Tall Mass Timber: Code Developments and Differential Material Movement

September 4, 2025

Presented by

Patrick Duffy, PE
WoodWorks

Image: 11 E Lenox, Monte French Design Studio, H+O Structural Engineers, Photo Jane Messinger


Timber House, Brooklyn, Credit: Travis Mark

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Exploring Tall Wood: New Code Provisions for Tall Timber Structures

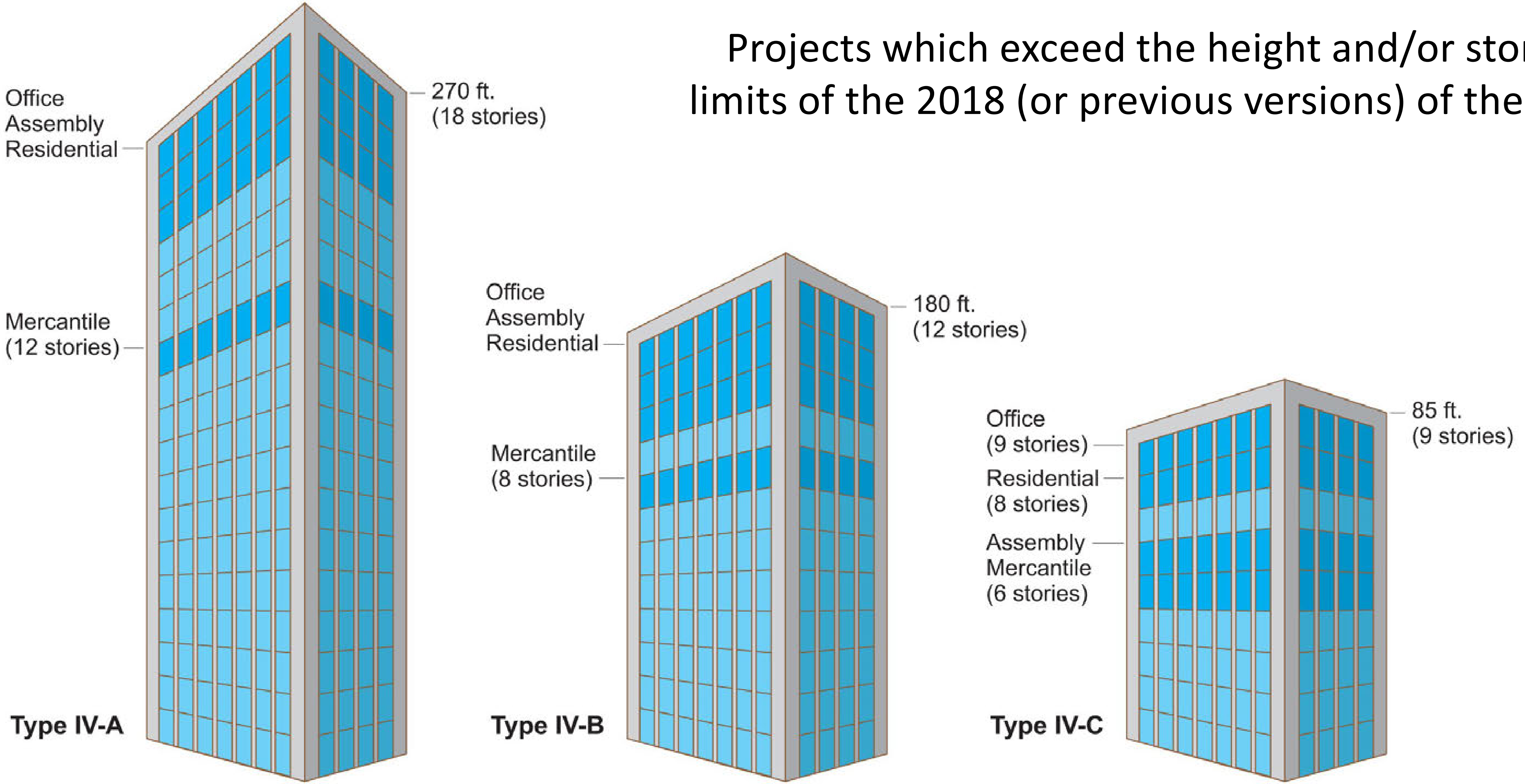
Patrick Duffy, PE
Regional Director - WoodWorks

What is Tall Mass Timber?

