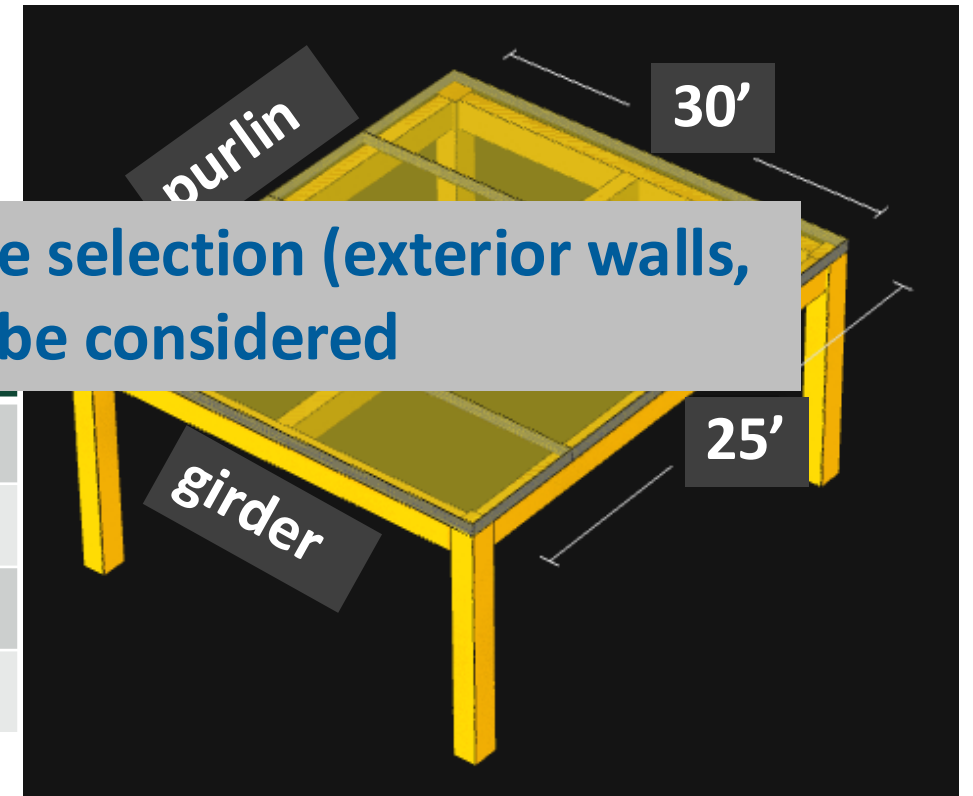
Source: Fast + Epp, Timber Bay Design Tool

Which is the most efficient option?

A general rule of thumb for efficient mass timber fiber volume is no higher than 0.75 CF per SF. Ratios in the 0.85 to 1.0 CF / SF range tend to become cost prohibitive.

There are other impacts of construction type selection (exterior walls, concealed spaces) that should be considered

IIIA – Option 1	0.73 CF / SF	Yes
IIIA – Option 2	0.74 CF / SF	Yes
IV-HT	0.51 CF / SF	Yes
IV-C	0.82 CF / SF	No



Source: Fast + Epp, Timber Bay Design Tool

Break



Outline

- » Key Early Design Decisions
- » Construction Types
- » Fire Design
- » Structural Grid
- **Connections**
 - » Penetrations & Firestopping
 - » MEP Layout and Integration
 - » Lateral Systems
 - » Acoustics
 - » Design Example



Connections

Many ways to demonstrate connection fire protection:
calculations, prescriptive NC, test results, others as approved by AHJ



Photo: John Stamets



Photo: Josh Partee



Photo: Christian Columbres

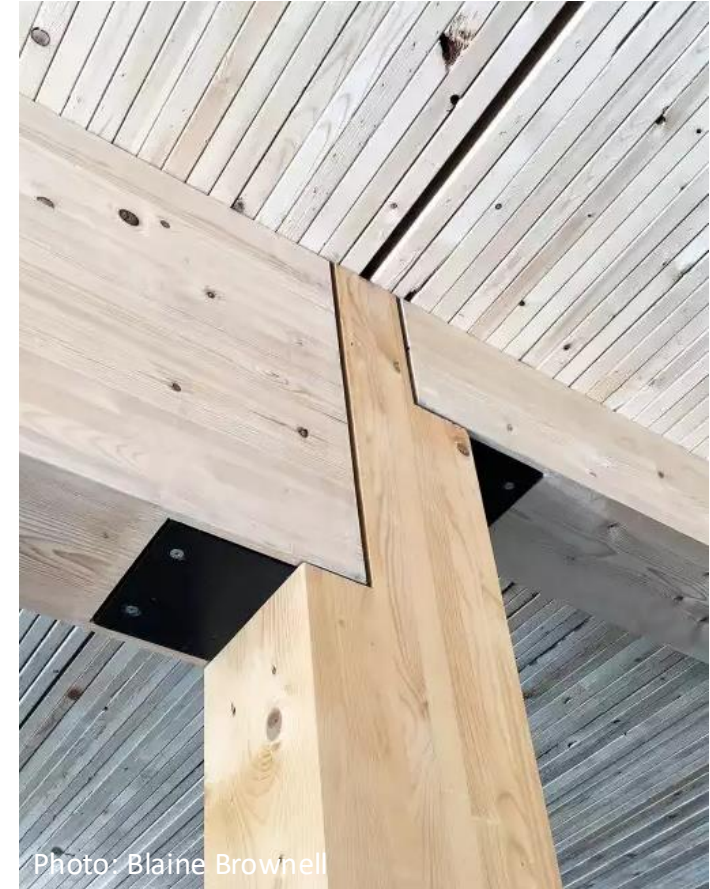
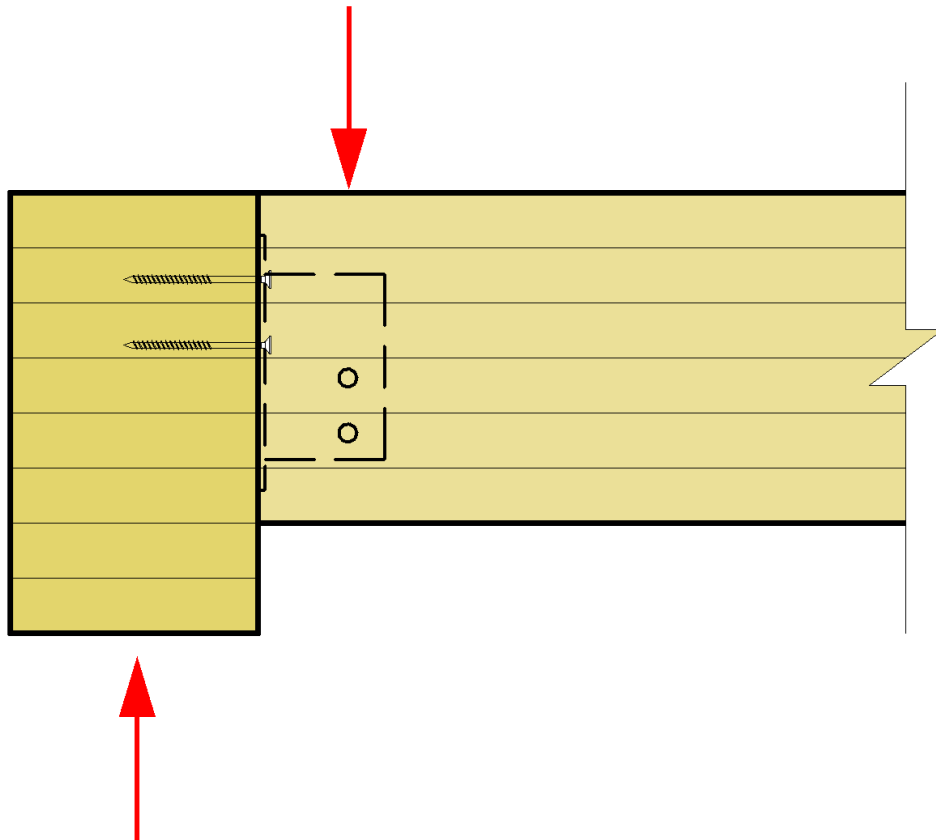


Photo: Blaine Brownell

Connections

Steel hangers/hardware fully concealed within a timber-to-timber connection is a common method of fire protection



Connections

Connection FRR and beam reactions could impact required beam/column sizes



Photos: Simpson Strong-Tie

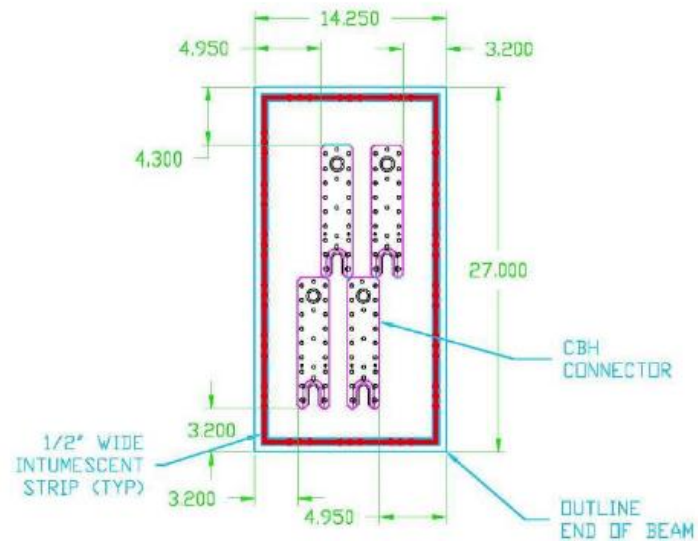


Photo: LEVER Architecture

Connections

2017 Glulam Beam to Column Connection Fire Tests under standard ASTM E119 time-temperature exposure



Photo: ARUP/SLB



Connections

Fire Test Results

Test	Beam	Connector	Applied Load	FRR
1	8.75” x 18” (222mm x 457mm)	1 x Ricon S VS 290x80	3,905lbs (17.4kN)	1hr
2	10.75” x 24” (273mm x 610mm)	Staggered double Ricon S VS 200x80	16,620lbs (73.9kN)	1.5hrs
3	10.75” x 24” (273mm x 610mm)	1 x Megant 430	16,620lbs (73.9kN)	1.5hrs

Connections

Member to member bearing also commonly used, can avoid some/all steel hardware at connection



Mass Timber Connections Index

A library of commonly used mass timber connections with designer notes and information on fire resistance, relative cost and load-carrying capacity.

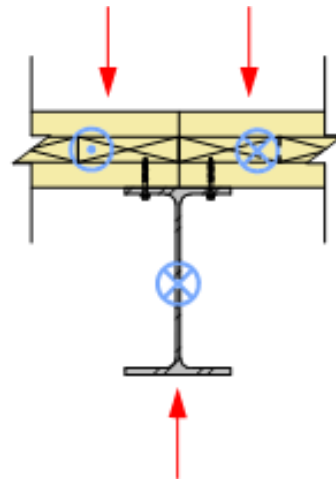
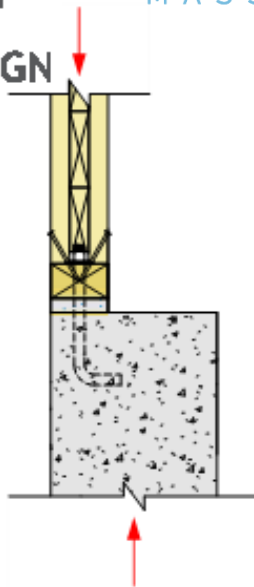
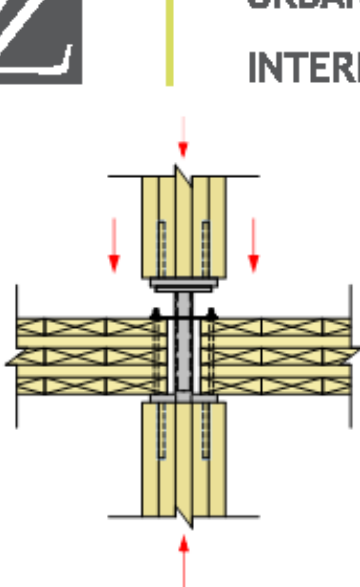


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Engineers & Builders



ARCHITECTURE
URBAN DESIGN
INTERIOR DESIGN

SWINERTON
MASS TIMBER



WoodWorks Index of
Mass Timber Connections



Connections

Other connection design considerations:

- » Structural capacity
- » Shrinkage
- » Constructability
- » Aesthetics
- » Cost



Outline

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 - » Design Example

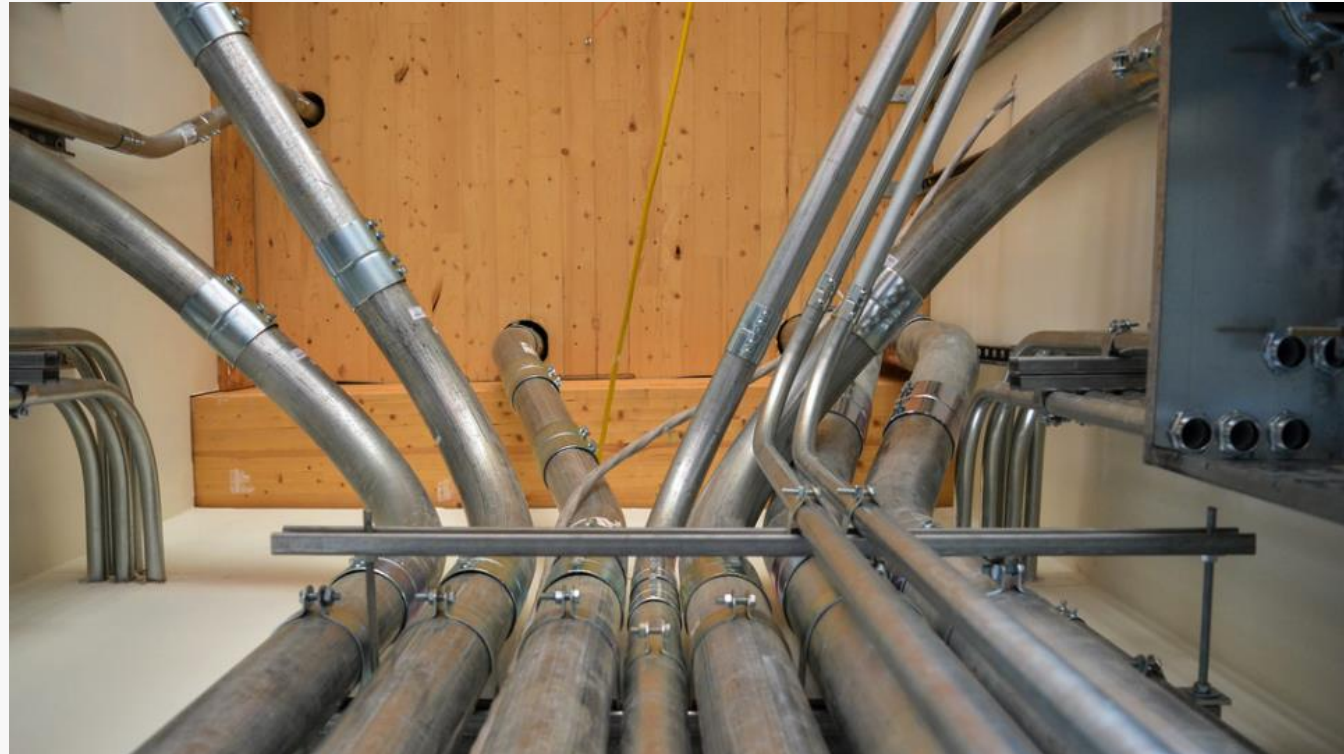


Photo: Alex Schreyer

Penetrations & Firestopping

Option 1: MT penetration firestopping via tested products

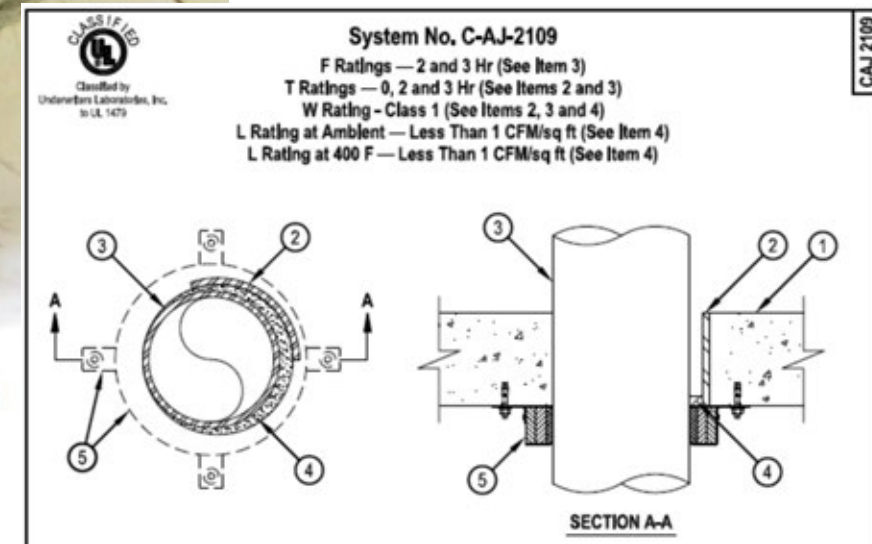
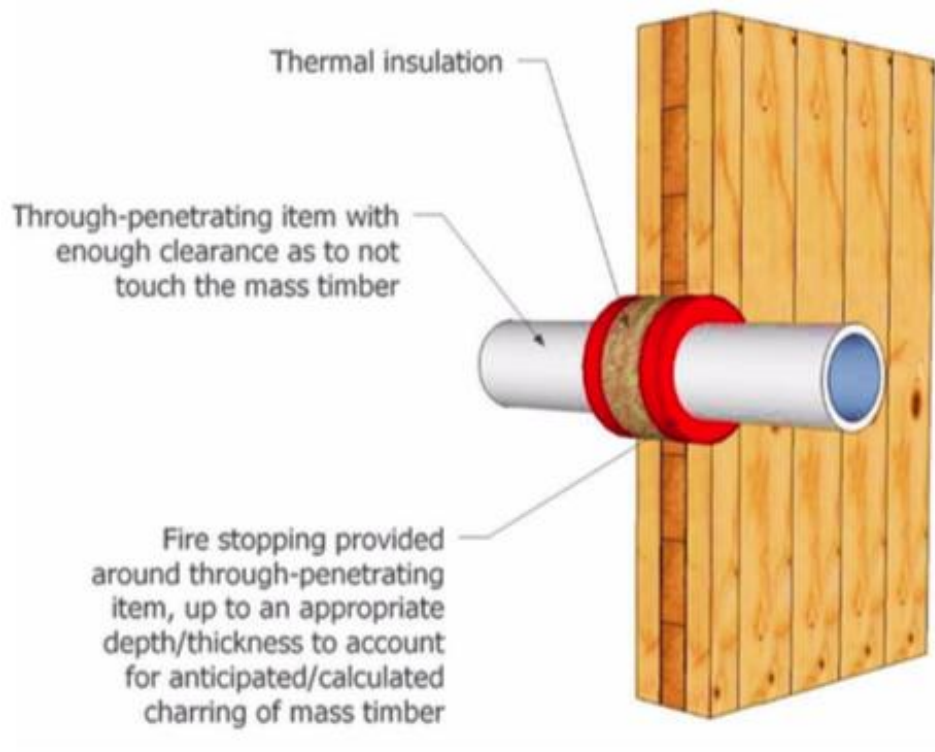


Photos: AWC/FPInnovations



Penetrations & Firestopping

Most firestopping systems include combination of fire safing (eg. noncombustible materials such as mineral wool insulation) plus fire caulk



Penetrations & Firestopping

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CHEMISTRY AND CHEMICAL ENGINEERING DIVISION

FIRE TECHNOLOGY DEPARTMENT
WWW.FIRE.SWRI.ORG
FAX (210) 522-3377



FIRE PERFORMANCE OF FIRESTOPS, PENETRATIONS, AND FIRE DOORS IN MASS TIMBER ASSEMBLIES

Lindsay Ranger¹, Christian Dagenais¹, Conroy Lum¹, Tony Thomas¹

ABSTRACT: Integrity and continuity must be maintained for fire separations required to provide fire resistance. Penetrations, which are required to prevent passage of hot gases or increased temperature on the unexposed side. Vulnerable locations, where penetrations are introduced into mass timber systems, are susceptible to fire spread. Service and closure penetrations in mass timber fire separation have been investigated. Many of the fire stop systems were able to achieve 1-1/2 hr fire resistance in accordance with CAN/ULC-S115, which would be required for 2-hr fire resistance rated assemblies, such as those found in tall wood buildings. Construction details are outlined which ensure adequate fire performance of these penetrations.

KEYWORDS: Firestop, through-penetrations, fire rated door, mass timber, cross-laminated timber, fire resistance

1 INTRODUCTION

Many tall wood buildings using mass timber are planned or are currently being designed for construction around the world. A few have been built in Canada, including an 18 storey cross-laminated timber (CLT) and glulam building in British Columbia. The prescriptive requirements in the National Building Code of Canada (NBCC) [1] do not (yet) permit the construction of wood buildings taller than six stories, however an alternative solutions approach can be used to demonstrate equivalent performance to prescriptive acceptable solutions requiring noncombustible construction. The

construction, as well as in several alternative building designs.