Photo: WoodWorks
Architect/Developer: oWOW

Tall Mass Timber

Projects which exceed the height and/or story limits of the 2018 (or previous versions) of the IBC



Tall Mass Timber

2021 IBC Introduces 3 new tall wood construction types:

» IV-A

» IV-B

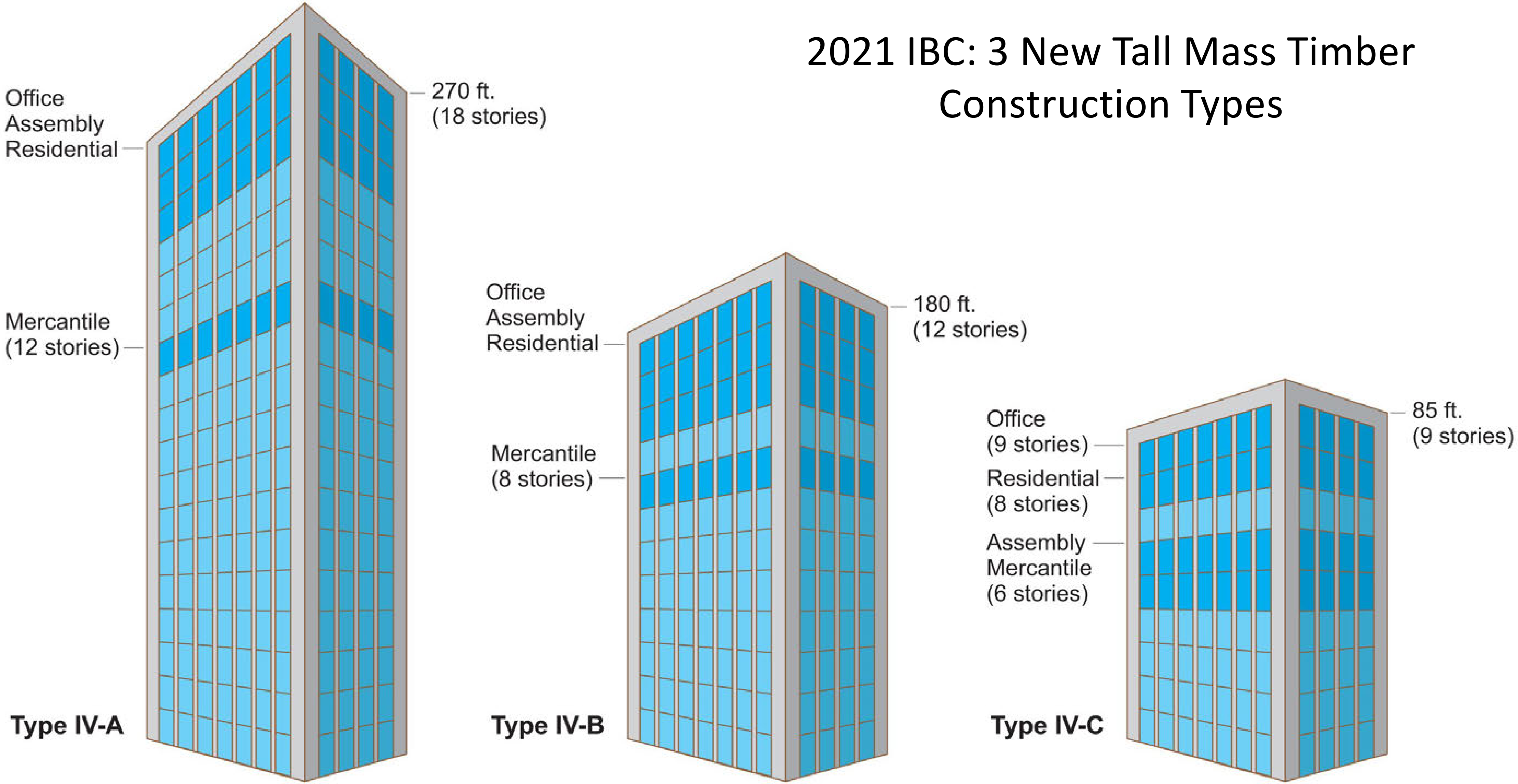
» IV-C

» Previous type IV renamed type IV-HT

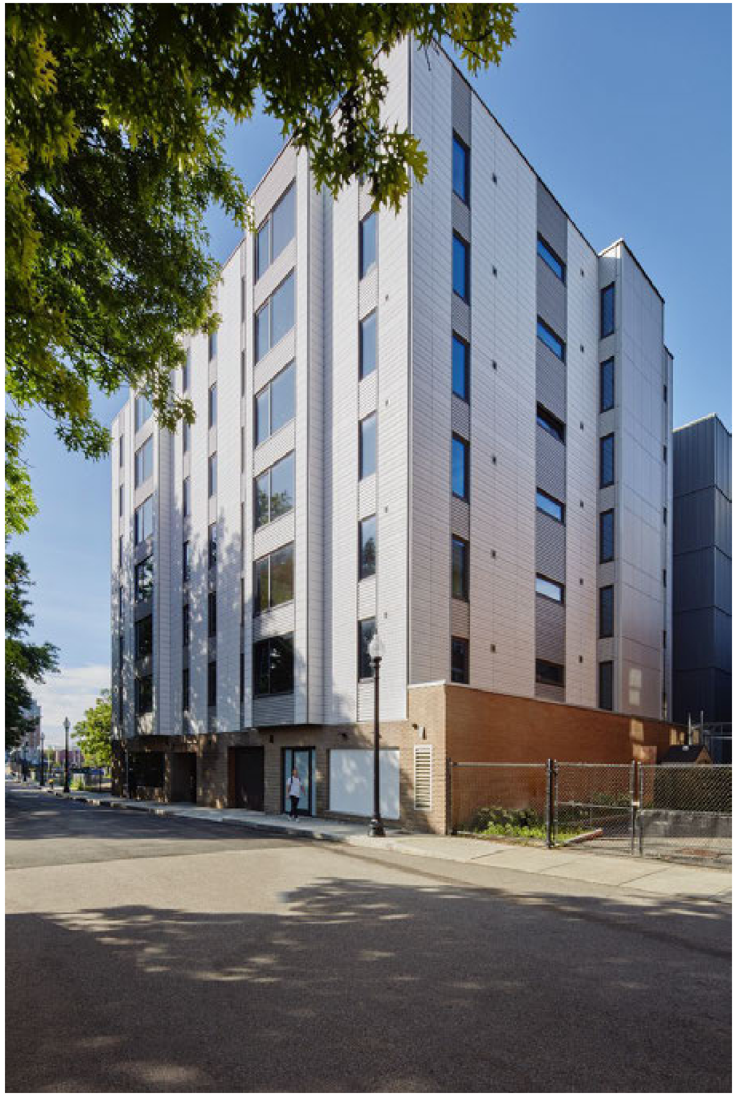
BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