Although the general fire performance of mass timber is well documented, there are still several areas that warrant further investigation to ensure that safety levels are met and a number of solutions are available for designers to use. Generating generic assemblies will reduce the need for testing completed on an individual construction which will help ease the approvals process and encourage widespread adoption of tall wood building

**FIRE RESISTANCE PERFORMANCE EVALUATION
OF A PENETRATION FIRESTOP SYSTEM TESTED
IN ACCORDANCE WITH ASTM E814-13A,
STANDARD TEST METHOD FOR FIRE TESTS OF
PENETRATION FIRESTOP SYSTEMS**

FINAL REPORT
Consisting of 18 Pages

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Prepared for:

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FIRESTOPPING TEST WITNESS REPORT

for

NORDIC STRUCTURES

Inventory of Fire Tested Penetrations in MT Assemblies



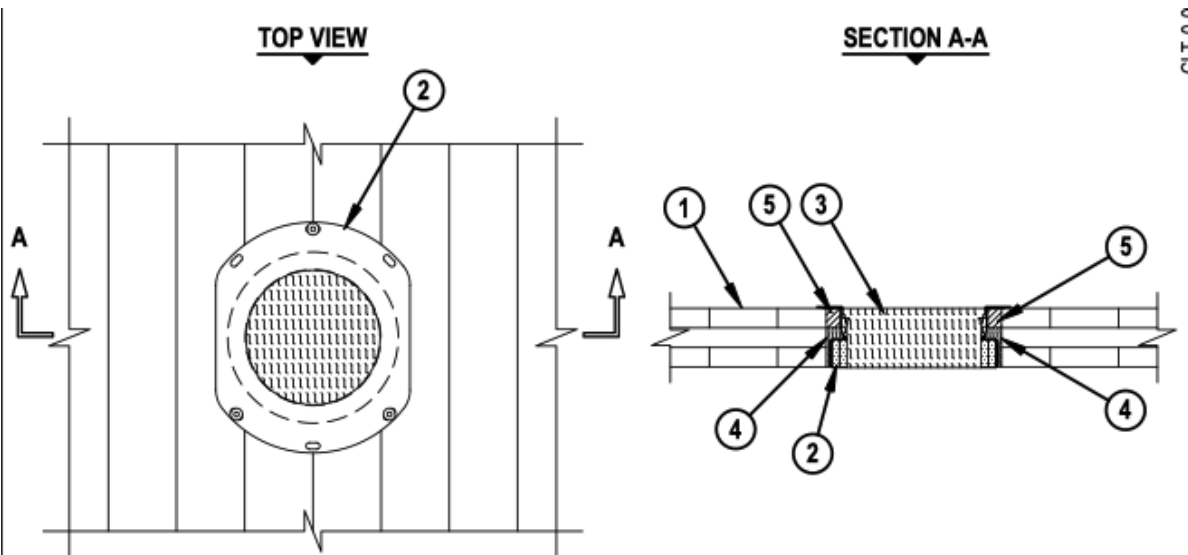
Table 3: North American Fire Tests of Penetrations and Fire Stops in CLT Assemblies

CLT Panel	Exposed Side Protection	Penetrating Item	Penetrant Centered or Offset in Hole	Firestopping System Description	F Rating	T Rating	Stated Test Protocol	Source	Testing Lab
3-ply (78mm 3.07")	None	1.5" diameter data cable bunch	Centered	3.5 in diameter hole. Mineral wool was installed in the 1 in. annular space around the data cables to a total depth of approximately 2 – 5/64 in. The remaining 1 in. annular space from the top of the mineral wool to the top of the floor assembly was filled with Hilti FS-One Max caulking.	1 hour	0.5 hour	CANULC S115	26	Intertek March 30, 2016
3-ply (78mm 3.07")	None	2" copper pipe	Centered	4.375 in diameter hole. Pipe wrap was installed around the copper pipe to a total depth of approximately 2 – 5/64 in. The remaining 1 in. annular space starting at the top of the mineral wool to the top of the floor assembly was filled with Hilti FS-One Max caulking.	1 hour	NA.	CANULC S115	26	Intertek March 30, 2016
3-ply (78mm 3.07")	None	2.5" sched. 40 pipe	Centered	4.92 in diameter hole. Pipe wrap was installed around the schedule 40 pipe to a total depth of approximately 2 – 5/64 in. The remaining 1 in. annular space starting at the top of the pipe wrap to the top of the floor assembly was filled with Hilti FS-One Max caulking.	1 hour	NA.	CANULC S115	26	Intertek March 30, 2016
3-ply (78mm 3.07")	None	6" cast iron pipe	Centered	8.35 in diameter hole. Mineral wool was installed in the 1 in. annular space around the cast iron pipe to a total depth of approximately 2 – 5/64 in. The remaining 1 in. annular space starting at the top of the pipe wrap to the top of the floor assembly was filled with Hilti FS-One Max caulking.	1 hour	NA.	CANULC S115	26	Intertek March 30, 2016
3-ply (78mm 3.07")	None	Hilti 6 in drop in device. System No.: F-B-2049	Centered	9.01" diameter hole. Mineral wool was installed in the 1 – 1/4 in. annular space around the drop-in device to a total depth of approximately 1 – 7/64 in and the remaining 1 in. annular space from the top of the mineral wool to the top edge of the 9 – 1/64 in. hole in the CLT was filled with Hilti FS-One Max caulking.	1 hour	0.75 hour	CANULC S115	26	Intertek March 30, 2016
5-ply CLT (131 mm 5.16")	None	1.5" diameter data cable bunch	Centered	3.5" diameter hole. Mineral wool was installed in the 1 in. annular space around the data cables to a total depth of approximately 4 – 5/32 in. The remaining 1 in. annular space from the top of the mineral wool to the top of the floor assembly was filled with Hilti FS-One Max caulking.	2 hours	1.5 hours	CANULC S115	26	Intertek March 30, 2016
5-ply CLT (131 mm 5.16")	None	2" copper pipe	Centered	4.375 in diameter hole. Pipe wrap was installed around the copper pipe to a total depth of approximately 4 – 5/32 in. The remaining 1 in. annular space starting at the top of the mineral wool to the top of the floor assembly was filled with Hilti FS-One Max caulking.	2 hours	NA.	CANULC S115	26	Intertek March 30, 2016
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5-ply (175mm 6.875")	None	1" nominal PVC pipe	Centered	4.21 in diameter with a 3/4 in plywood reducer flush with the top of the slab reducing the opening to 2.28 in. Two wraps of Hilti CP 648-E W45/1-3/4" Firestop wrap strip at two locations with a 30 gauge steel sleeve which extended from the top of the slab to 1 in below the slab. The first location was with the bottom of the wrap strip flush with the bottom of the steel sleeve and the second was with the bottom of the wrap strip 3 in. from the bottom of the slab. The void between the steel sleeve and the CLT and between the steel sleeve and pipe at the top was filled with Roxul Safe mineral wool leaving a 3/4 in deep void at the top of the assembly. Hilti FS-One Max Intumescent Firestop Sealant was applied to a depth of 3/4 in on the top of the assembly between the plywood and steel sleeve as well as the steel sleeve and pipe.	2 hours	2 hours	ASTM E814	24	QAI Laboratories March 3, 2017
5-ply (175mm 6.875")	2 layers 5/8" Tyne Xevonsum	1.5 inch O.D. closed PVC nine	Centered	Hilti System C-AJ-2109 modified: no steel sleeve, 3.5" long wood screws used to attach the collar; pipe placed concentrically within hole; 2.5" sealant depth	2 hours	2 hours	ASTM E814	23	SwRI September 30, 2015

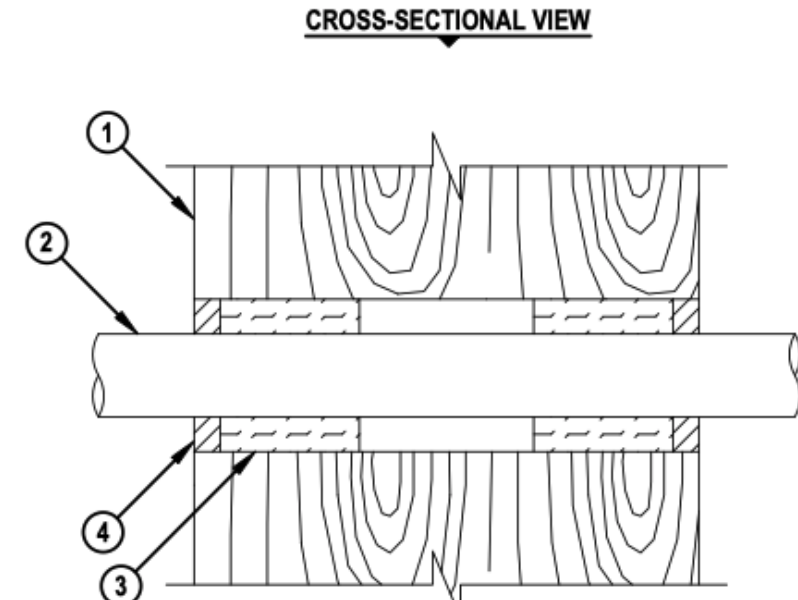
Penetrations & Firestopping

Option 2: MT penetration firestopping of penetrations via engineering judgement details (contact firestop manufacturer)

F-RATING = 1-HR. OR 2-HR. (SEE NOTE NO. 3 BELOW)



1. 3-PLY CROSS LAMINATED TIMBER FLOOR ASSEMBLY (MINIMUM 3" THICK) (1-HR. FIRE-RATING).
2. HILTI CFS-DID FIRESTOP DROP-IN DEVICE INSERTED INTO OPENING (SEE TABLE BELOW) AND SECURED TO TOP SURFACE OF CROSS LAMINATED TIMBER FLOOR ASSEMBLY WITH THREE 1/4" x 1" LONG STEEL WOOD SCREWS WITH WASHERS.
3. MINIMUM 3" THICKNESS MINERAL WOOL (MIN. 4 PCF DENSITY) TIGHTLY PACKED, AND FLUSH WITH TOP AND BOTTOM SURFACE OF CFS-DID FIRESTOP DROP-IN DEVICE.
4. MINERAL WOOL (MIN. 4 PCF DENSITY) TIGHTLY PACKED, RECESSED TO ACCOMMODATE SEALANT, AND COMPLETELY FILLING SPACE BETWEEN CFS-DID FIRESTOP DROP-IN DEVICE AND PERIPHERY OF OPENING.
5. MINIMUM 1" DEPTH HILTI FS-ONE MAX INTUMESCENT FIRESTOP SEALANT BETWEEN CFS-DID FIRESTOP DROP IN DEVICE AND PERIPHERY OF OPENING.

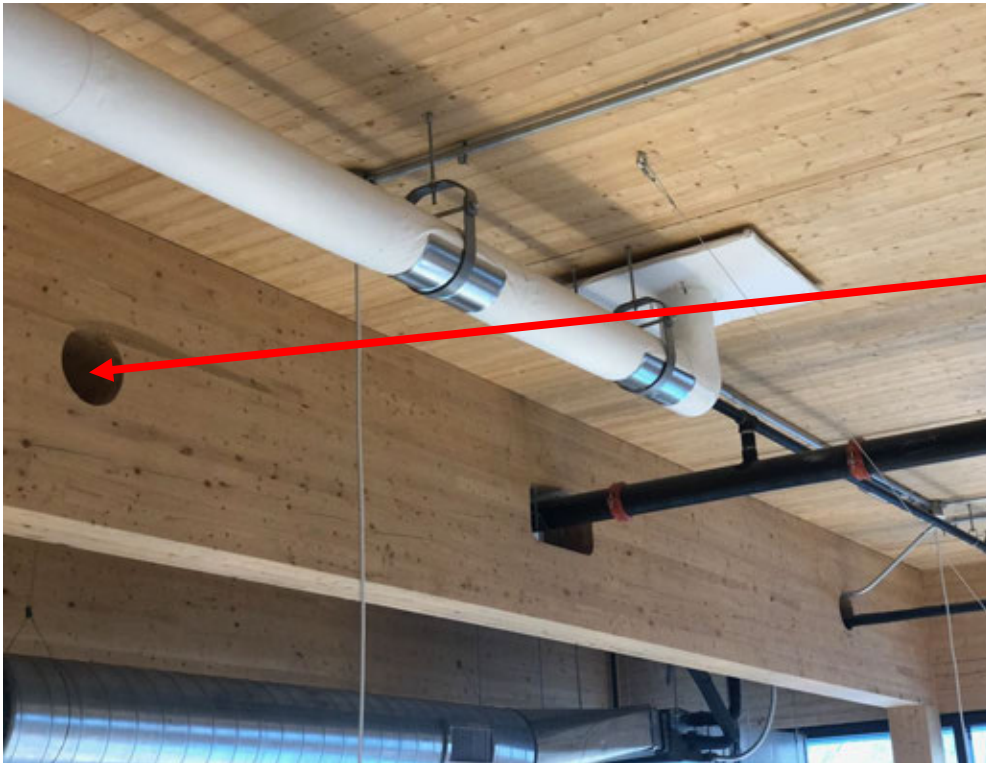


1. MASS TIMBER WALL ASSEMBLY (MINIMUM 12" THICK) (1-HR. OR 2-HR. FIRE-RATING).
2. MAXIMUM 2" NOMINAL DIAMETER PVC PLASTIC PIPE (SCH 40).
3. MINIMUM 4" THICKNESS MINERAL WOOL (MIN. 4 PCF DENSITY) TIGHTLY PACKED AND RECESSED TO ACCOMMODATE SEALANT.
4. MINIMUM 3/4" DEPTH HILTI FS-ONE MAX INTUMESCENT FIRESTOP SEALANT.

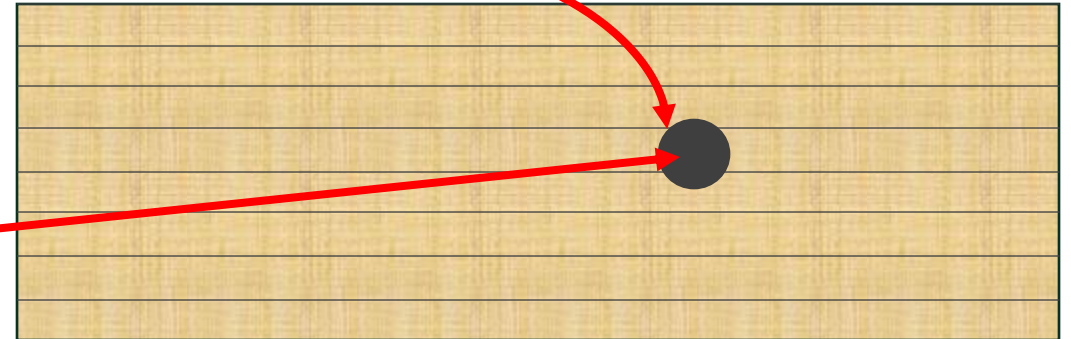
Penetrations & Firestopping

Beam penetrations:

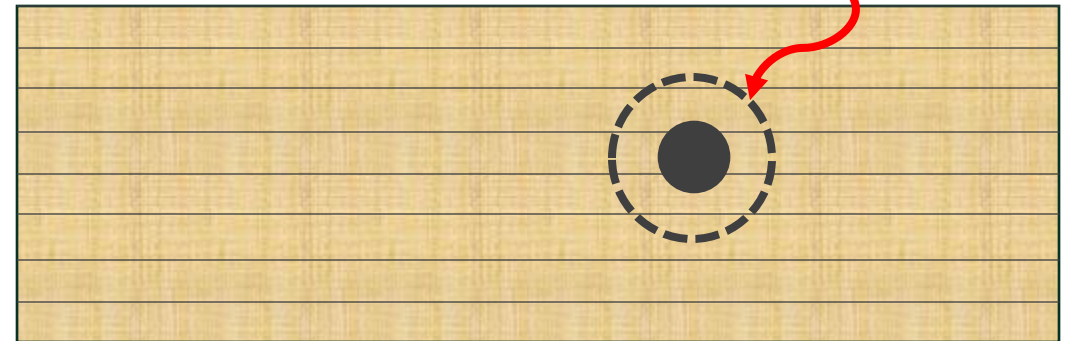
- » If FRR = 0-hr, analyze structural impact of hole diameter only
- » If FRR > 0-hr, account for charred hole diameter or firestop penetration



Hole diameter



Hole diameter after 1-hr char



Outline

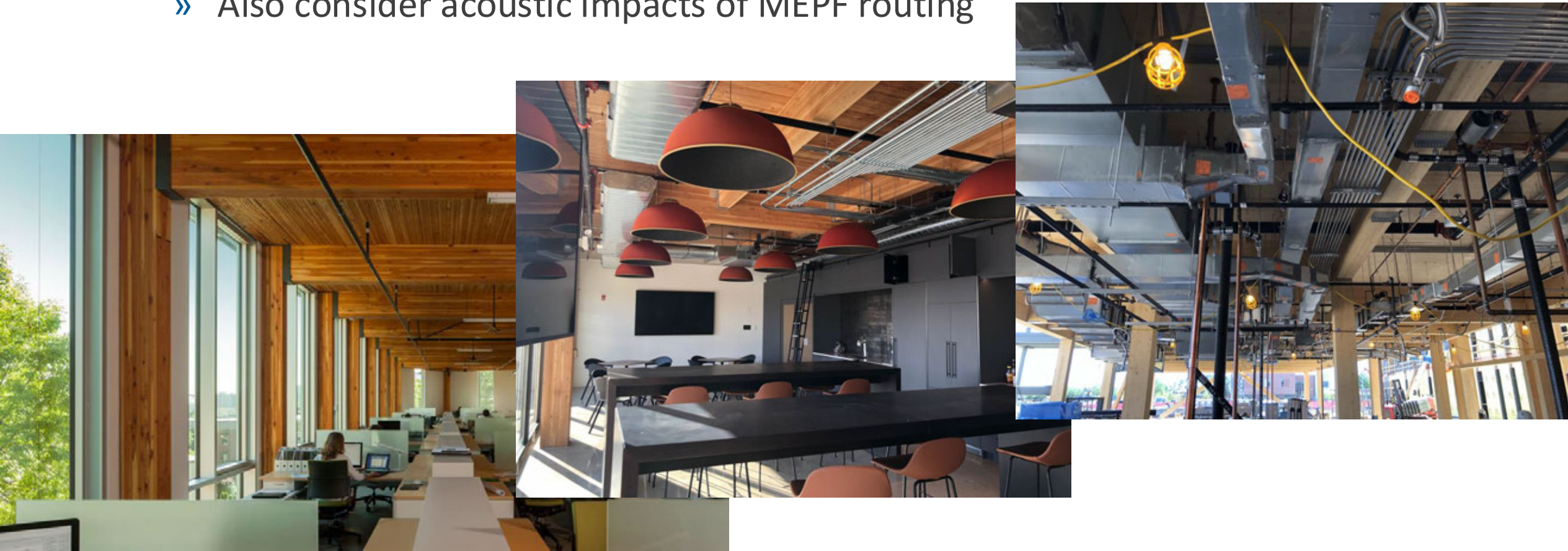
- » Key Early Design Decisions
- » Construction Types
- » Fire Design
- » Structural Grid
- » Connections
- » Penetrations & Firestopping
- **MEP Layout and Integration**
- » Lateral Systems
- » Acoustics
- » Design Example



MEP Layout & Integration

Set Realistic Owner Expectations About Aesthetics

- » MEP fully exposed with MT structure, or limited exposure?
- » Also consider acoustic impacts of MEPPF routing



MEP Layout & Integration

Key considerations:

- » Level of exposure desired
- » Floor to floor, structure depth & desired head height
- » Building occupancy and configuration (i.e. central core vs. double loaded corridor)
- » Grid layout and beam orientations
- » Need for future tenant reconfiguration
- » Impact on fire & structural design: concealed spaces, penetrations

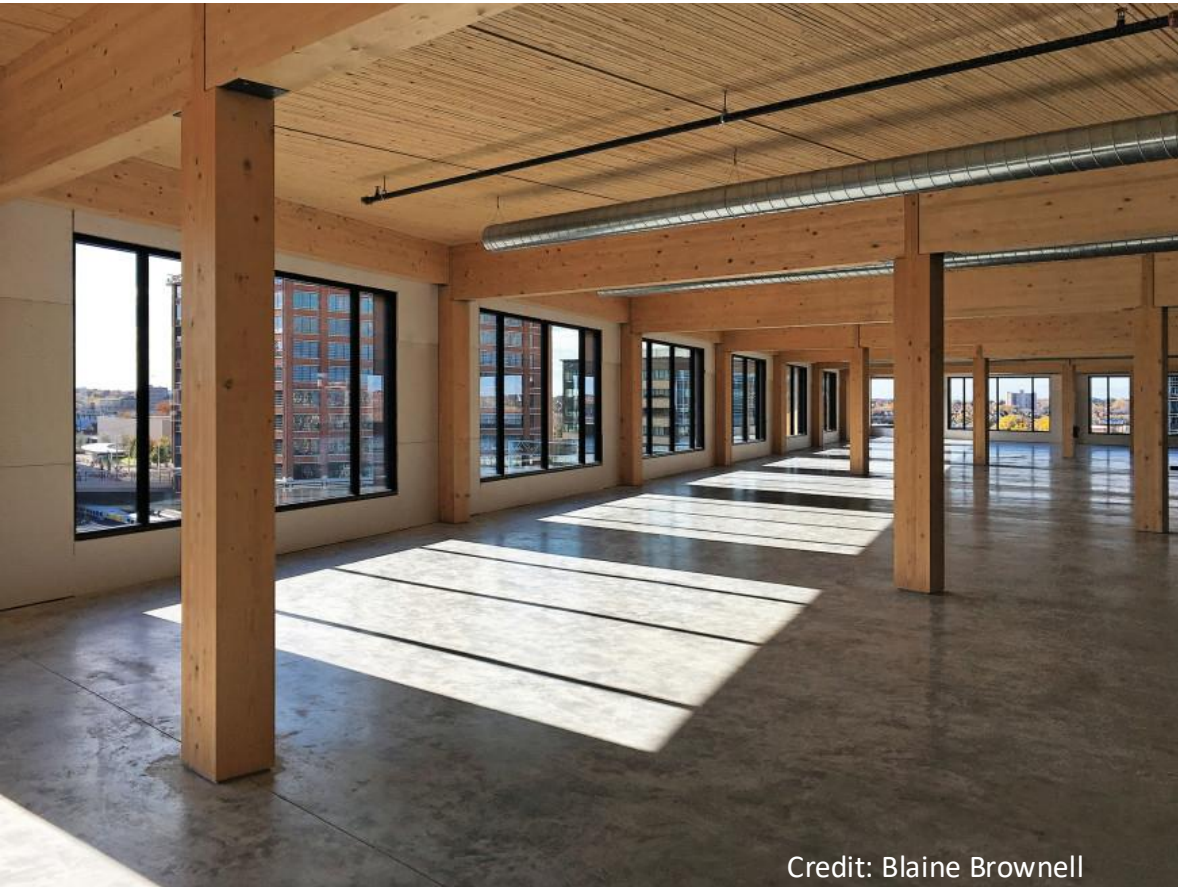
Credit: WoodWorks



MEP Layout & Integration

Smaller grid bays at central core (more head height)

» Main MEP trunk lines around core, smaller branches in exterior bays

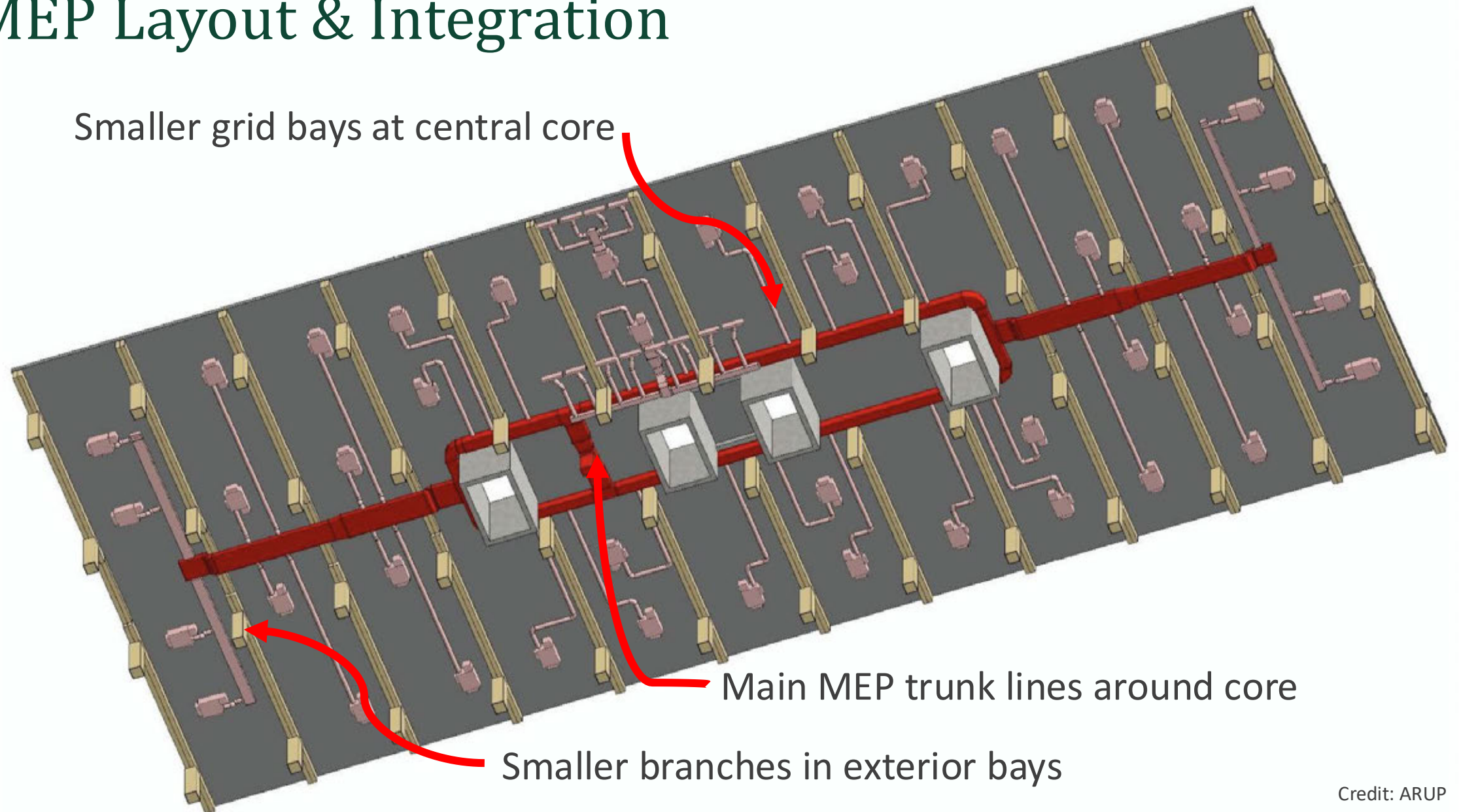


Credit: Blaine Brownell



Credit: WoodWorks

MEP Layout & Integration



MEP Layout & Integration

Grid impact: Relies on one-way beam layout. Columns/beams spaced at panel span limits in one direction.

Beam penetrations are minimized or eliminated

Recall typical panel span limits:

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



Credit: Hacker Architects

MEP Layout & Integration

Dropped below MT framing

- » Can simplify coordination (fewer penetrations)
- » Bigger impact on head height



MEP Layout & Integration

In penetrations through MT framing

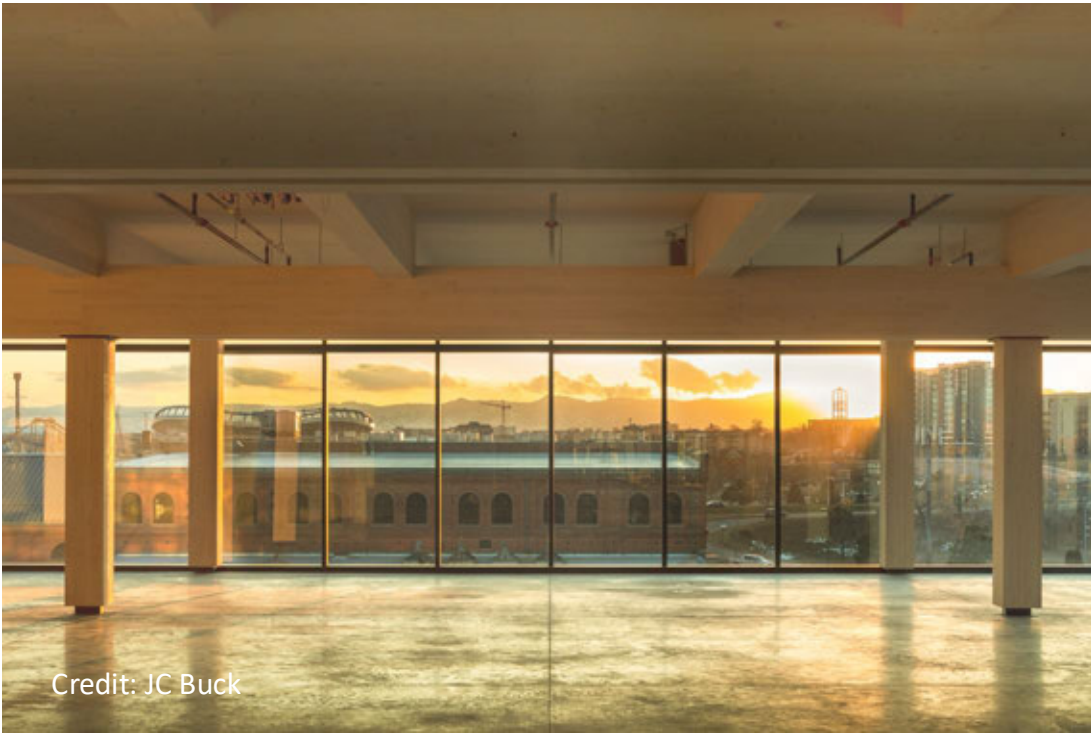
- » Requires more coordination (penetrations)
- » Bigger impact on structural capacity of penetrated members
- » Minimal impact on head height



MEP Layout & Integration

In chases above beams and below panels

- » Fewer penetrations
- » Bigger impact on head height (overall structure depth is greater)
- » FRR impacts: top of beam exposure



Credit: JC Buck



Credit: KL&A Engineers & Builders

MEP Layout & Integration

In gaps between MT panels

- » Fewer penetrations, can allow for easier modifications later



Credit: Ema Peter/MGA

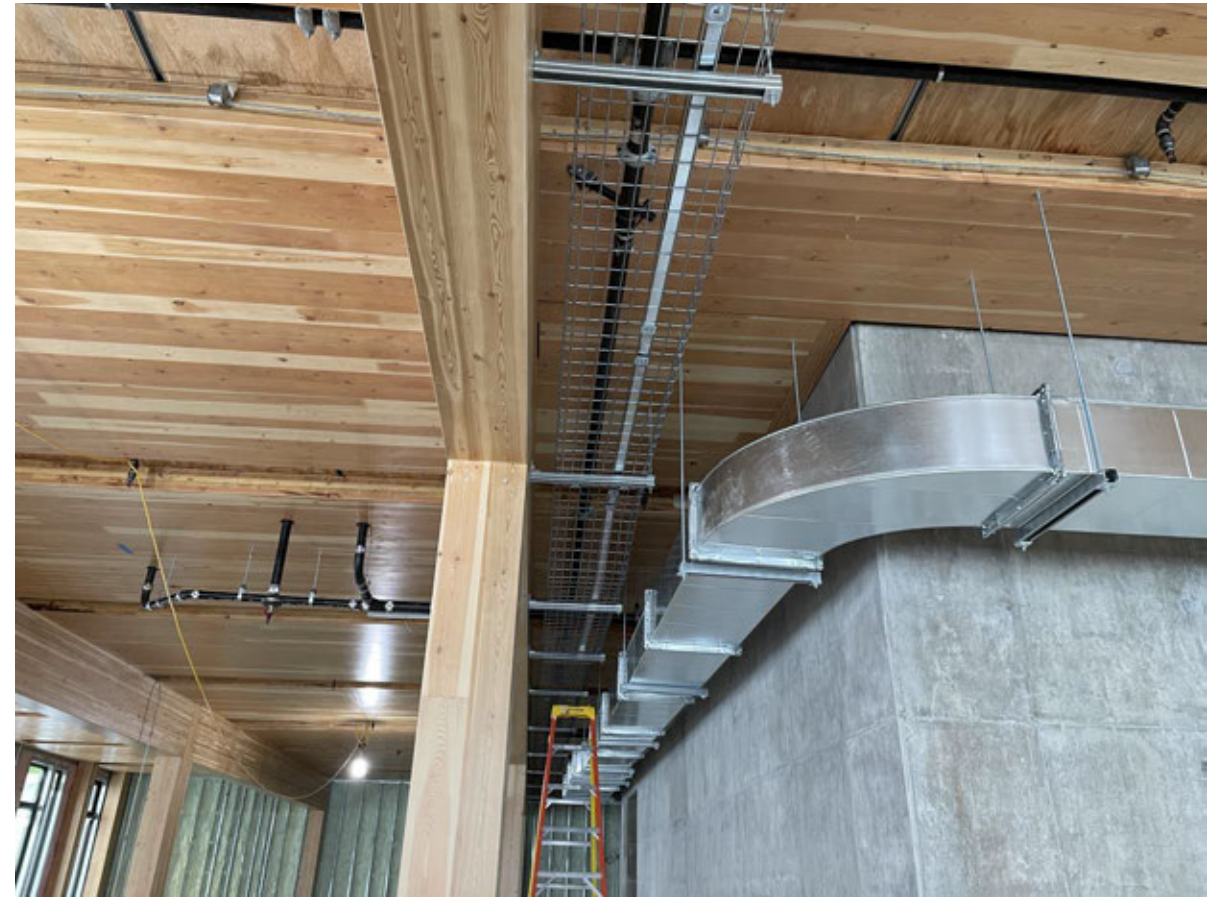
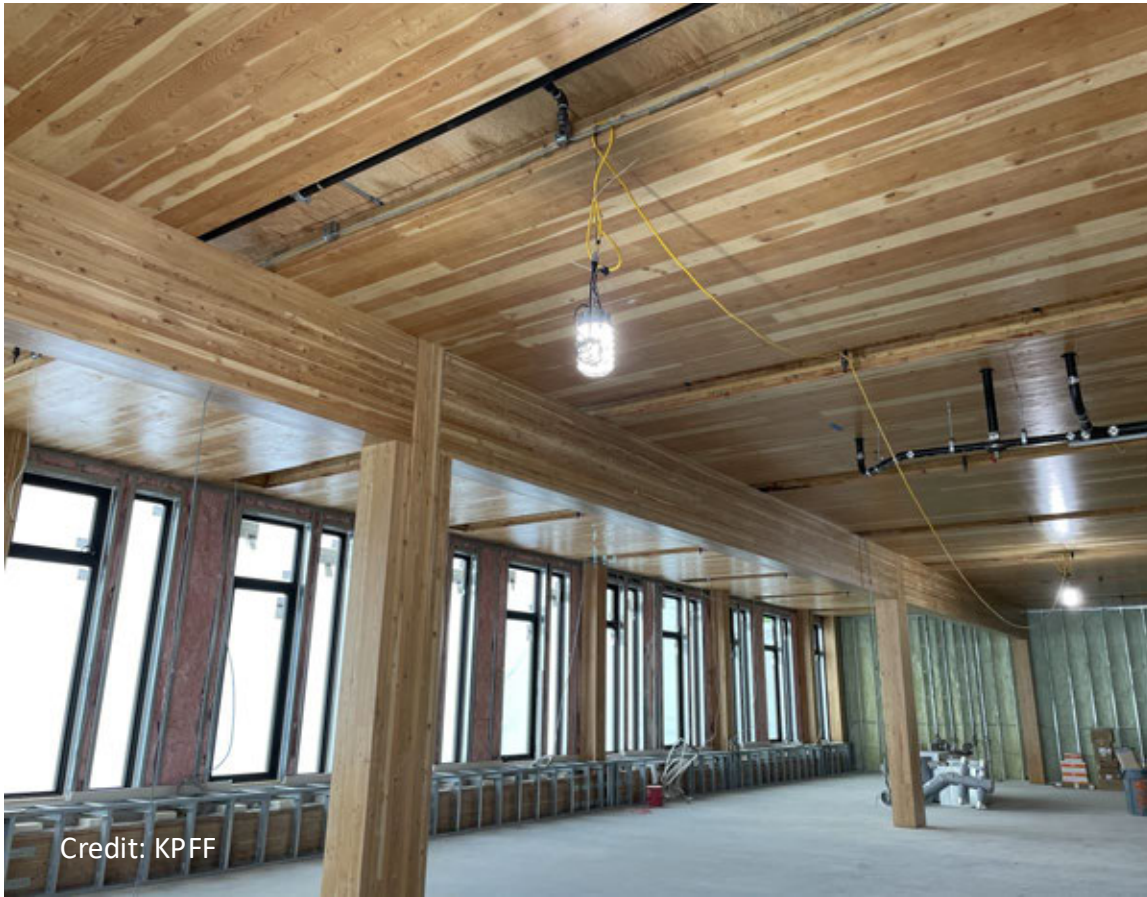


Credit: Hacker Architects

MEP Layout & Integration

In gaps between MT panels

» FRR impacts: generally topping slab relied on for FRR



MEP Layout & Integration

In gaps between MT panels

» Impact on assembly acoustics performance



Credit: KPFF



MEP Layout & Integration

In gaps between MT panels

- » Aesthetics: often uses ceiling panels to cover gaps
- » Acoustic impacts: rely more on topping



Credit: Ema Peter/MGA

MEP Layout & Integration

In raised access floor (RAF) above MT

- » Aesthetics (minimal exposed MEP)
- » Acoustic impacts (usually thinner topping req'd)



RAF

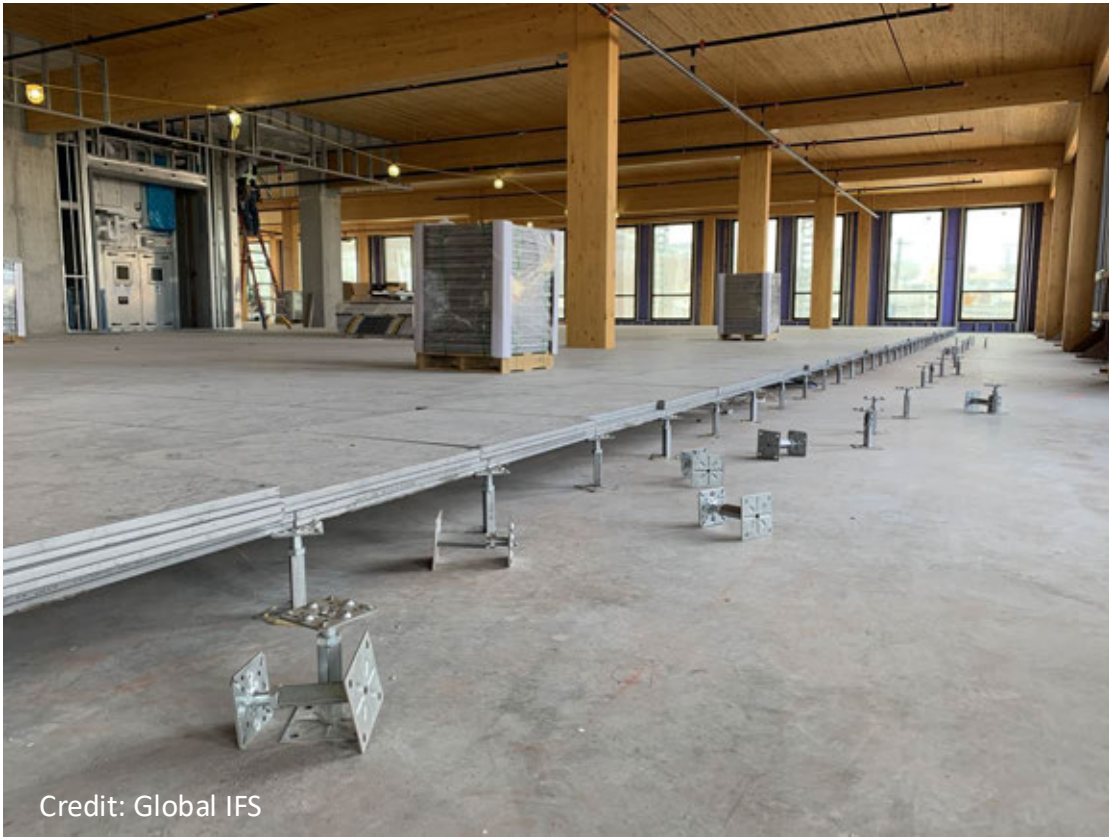


NON-RAF

MEP Layout & Integration

In raised access floor (RAF) above MT

- » Impact on head height
- » Concealed space code provisions



Credit: Global IFS



MEP Layout & Integration

In topping slab above MT

- » Greater need for coordination prior to slab pour
- » Limitations on what can be placed (thickness of topping slab)
- » No opportunity for renovations later



Outline

- » Key Early Design Decisions
- » Construction Types
- » Fire Design
- » Structural Grid
- » Connections
- » Penetrations & Firestopping
- » MEP Layout and Integration
- **Lateral Systems**
 - » Acoustics
 - » Design Example



Lateral System Choices

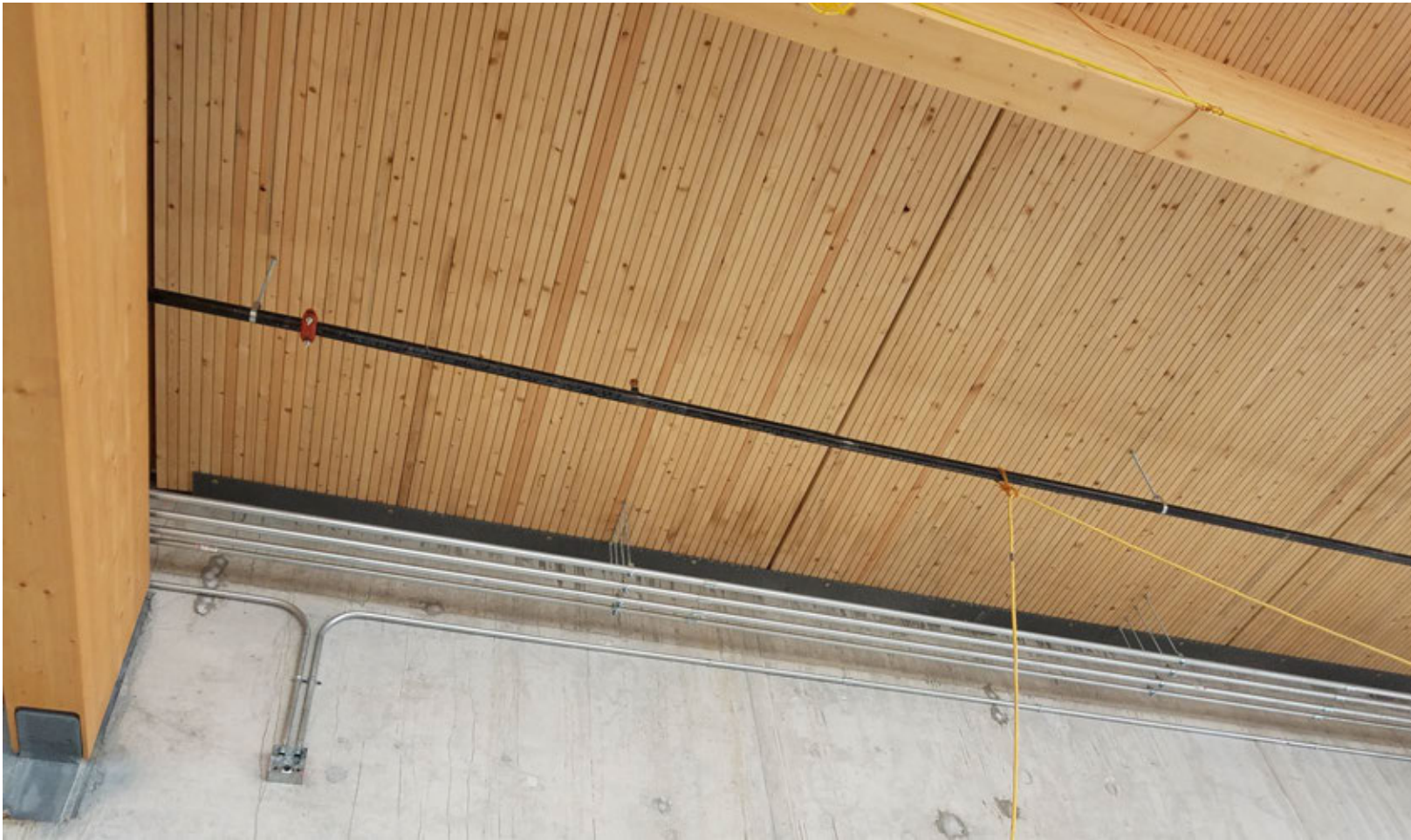
Concrete Shear walls



Credit: Hacker Architects

Lateral System Choices

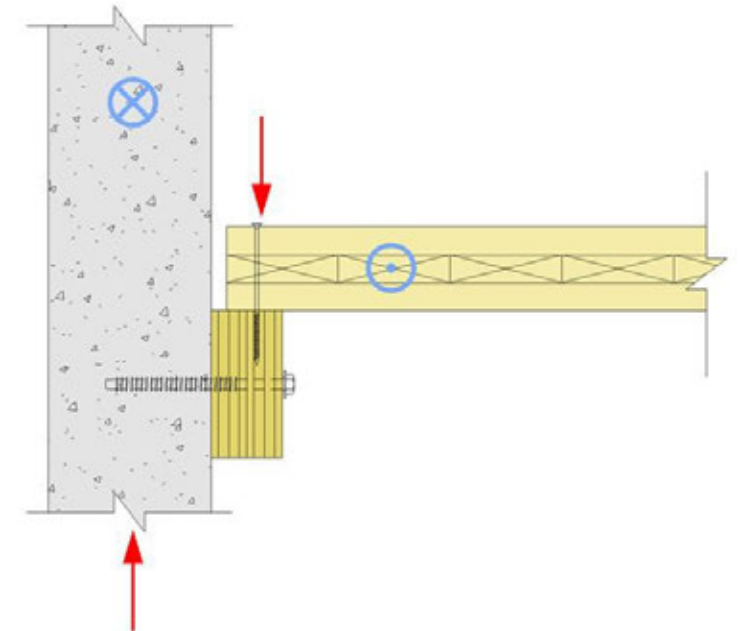
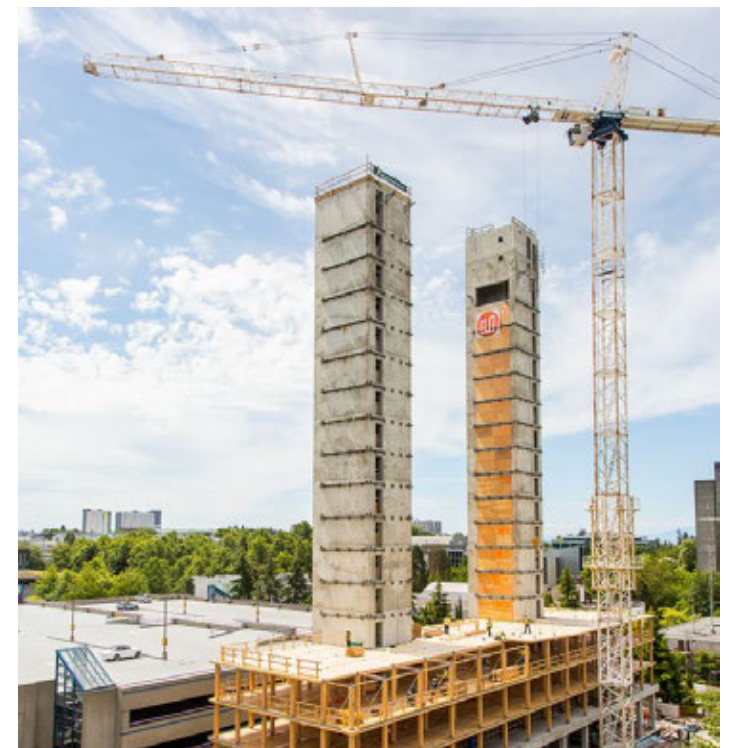
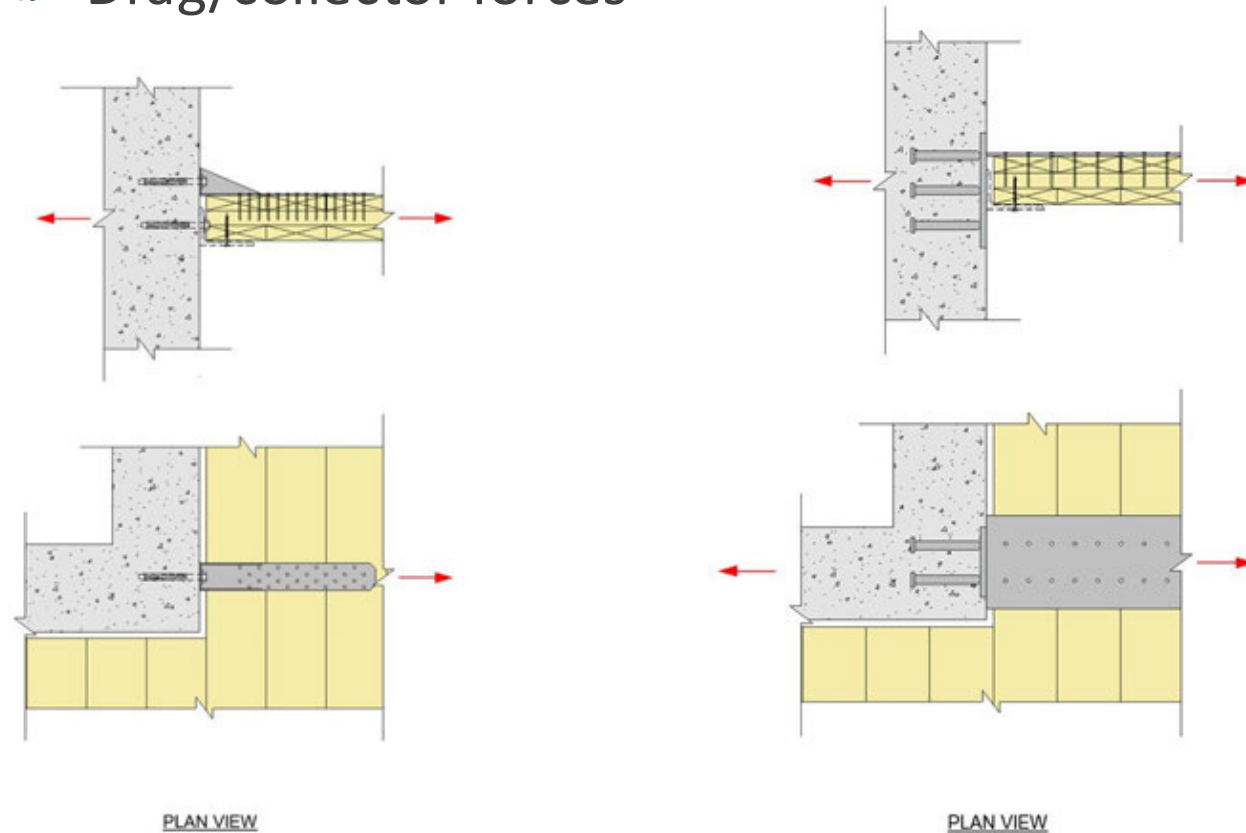
Connection to concrete core



Lateral System Choices

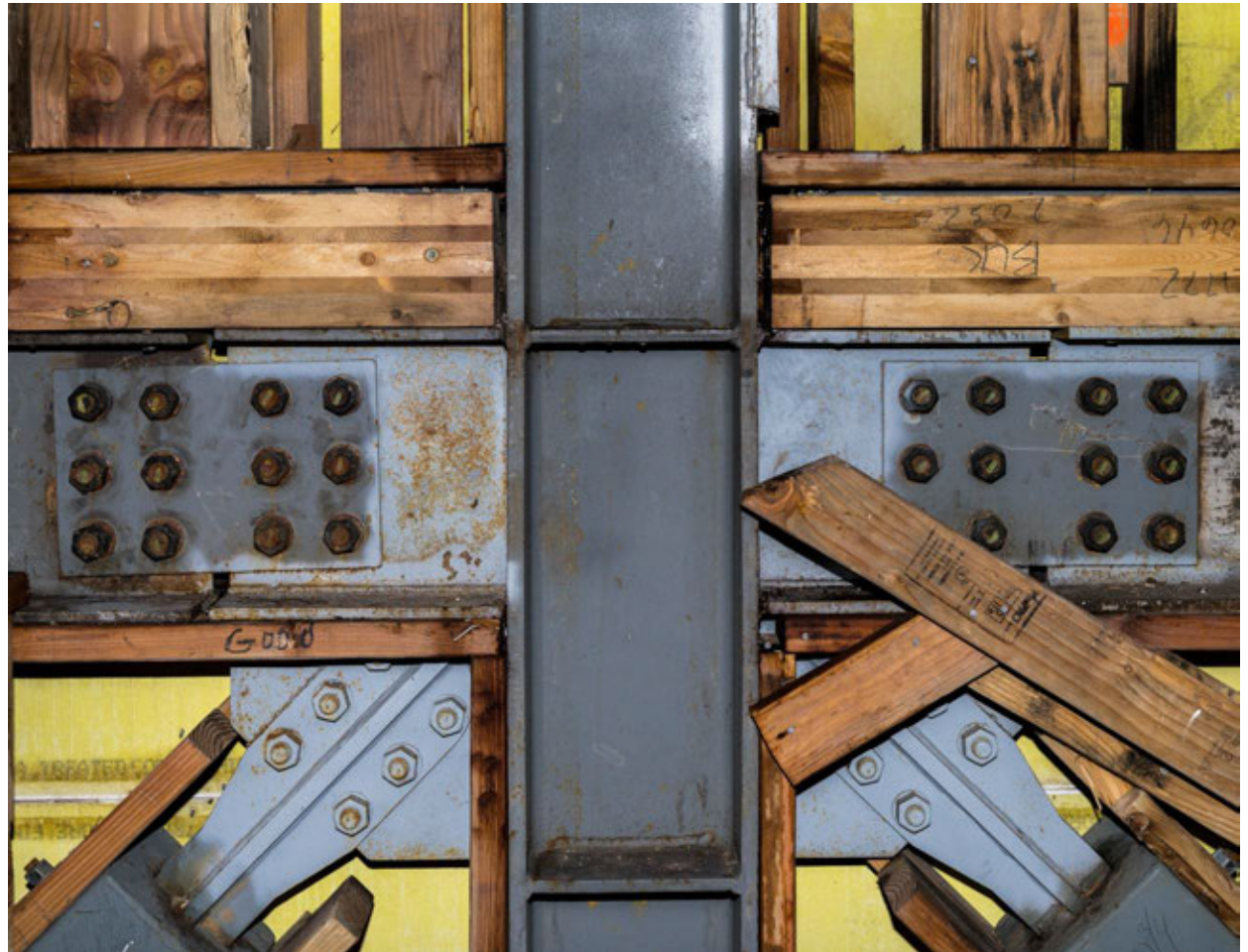
Connections to concrete core

- » Tolerances & adjustability
- » Drag/collector forces



Lateral System Choices

Steel Braced Frame



Lateral System Choices

Connections to steel frame

- » Tolerances & adjustability
- » Consider temperature fluctuations
- » Ease of installation

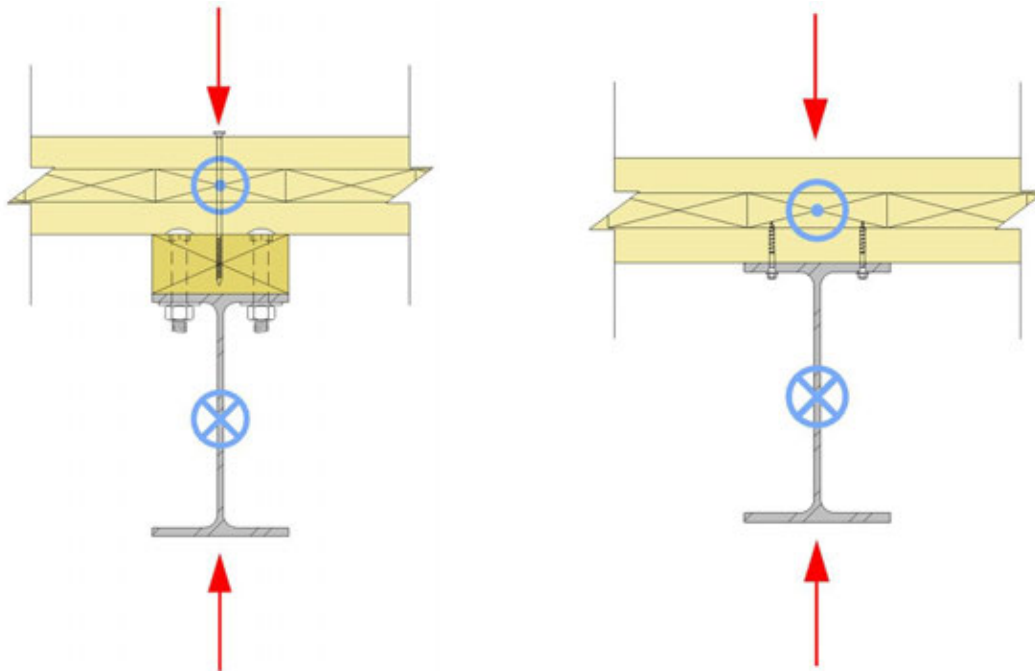
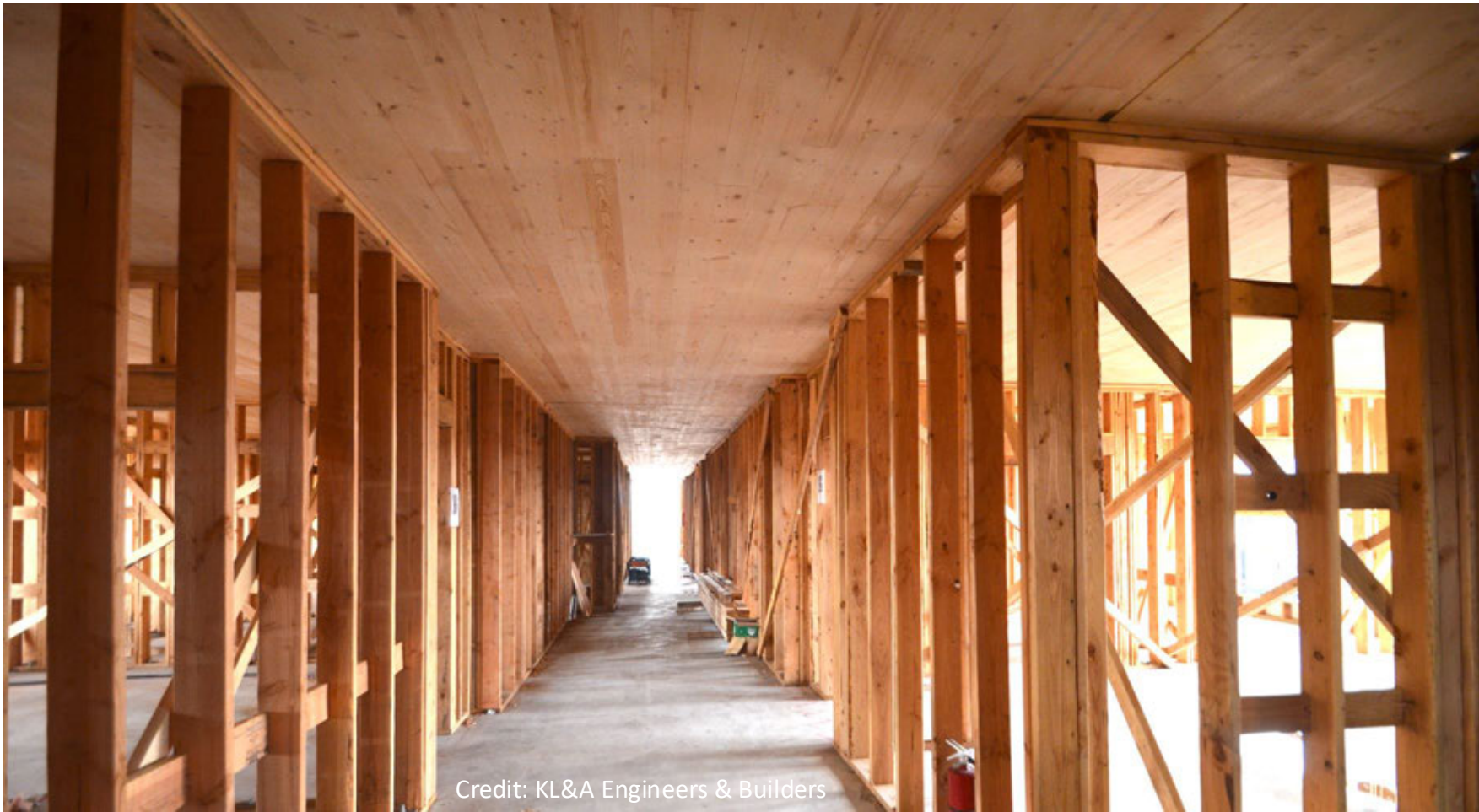


Photo: Marcus Kauffmann, ODF

Lateral System Choices

Wood-Frame Shear walls



Credit: KL&A Engineers & Builders

Lateral System Choices

MT Shear walls



Photo: Alex Schreyer



Lateral System Choices

MT Rocking Shear walls



Photo: WoodWorks

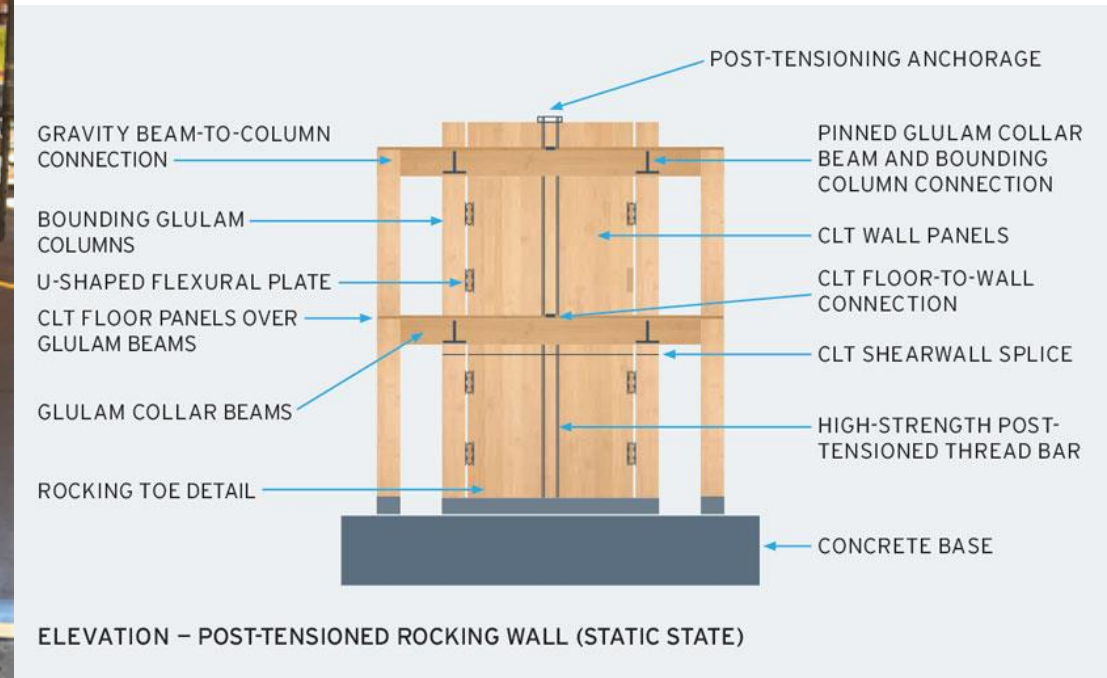


Image: KPFF

Lateral System Choices

Timber Braced Frame



Lateral System Choices

Prescriptive Code Compliance

Concrete Shear walls



Steel Braced Frames



Light Wood-Frame Shear walls



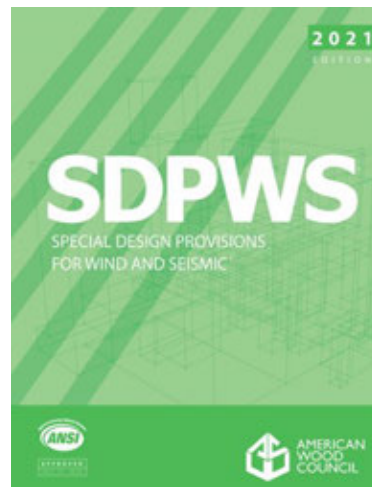
CLT Shear walls



CLT Rocking Walls



Timber Braced Frames



2021 SDPWS
ASCE 7-22

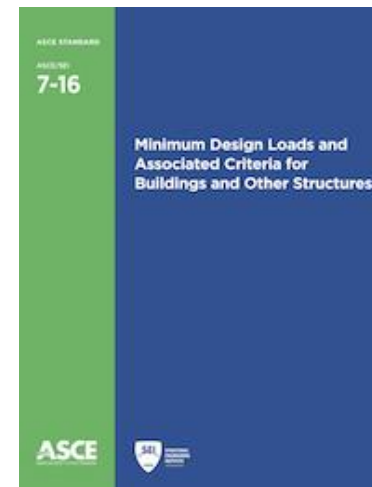


Photo: WoodWorks



Outline

- » Key Early Design Decisions
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 - » Design Example

Acoustics & Sound Control

Consider Impacts of:

- » Timber & Topping Thickness
- » Panel Layout
- » Gapped Panels
- » Connections & Penetrations
- » MEP Layout & Type



Credit: Rothoblaas



Acoustics & Sound Control



Images: Maxxon

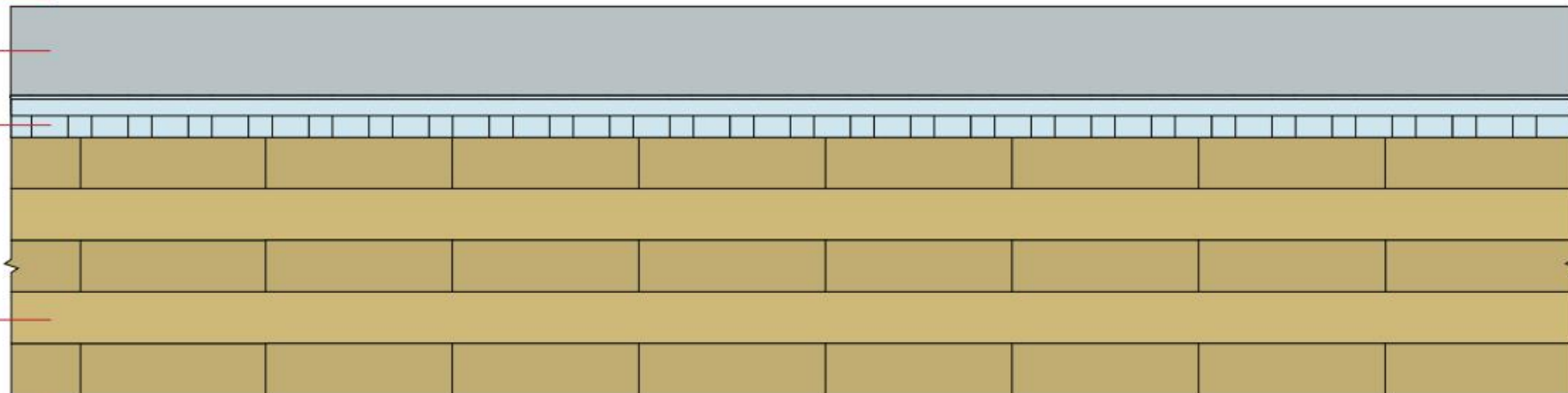
Finish Floor if Applicable _____

Concrete/Gypsum Topping _____

Acoustical Mat Product _____

CLT Panel _____

No direct applied or hung ceiling _____

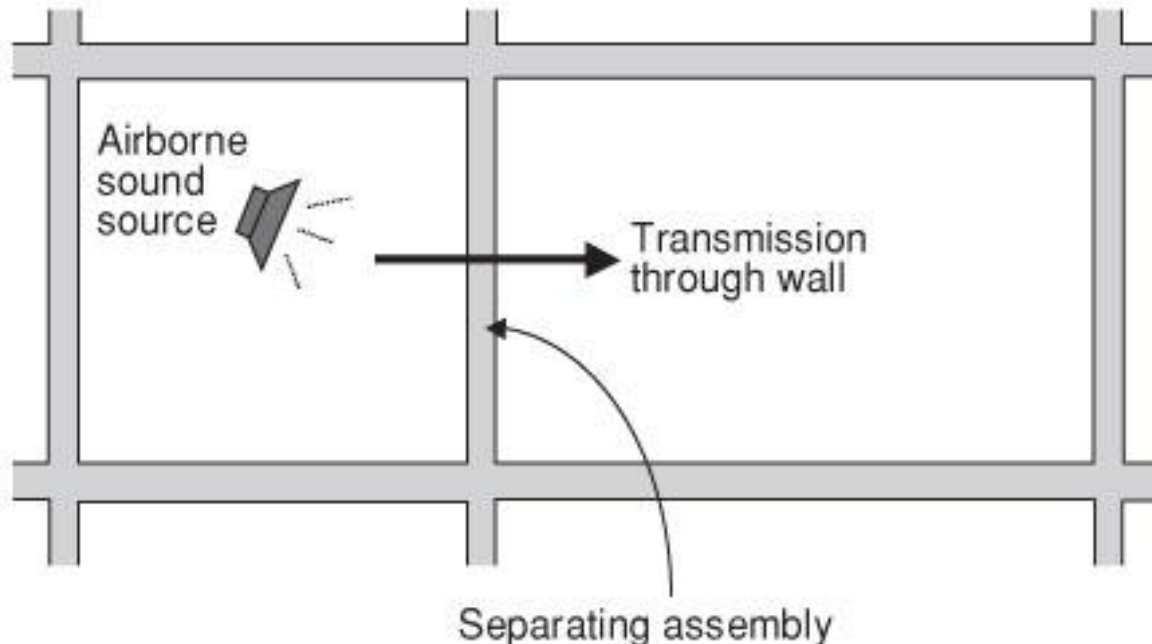


Acoustics & Sound Control

Air-Borne Sound:

Sound Transmission Class (STC)

- » Measures how effectively an assembly isolates air-borne sound and reduces the level that passes from one side to the other
- » Applies to walls and floor/ceiling assemblies

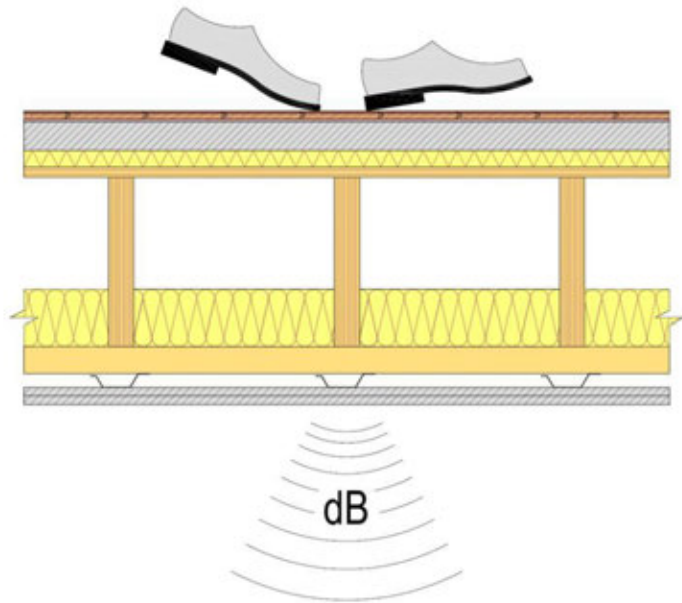


Acoustics & Sound Control

Structure-Borne Sound:

Impact Insulation Class (IIC)

- » Evaluates how effectively an assembly blocks impact sound from passing through it
- » Only applies to floor/ceiling assemblies



Acoustics & Sound Control

Code requirements only address residential occupancies:

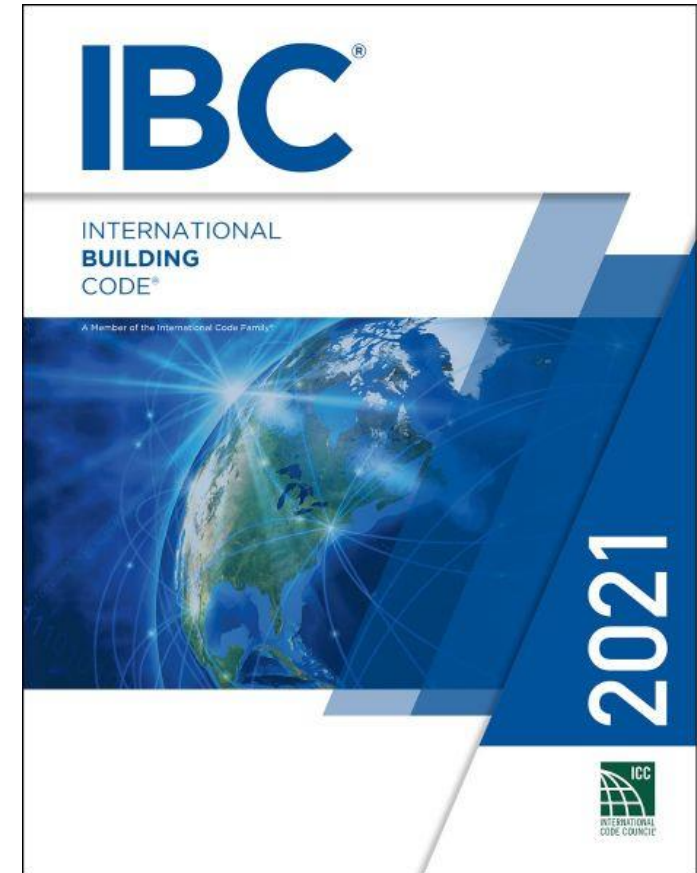
For unit to unit or unit to public or service areas:

Min. STC of 50 (45 if field tested):

» Walls, Partitions, and Floor/Ceiling Assemblies

Min. IIC of 50 (45 if field tested) for:

» Floor/Ceiling Assemblies

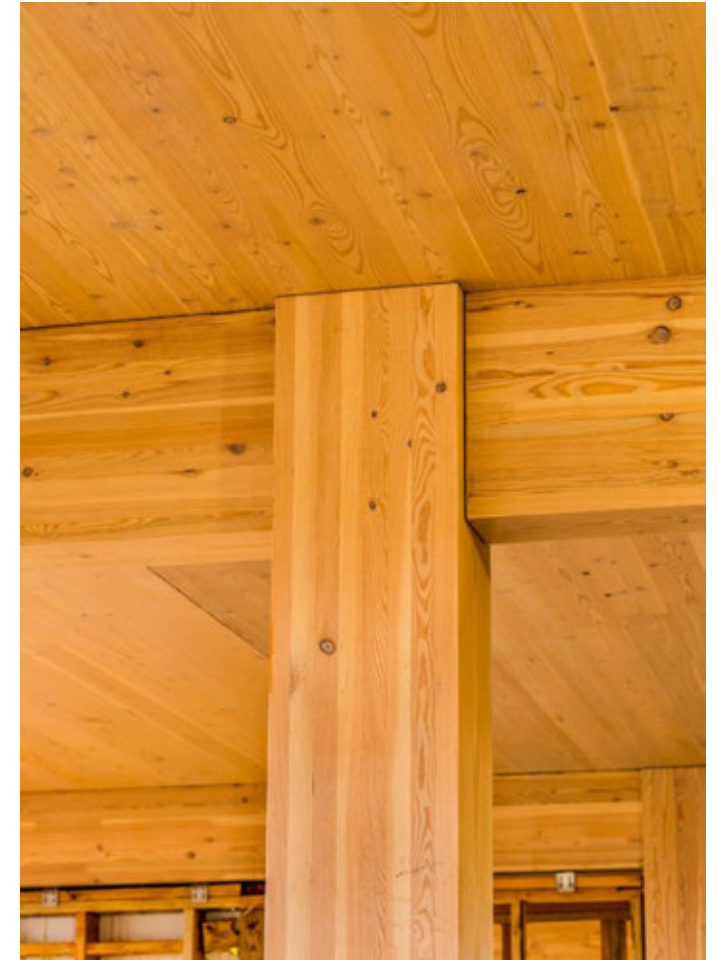


Acoustics & Sound Control

STC	What can be heard
25	Normal speech can be understood quite easily and distinctly through wall
30	Loud speech can be understood fairly well, normal speech heard but not understood
35	Loud speech audible but not intelligible
40	Onset of "privacy"
42	Loud speech audible as a murmur
45	Loud speech not audible; 90% of statistical population not annoyed
50	Very loud sounds such as musical instruments or a stereo can be faintly heard; 99% of population not annoyed.
60+	Superior soundproofing; most sounds inaudible

Acoustics & Sound Control

MT: Structure Often is Finish



Acoustics & Sound Control

But by Itself, Not Adequate for Acoustics



Acoustics & Sound Control

TABLE 1:

Examples of Acoustically-Tested Mass Timber Panels

Mass Timber Panel	Thickness	STC Rating	IIC Rating
3-ply CLT wall ⁴	3.07"	33	N/A
5-ply CLT wall ⁴	6.875"	38	N/A
5-ply CLT floor ⁵	5.1875"	39	22
5-ply CLT floor ⁴	6.875"	41	25
7-ply CLT floor ⁴	9.65"	44	30
2x4 NLT wall ⁶	3-1/2" bare NLT 4-1/4" with 3/4" plywood	24 bare NLT 29 with 3/4" plywood	N/A
2x6 NLT wall ⁶	5-1/2" bare NLT 6-1/4" with 3/4" plywood	22 bare NLT 31 with 3/4" plywood	N/A
2x6 NLT floor + 1/2" plywood ²	6" with 1/2" plywood	34	33

Source: Inventory of Acoustically-Tested Mass Timber Assemblies, WoodWorks⁷

Acoustics & Sound Control

Regardless of the structural materials used in a wall or floor ceiling assembly, there are 3 effective methods of improving acoustical performance:

1. Add mass
2. Add noise barriers
3. Add decouplers

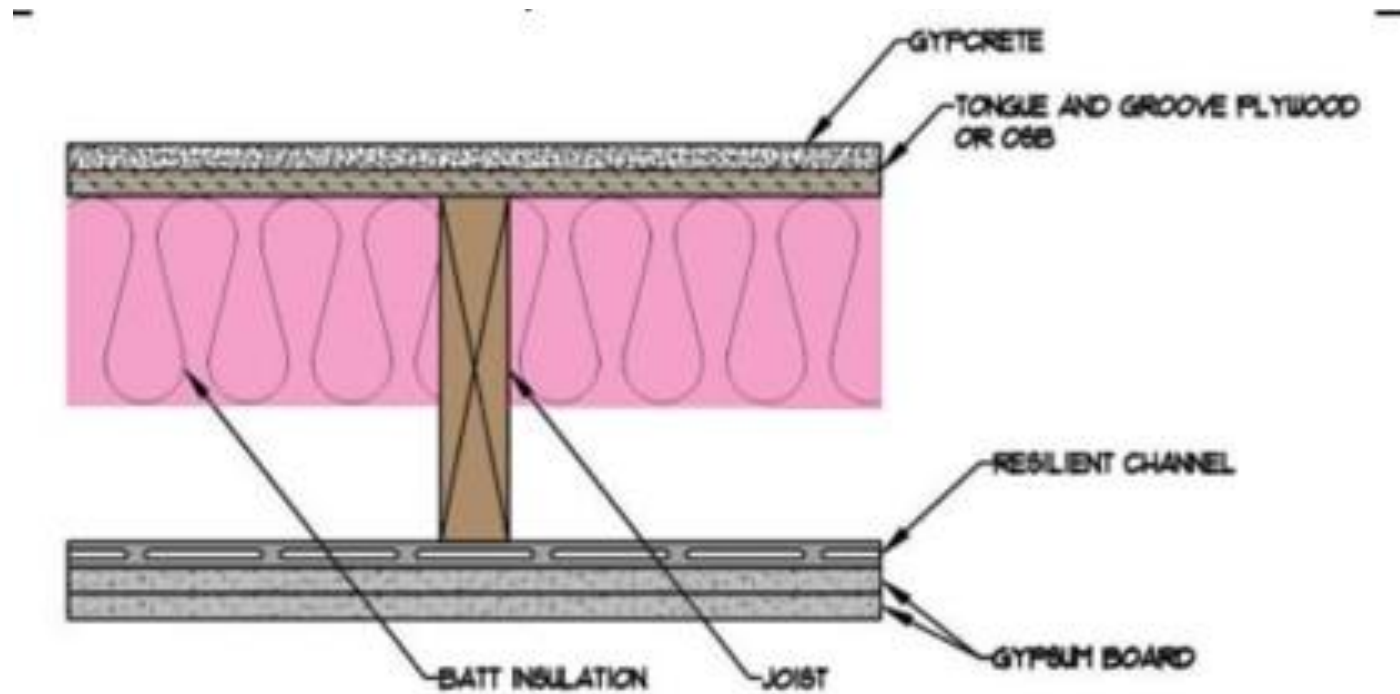


Image credit: Christian Columbres

Acoustics & Sound Control

What does this look like in typical wood-frame construction:

1. Add mass
2. Add noise barriers
3. Add decouplers

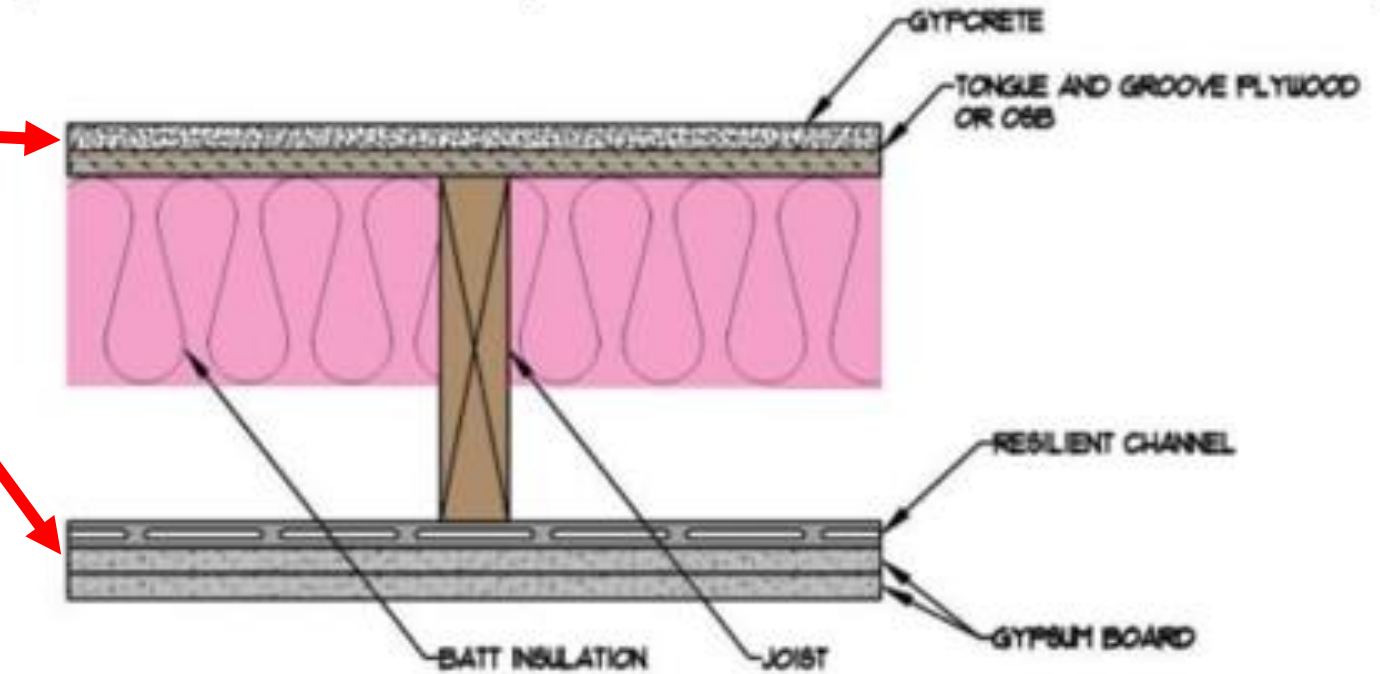


STC 62

Acoustics & Sound Control

What does this look like in typical wood-frame construction:

1. Add mass
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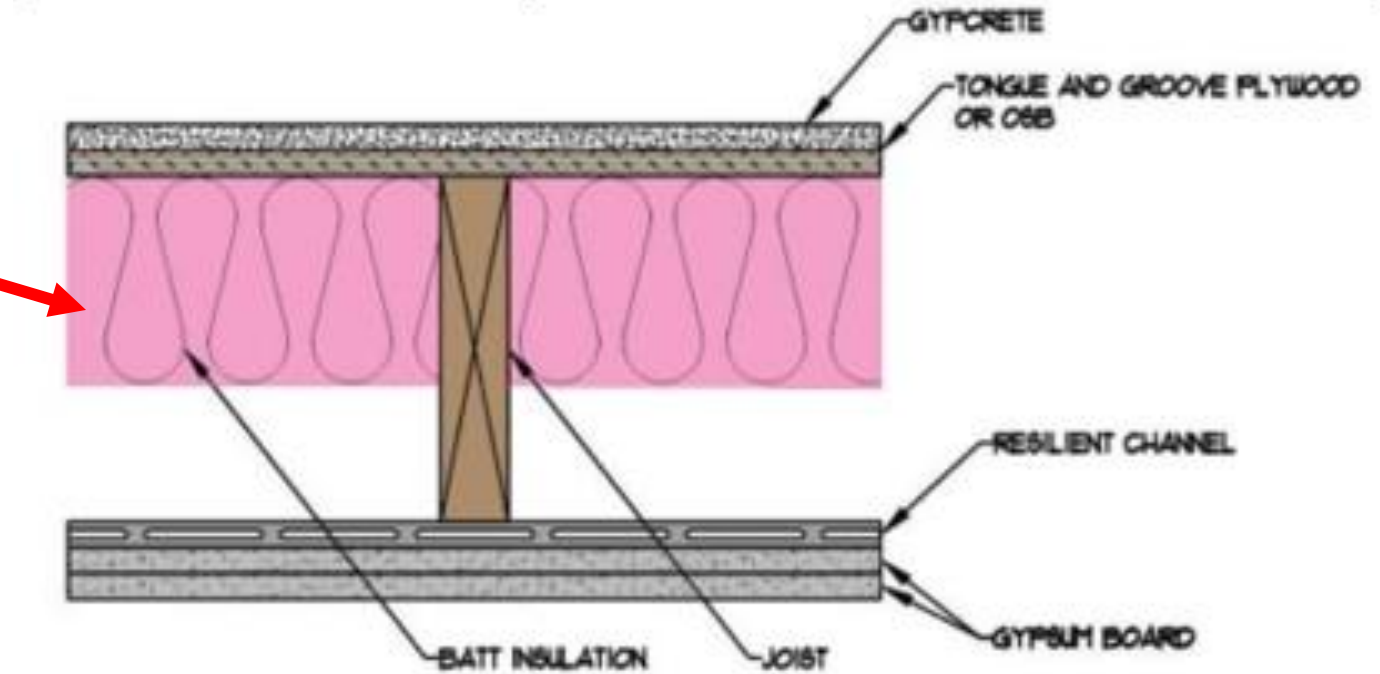


STC 62

Acoustics & Sound Control

What does this look like in typical wood-frame construction:

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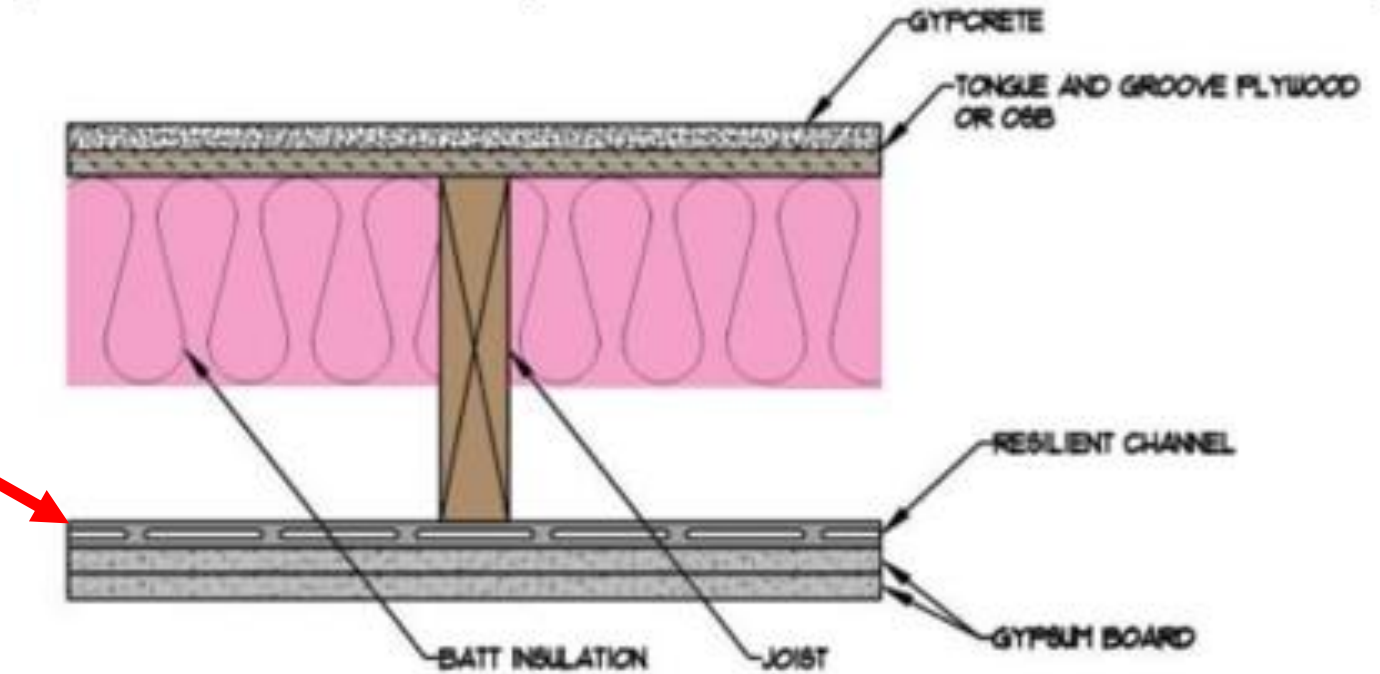


STC 62

Acoustics & Sound Control

What does this look like in typical wood-frame construction:

1. Add mass
2. Add noise barriers
3. Add decouplers



STC 62

Acoustics & Sound Control

Mass timber has relatively low “mass”

Recall the three ways to increase acoustical performance:

1. Add mass
2. Add noise barriers
3. Add decouplers



Image credit: Christian Columbres

Acoustics & Sound Control



Concrete Slab:

6" Thick

80 PSF

STC 53



CLT Slab:

6-7/8" Thick

18 PSF

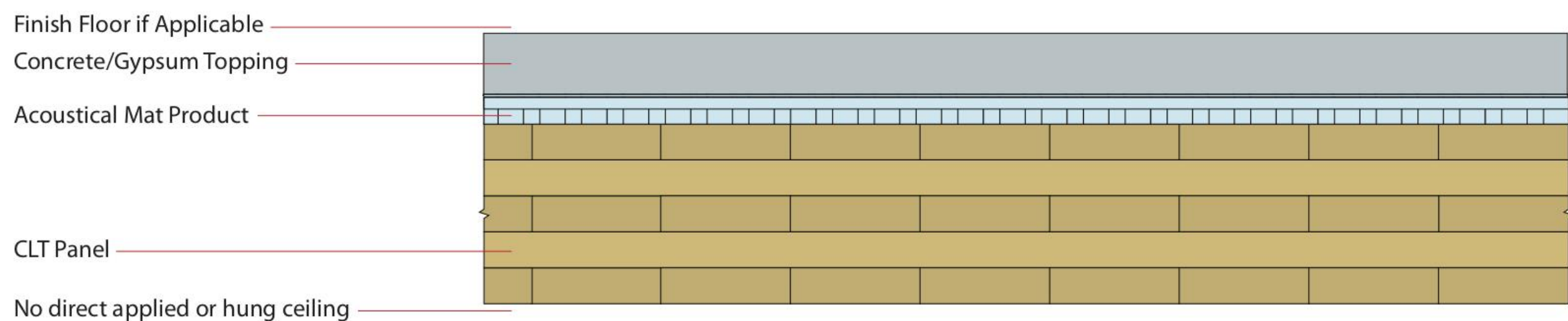
STC 41



Acoustics & Sound Control

There are three main ways to improve an assembly's acoustical performance:

1. Add mass
2. Add noise barriers
3. Add decouplers



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2. Add noise barriers
- 3. Add decouplers

Acoustical Mat:

- » Typically roll out or board products
- » Thicknesses vary: Usually $\frac{1}{4}$ " to 1"+



Credit: Maxxon

Acoustics & Sound Control

Acoustical floor underlayments



Photo: AcoustiTECH¹⁰

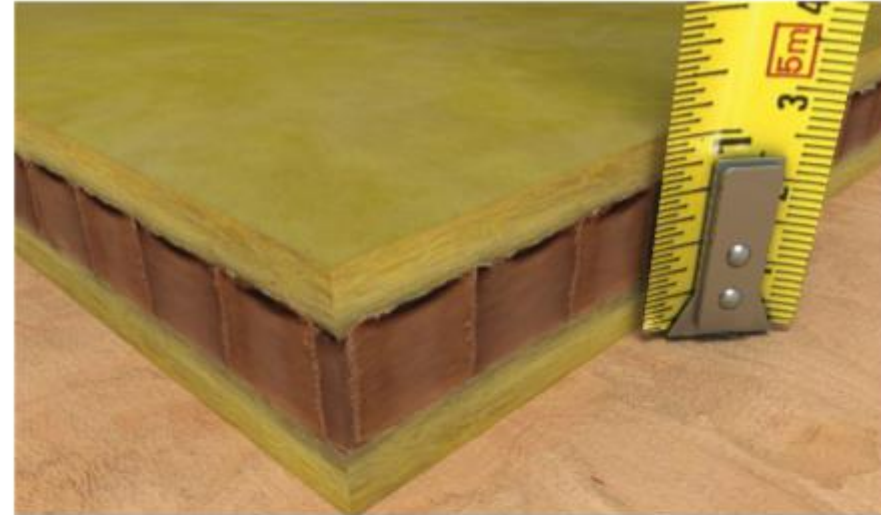


Photo: Kinetics Noise Control, Inc.,¹¹



Photo: Maxxon Corporation

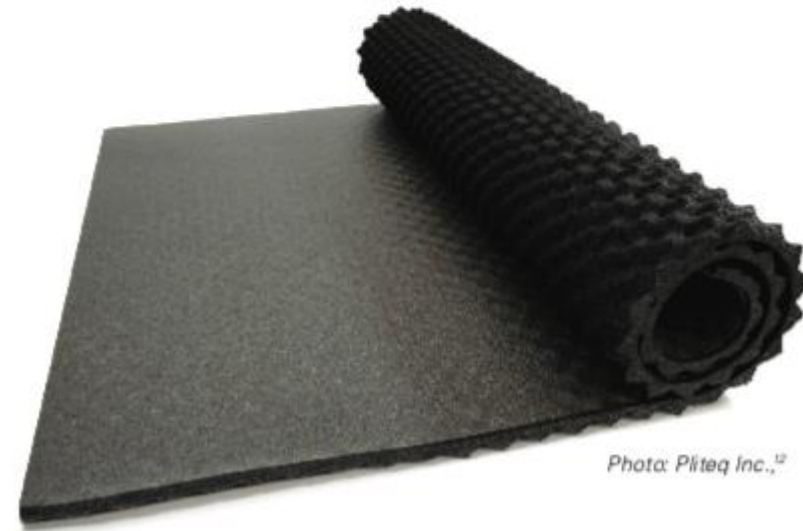


Photo: Pliteq Inc.,¹²

Acoustics & Sound Control

Common mass timber floor assembly:

- » Finish floor (if applicable)
- » Underlayment (if finish floor)
- » 1.5" to 4" thick concrete/gypcrete topping
- » Acoustical mat
- » WSP (if applicable)
- » Mass timber floor panels



Acoustics & Sound Control

Solutions Paper

http://www.woodworks.org/wp-content/uploads/wood_solution_paper-MASS-TIMBER-ACOUSTICS.pdf



Acoustics and Mass Timber: Room-to-Room Noise Control

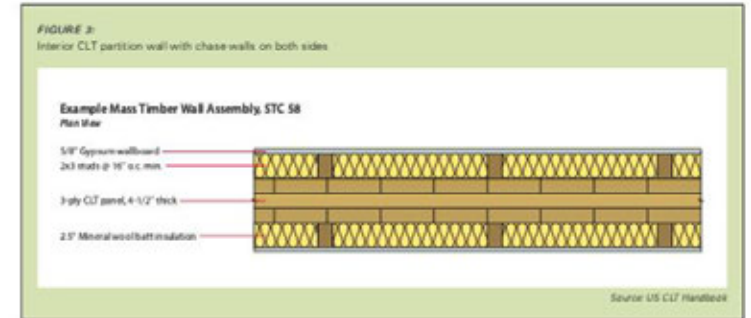
Richard McLain, PE, SE • Senior Technical Director • WoodWorks



T3 Minneapolis
Architect: MOA | Michael Green Architecture, DLR Group
Structural Engineer: Magnusson Klemencic Associates
Design Assist • Build: StructureCraft

The growing availability and code acceptance 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 has given designers a low-carbon alternative to steel, concrete, and masonry for many applications. However, the use of mass timber in multi-family and commercial buildings presents unique acoustic challenges.

While laboratory measurements of the impact and airborne sound isolation of traditional building assemblies such as light wood-frame, steel and concrete are widely available, fewer resources exist that quantify the acoustic performance of mass timber assemblies. Additionally, one of the most desired aspects of mass timber construction is the ability to leave a building's structure exposed as finish, which creates the need for asymmetric assemblies. With careful design and detailing, mass timber buildings can meet the acoustic performance expectations of most building types.



Mass Timber Assembly Options: Walls

Mass timber panels can also be used for interior and exterior walls—both bearing and non-bearing. For interior walls, the need to conceal services such as electrical and plumbing is an added consideration. Common approaches include building a chase wall in front of the mass timber wall or installing gypsum wallboard on resilient channels that are attached to the mass timber wall. As with bare mass timber floor panels, bare mass timber walls don't typically provide adequate noise control, and chase walls also function as acoustical improvements. For example, a 3-ply CLT wall panel with a thickness of 3.07" has an STC rating of 33.¹ In contrast, Figure 3 shows an interior CLT partition wall with chase walls on both sides. This assembly achieves an STC rating of 58, exceeding the IBC's acoustical requirements for multi-family construction. Other examples are included in the inventory of tested assemblies noted above.

Acoustical Differences between Mass Timber Panel Options

The majority of acoustically-tested mass timber assemblies include CLT. However, tests have also been done on other mass timber panel options such as NLT and dowel-laminated timber (DLT), as well as traditional heavy timber options such as tongue and groove decking. Most tests have concluded that CLT acoustical performance is slightly better than that of other mass timber options, largely because the cross-orientation of laminations in a CLT panel limits sound flanking.

For those interested in comparing similar assemblies and mass timber panel types and thicknesses, the inventory noted above contains tested assemblies using CLT, NLT, glued-laminated timber panels (GLT), and tongue and groove decking.

Improving Performance by Minimizing Flanking

Even when the assemblies in a building are carefully designed and installed for high acoustical performance, consideration of flanking paths—in areas such as assembly intersections, beam-to-column/wall connections, and MEP penetrations—is necessary for a building to meet overall acoustical performance objectives.

One way to minimize flanking paths at these connections and interfaces is to use resilient connection isolation and sealant strips. These products are capable of resisting structural loads in compression between structural members and connections while providing isolation and breaking hard, direct connections between members. In the context of the three methods for improving acoustical performance noted above, these strips act as decouplers. With airtight connections, interfaces and penetrations, there is a much greater chance that the acoustic performance of a mass timber building will meet expectations.



Acoustical isolation strips

Photo: Rensselaer

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Inventory of Acoustically Tested Mass Timber Assemblies



Following is a list of mass timber assemblies that have been acoustically tested as of April 5, 2024. Sources are noted at the end of this document. For free technical assistance on any questions related to the acoustical design of mass timber assemblies, or free technical assistance related to any aspect of the design, engineering or construction of a commercial or multi-family wood building in the U.S., email help@woodworks.org or contact the WoodWorks Regional Director nearest you:
<http://www.woodworks.org/project-assistance>

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Inventory of Tested Assemblies

Table 1: CLT Floor Assemblies with Concrete/Gypsum Topping, Ceiling Side Exposed



CLT Panel	Concrete/Gypsum Topping	Acoustical Mat Product Between CLT and Topping	Finish Floor	STC ¹	IIC ¹	Source
CLT 5-ply (6.875")	1-1/2" Gyp-Crete®	<u>Maxxon Acousti-Mat® 3/4</u>	None	47 ² ASTC	47 ² AIIC	1
			LVT	-	49 ² AIIC	
			Carpet + Pad	-	75 ² AIIC	
			LVT on <u>Acousti-Top®</u>	-	52 ² AIIC	
			Eng Wood on <u>Acousti-Top®</u>	-	51 ² AIIC	
		<u>Maxxon Acousti-Mat® ¾ Premium</u>	None	49 ² ASTC	45 ² AIIC	
			LVT	-	47 ² AIIC	
			LVT on <u>Acousti-Top®</u>	-	49 ² AIIC	
	1-1/2" Levelrock®	USG SAM N25 Ultra	None	45 ⁶	39 ⁶	15
			LVT	48 ⁶	47 ⁶	16
			LVT Plus	48 ⁶	49 ⁶	58
			Eng Wood	47 ⁶	47 ⁶	59
			Carpet + Pad	45 ⁶	67 ⁶	60
			Ceramic Tile	50 ⁶	46 ⁶	61
			None	45 ⁶	42 ⁶	15
			LVT	48 ⁶	44 ⁶	16

Outline

- » Key Early Design Decisions
- » Construction Types
- » Fire Design
- » Structural Grid
- » Connections
- » Penetrations & Firestopping
- » MEP Layout and Integration
- » Lateral Systems
- » Acoustics

Design Example

Early Design Decision Example

7-story, 84 ft tall multi-family building

- » Amenity & Retail on 1st floor, residential units on floors 2-7
- » NFPA 13 sprinklers throughout
- » Floor plate = 18,000 SF
- » Total Building Area = 126,000 SF



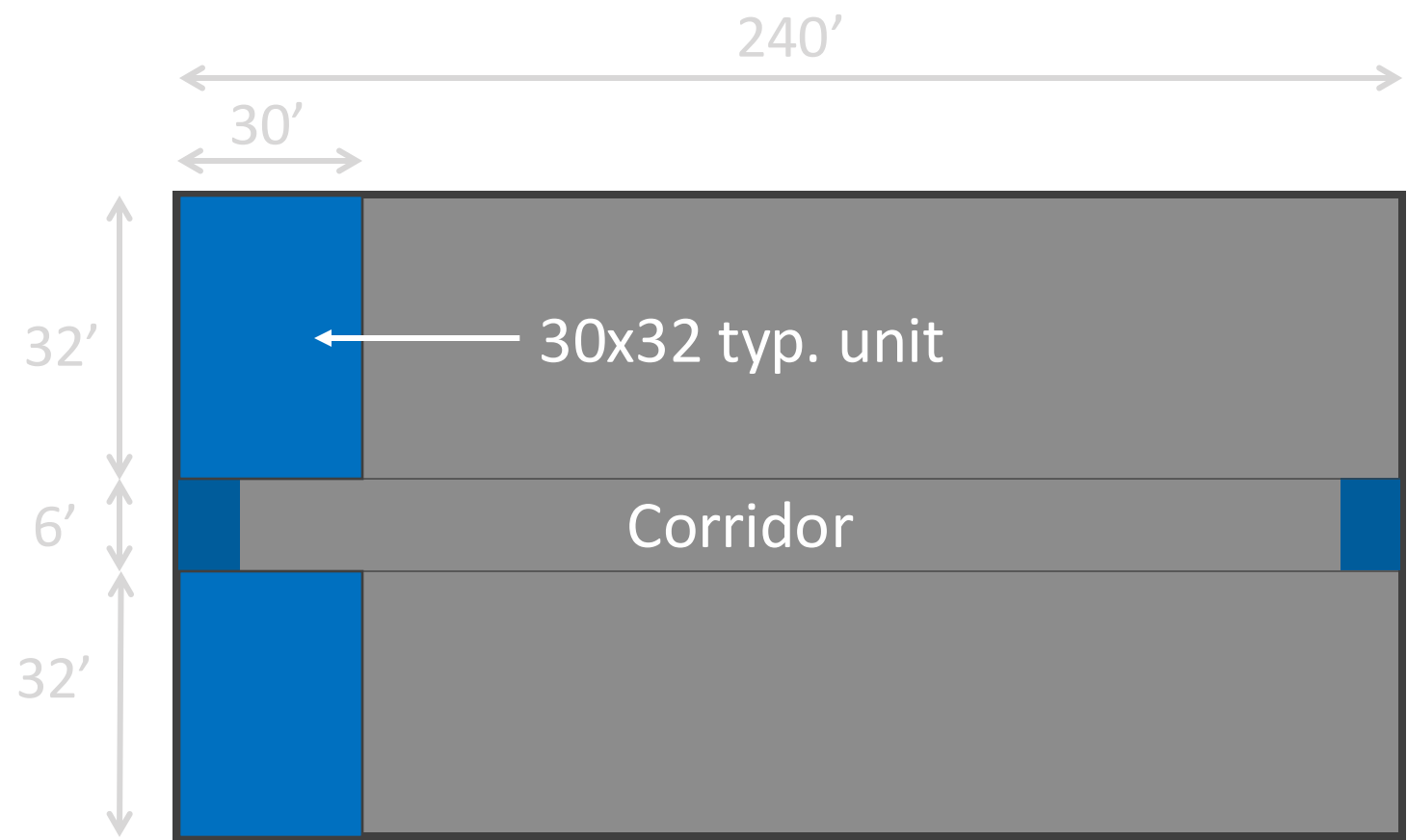
Credit: Monte French Design Studio



Credit: Monte French Design Studio

Early Design Decision Example

7-story, multi-family building, typ. floor plan:

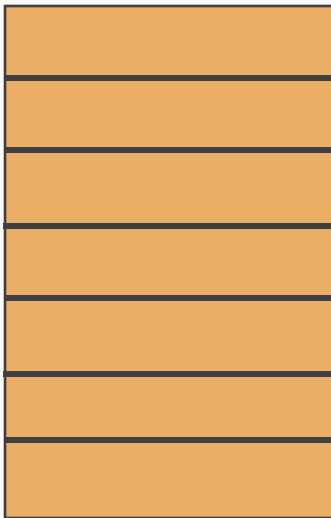


Credit: Monte French Design Studio

Early Design Decision Example

MT Construction Type Options:

- » 7 stories of IV-C
- » 5 stories of IIIA over 2 stories of IA podium
- » 5 stories of IV-HT over 2 stories of IA podium



Credit: Monte French Design Studio

Early Design Decision Example

MT Construction Type Options:

- » 7 stories of IV-C
- » 5 stories of IIIA over 2 stories of IA podium
- » 5 stories of IV-HT over 2 stories of IA podium

Implications of Type IV-C:

- » 2 hr FRR, all exposed floor panels, beams, columns
- » Likely will need at least 5-ply CLT / 2x6 NLT/DLT
- » Efficient spans in the 14-17 ft range
- » Efficient grids of that or multiples of that (i.e. 30x25, etc)
- » No podium required
- » CLT exterior walls permitted

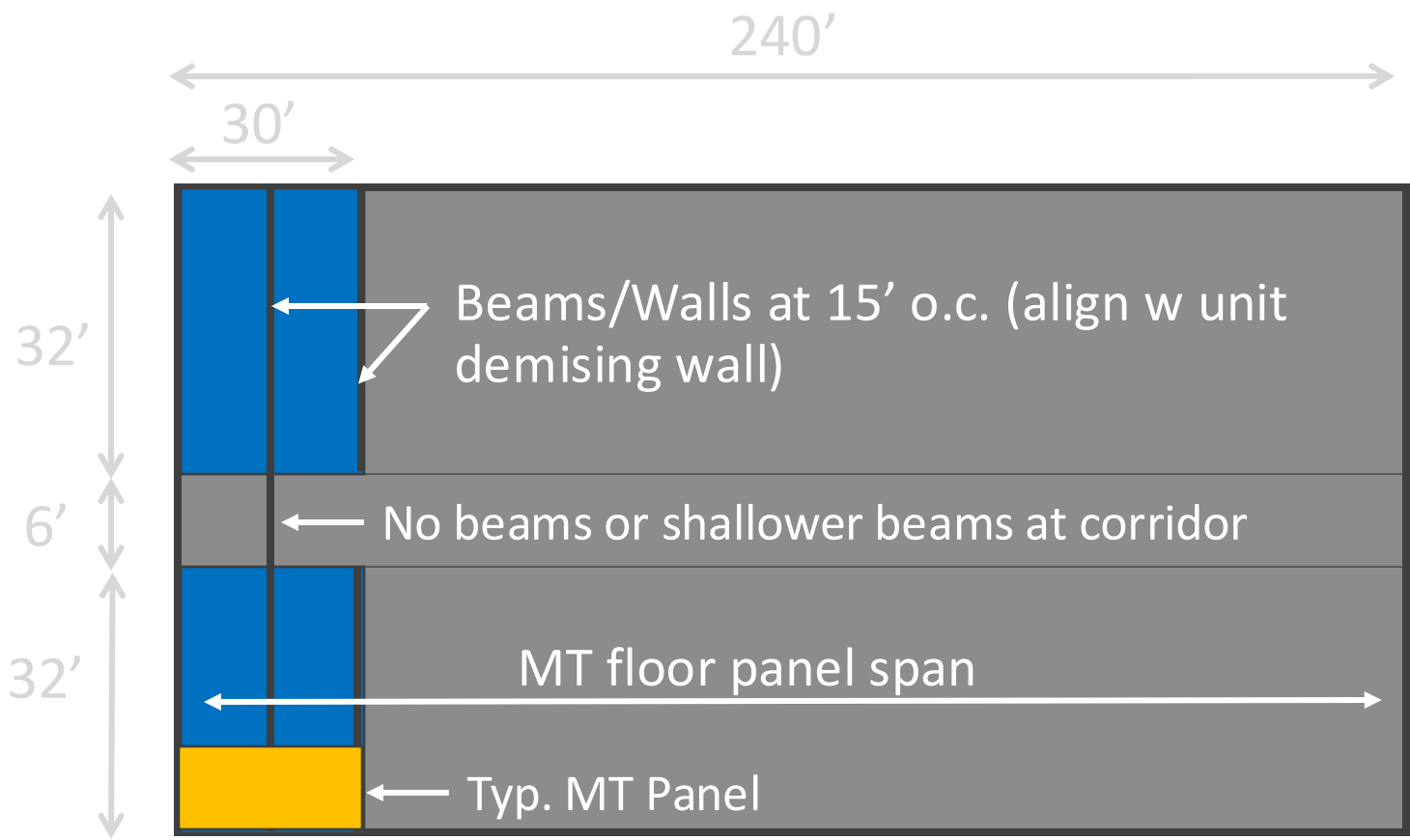


Credit: Monte French Design Studio

Early Design Decision Example

Type IV-C Grid Options

» Option 1

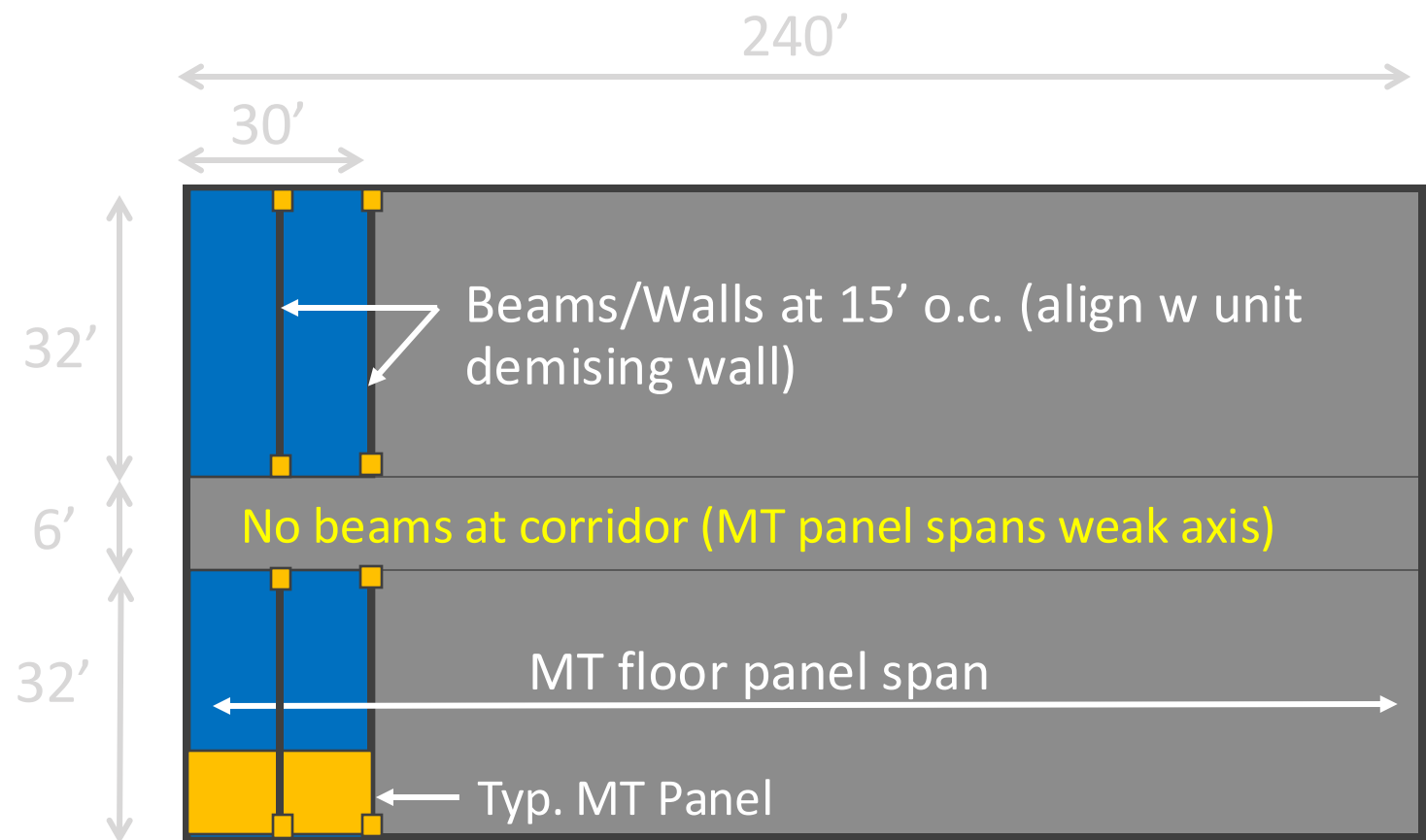


Credit: Monte French Design Studio

Early Design Decision Example

Type IV-C Grid Options

» Option 1

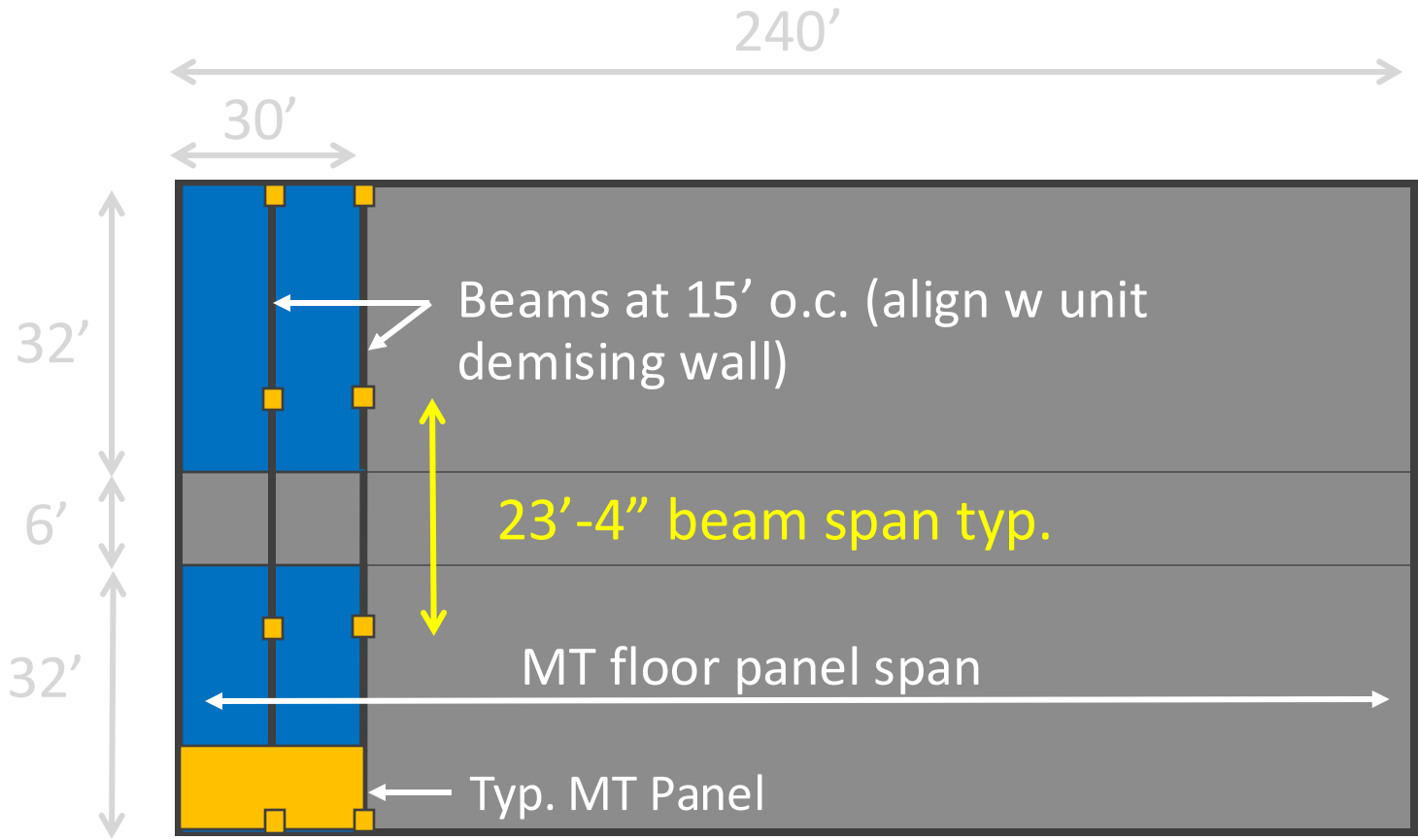


Credit: Monte French Design Studio

Early Design Decision Example

Type IV-C Grid Options

» Option 1

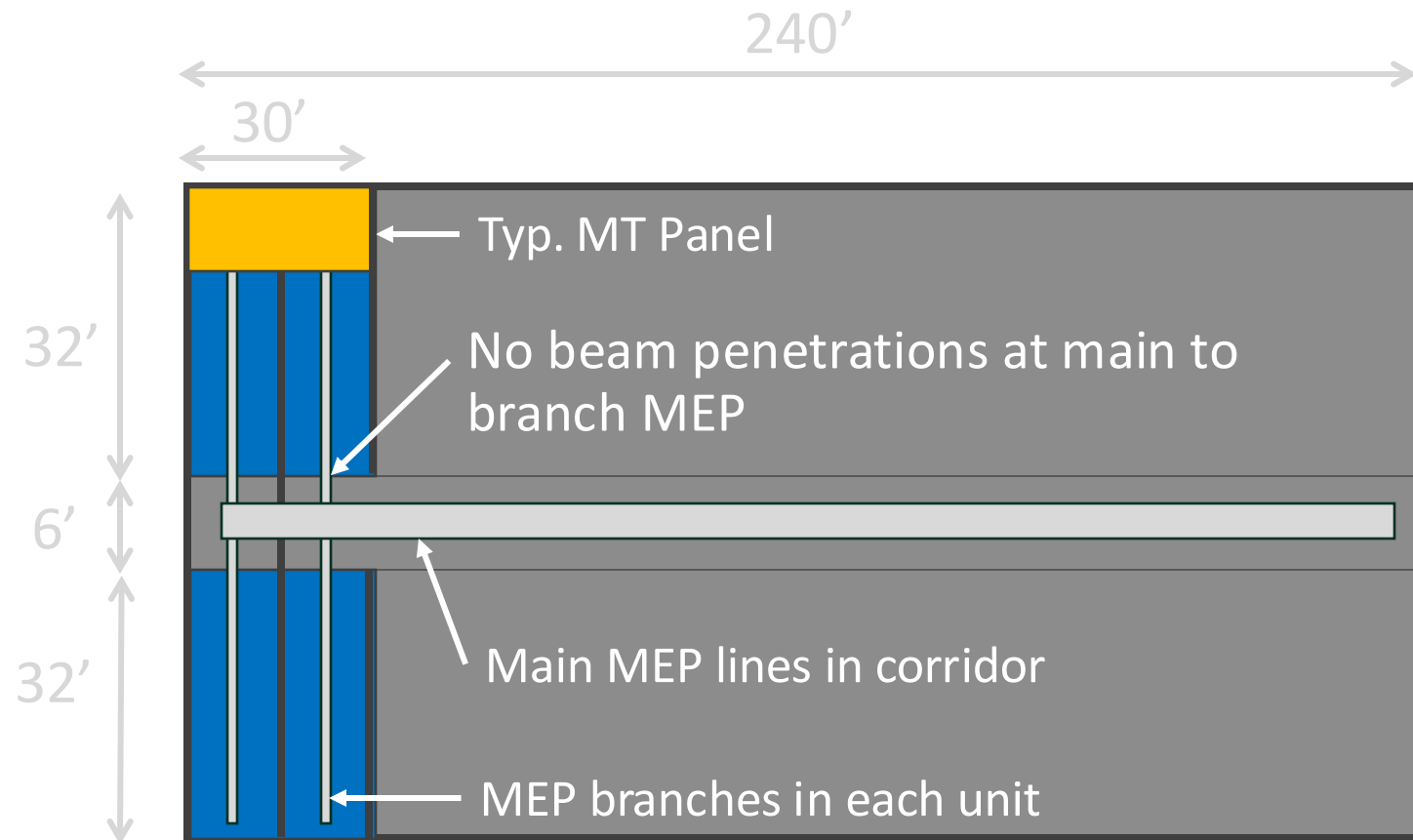


Credit: Monte French Design Studio

Early Design Decision Example

Type IV-C Grid Options

» Option 1

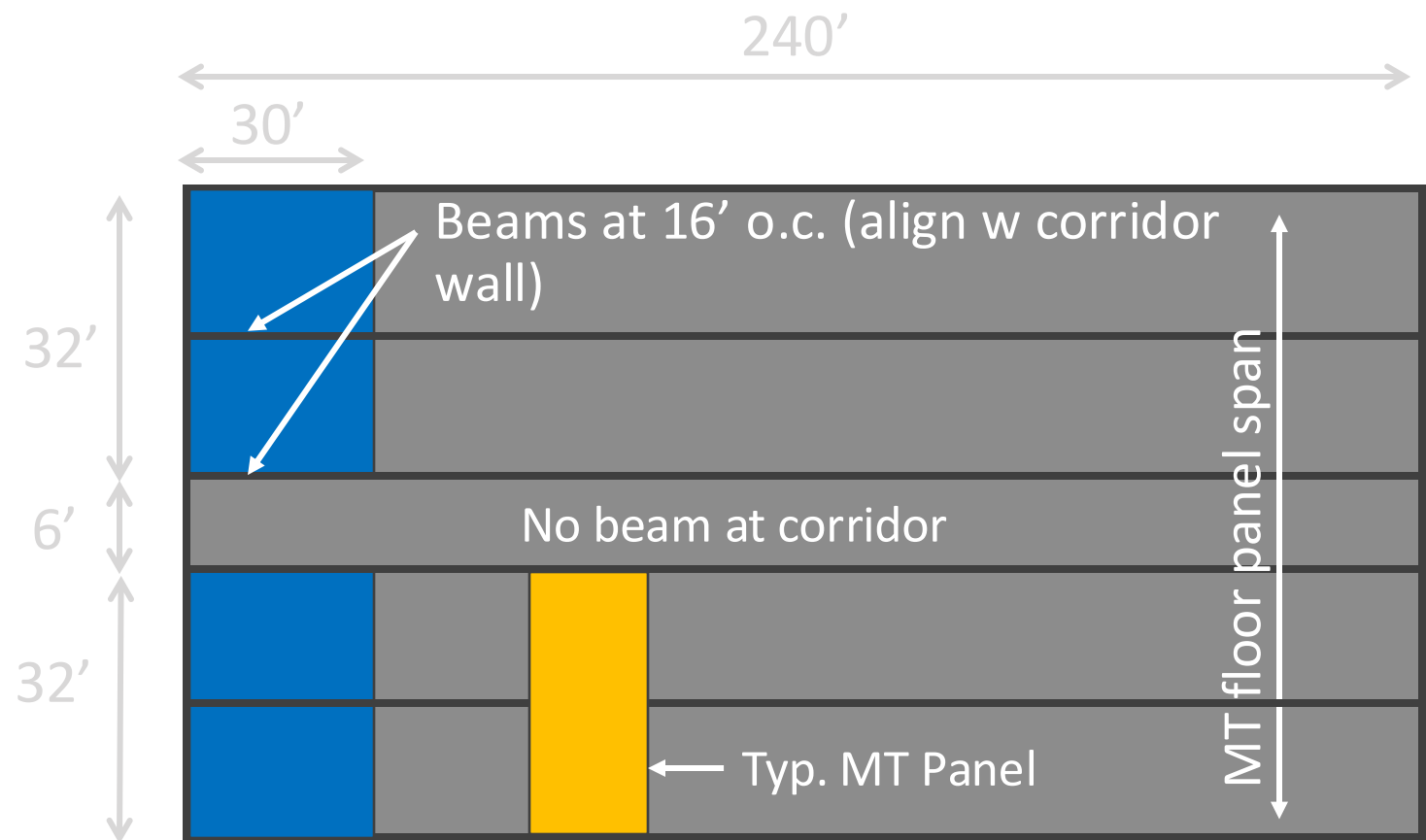


Credit: Monte French Design Studio

Early Design Decision Example

Type IV-C Grid Options

» Option 2

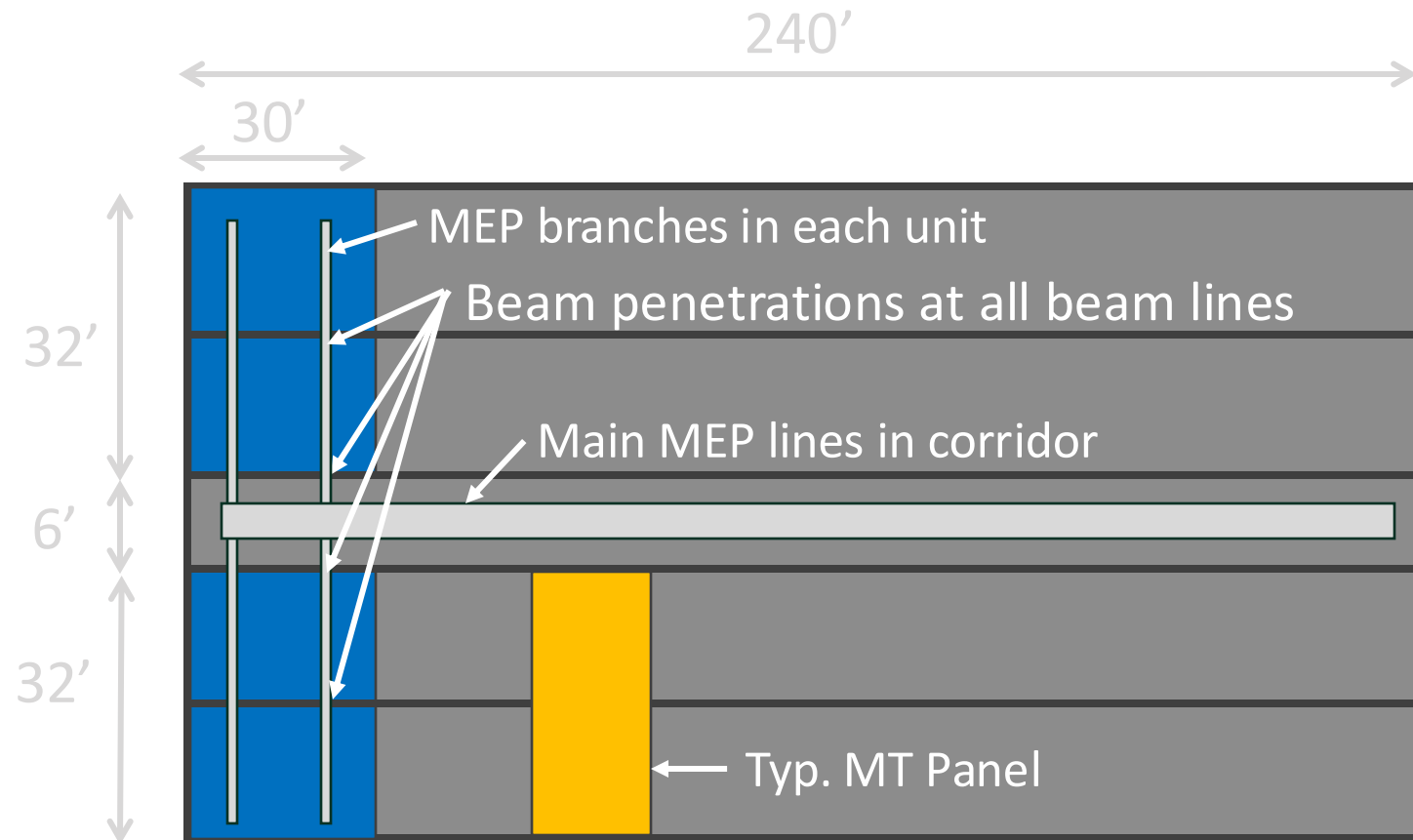


Credit: Monte French Design Studio

Early Design Decision Example

Type IV-C Grid Options

» Option 2



Credit: Monte French Design Studio

Early Design Decision Example



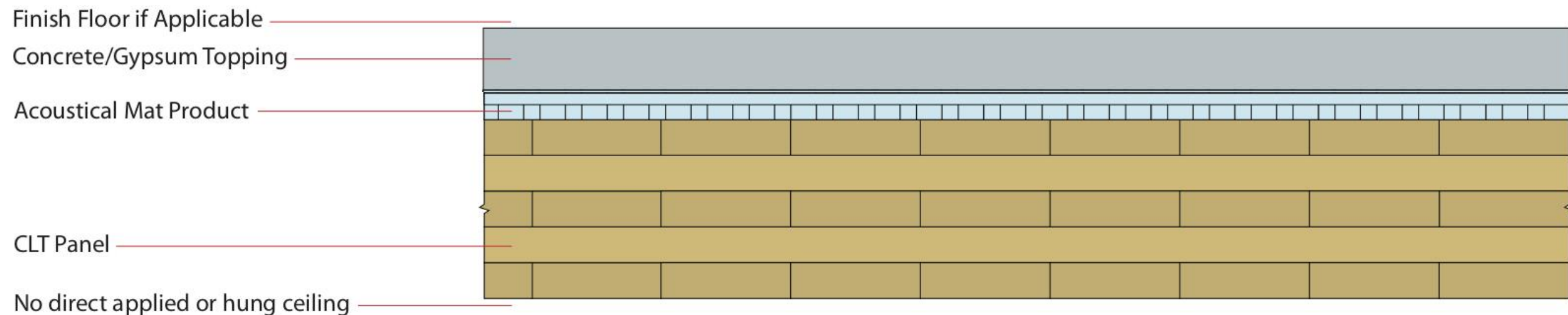
Credit: Monte French Design Studio

Type IV-C Floor Assembly Options

- » 2-hr FRR: 5-ply CLT (tested assembly) or 7-ply CLT (char calculations)
- » STC & IIC 50 min: 2" topping (5-ply CLT) or 1.5" topping (7-ply CLT)

Note: many other acoustic mat and topping options exist, one example shown here

Note: 5-ply is most efficient for the 15-16 ft panel spans shown



Early Design Decision Example

MT Construction Type Options:

- » 7 stories of IV-C
- » 5 stories of IIIA over 2 stories of IA podium
- » 5 stories of IV-HT over 2 stories of IA podium

Implications of Type IIIA:

- » 1 hr FRR
- » Potential to use 3-ply or thin 5-ply CLT
- » Efficient spans vary with panel thickness
- » Efficient grids of that or multiples of that (i.e. 20x25, etc)
- » 1 story Type IA podium required
- » CLT exterior walls not permitted



Credit: Monte French Design Studio

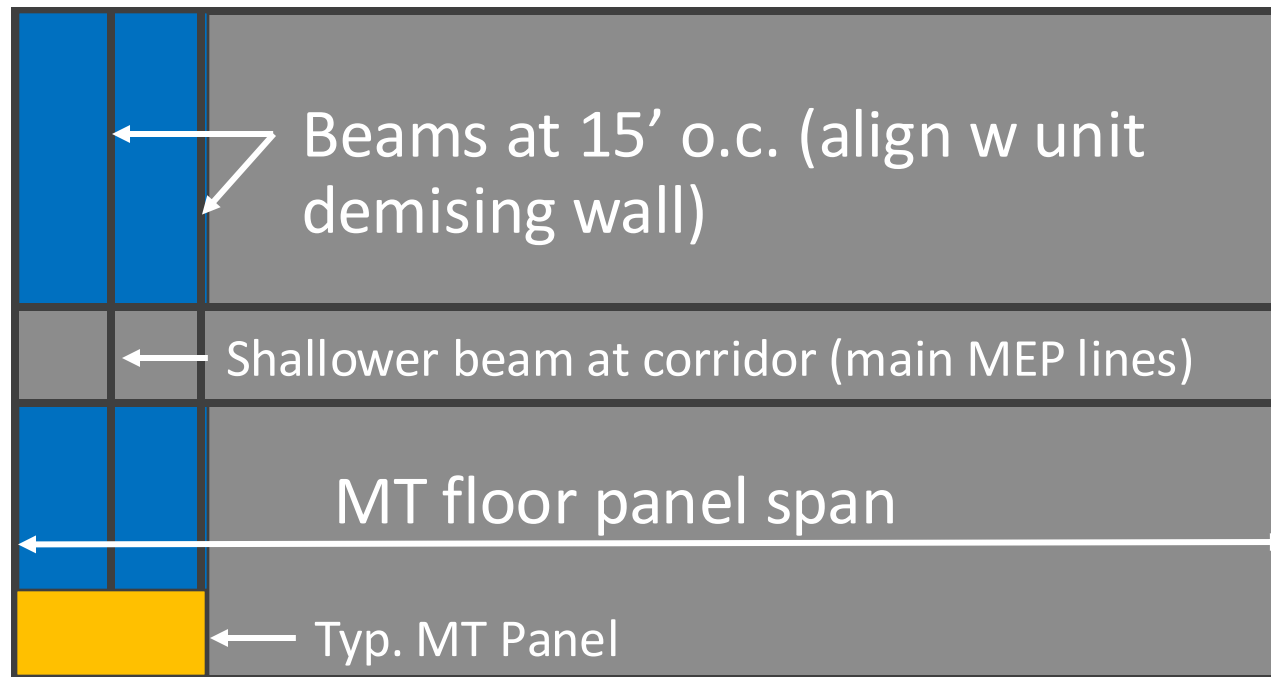
Early Design Decision Example

Type IIIA Grid Options

» Option 1



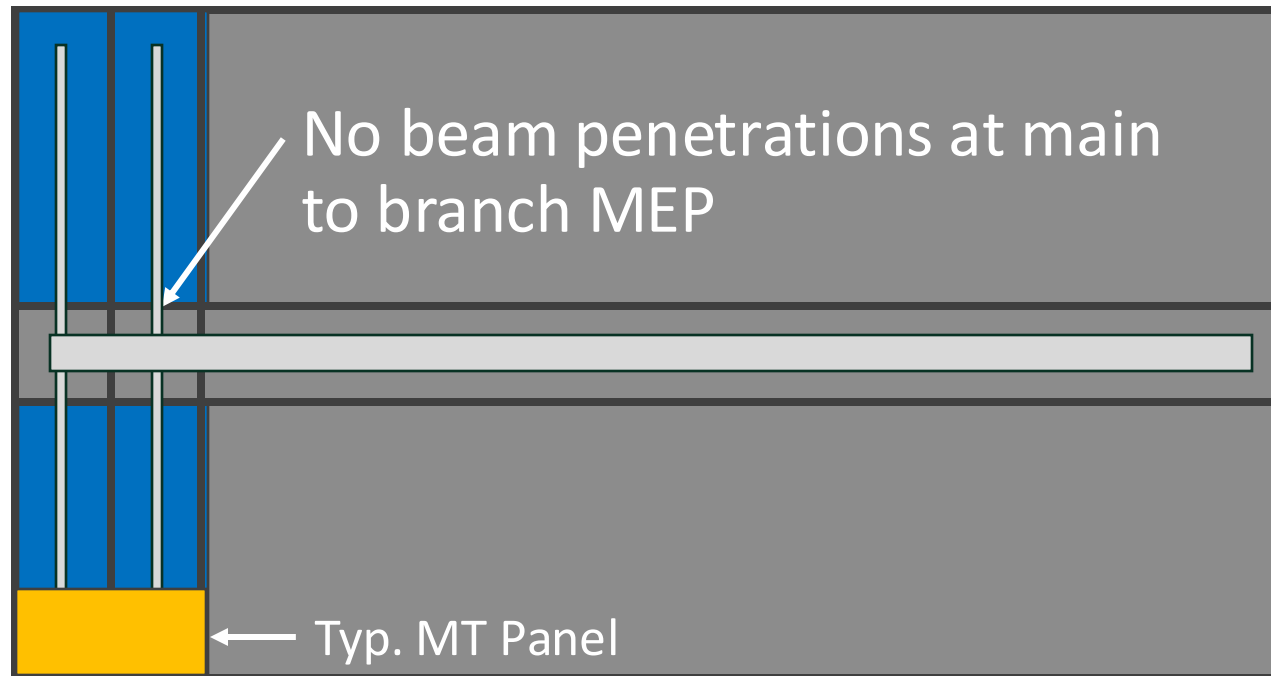
Credit: Monte French Design Studio



Early Design Decision Example

Type IIIA Grid Options

» Option 1



Credit: Monte French Design Studio

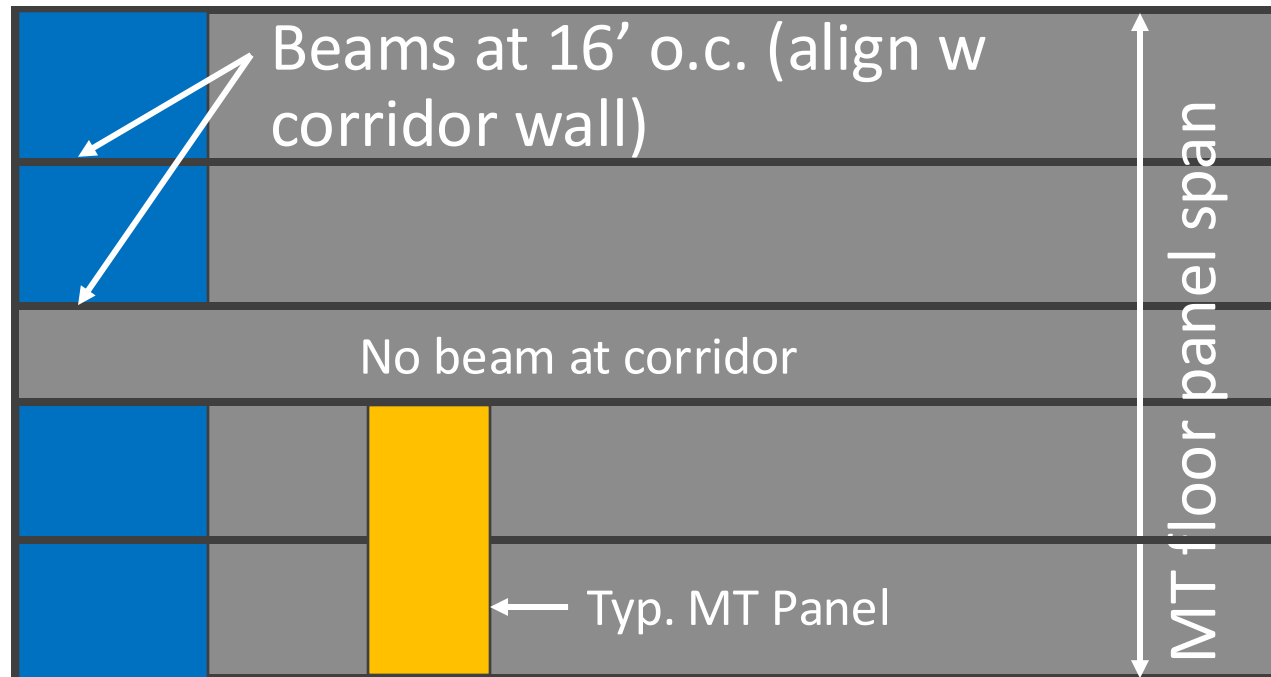
Early Design Decision Example

Type IIIA Grid Options

» Option 2



Credit: Monte French Design Studio



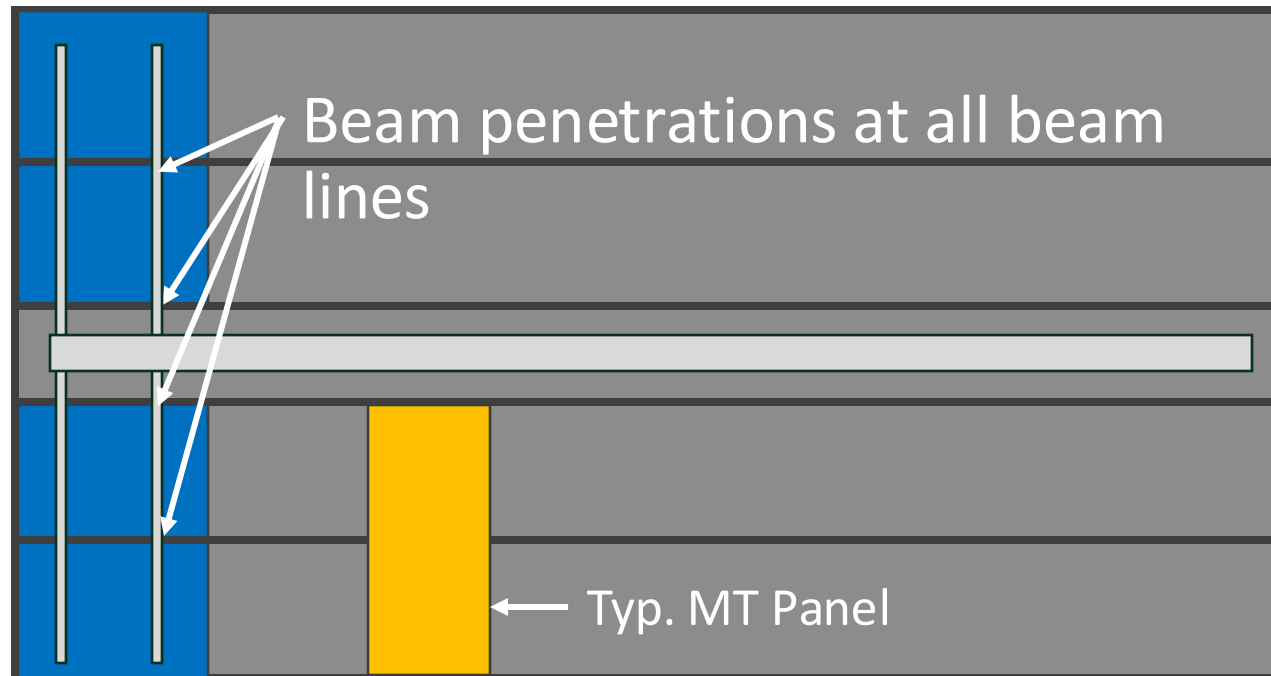
Early Design Decision Example

Type IIIA Grid Options

» Option 2



Credit: Monte French Design Studio



Early Design Decision Example

Type IIIA Floor Assembly Options

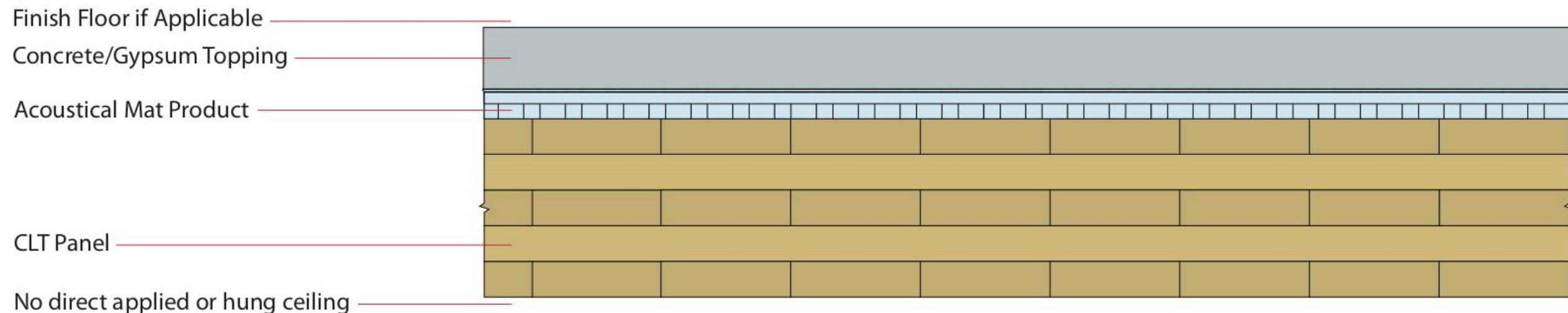
- » 1-hr FRR: 5-ply CLT (tested assembly or char calculations)
- » STC & IIC 50 min: 2" topping (5-ply CLT)

Note: many other acoustic mat and topping options exist, one example shown here

Note: 5-ply is most efficient for the 15-16 ft panel spans shown



Credit: Monte French Design Studio



Early Design Decision Example

MT Construction Type Options:

- » 7 stories of IV-C
- » 5 stories of IIIA over 2 stories of IA podium
- » 5 stories of IV-HT over 2 stories of IA podium

Type IV-HT in Group R Occupancy:

- » Separation walls (fire partitions) and horizontal separation (horizontal assemblies) between dwelling units require a 1-hour rating.
- » Floor panels require a 1-hour rating in addition to minimum sizes
- » Essentially the same panel and grid options as IIIA

Ref. IBC 420.2, 420.3, 708.3, 711.2.4.3



Credit: Monte French Design Studio

Early Design Decision Example

MT Construction Type Options:

- » 7 stories of IV-C
- » 5 stories of IIIA over 2 stories of IA podium
- » 5 stories of IV-HT over 2 stories of IA podium

Implications of Type IV-HT:

- » 1 hr FRR and min. sizes
- » Potential to use 3-ply or thin 5-ply CLT
- » Efficient spans vary with panel thickness
- » Efficient grids of that or multiples of that (i.e. 20x25, etc)
- » 1 story Type IA podium required
- » CLT exterior walls permitted



Credit: Monte French Design Studio

Reduce Risk

Optimize Costs

- » For the entire project team, not just builders
- » Lots of reference documents

Download Checklists at
www.woodworks.org

www.woodworks.org/wp-content/uploads/wood_solution_paper-Mass-Timber-Design-Cost-Optimization-Checklists.pdf



Mass Timber Cost and Design Optimization Checklists

WoodWorks has developed the following checklists to assist in the design and cost optimization of mass timber projects.

The *design optimization* checklists are intended for building designers (architects and engineers), but many of the topics should also be discussed with the fabricators and builders. The *cost optimization* checklists will help guide coordination between designers and builders (general contractors, construction managers, estimators, fabricators, installers, etc.) as they are estimating and making cost-related decisions on a mass timber project. The *pre-design* checklist should be reviewed by the developer/owner, designers and builders.

1 De Haro
San Francisco, CA
ARCHITECT:
Perkins&Will
ENGINEERS:
DCI Engineers
CONTRACTOR:
Hathaway Dinwiddie

WoodWorks offers a wide range of resources at woodworks.org, many of which are referenced in this document. We also recommend that designers and builders download the following:

Mass Timber Design Manual¹ – Includes technical papers, continuing education articles, expert Q&As and more. Published in partnership with Think Wood.

U.S. Mass Timber Construction Manual² – Provides a framework for the planning, procurement and management of mass timber projects.



Photo: David Wiskelly

Keys to Mass Timber Success:

Know Your WHY

Design it as Mass Timber From the Start

Leverage Manufacturer Capabilities

Understand Supply Chain

Optimize Grid

Take Advantage of Prefabrication & Coordination

Expose the Timber

Discuss Early with AHJ

Work with Experienced People

Create Your Market Distinction

Let WoodWorks Help for Free



Photo Credit: Hacker Architects, Jeremy Bittermann

Questions? Ask us anything.



Please take our survey!

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