	A	B	A	B	A	B	A	B	C	HT	A	B

Tall Mass Timber

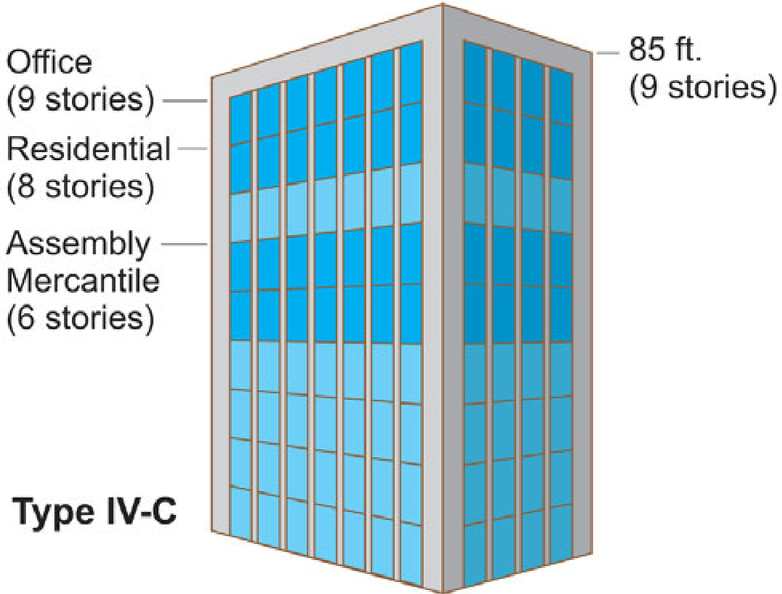
2021 IBC: 3 New Tall Mass Timber Construction Types



Type IV-C



Monte French Design Studio
Photos: Jane Messinger

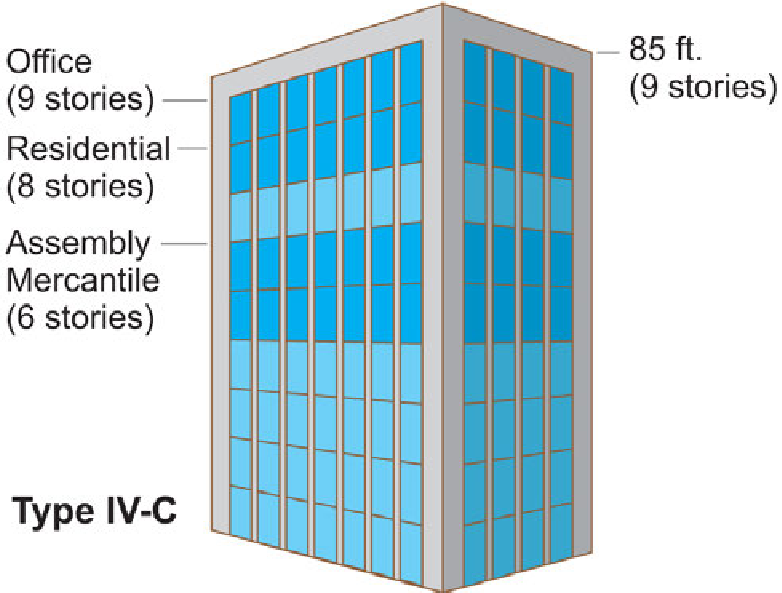


Type IV-C Exposure Limits

All Mass Timber surfaces may be exposed

Exceptions: Shafts, concealed spaces, outside face of exterior walls

Monte French Design Studio
Photo: Jane Messinger



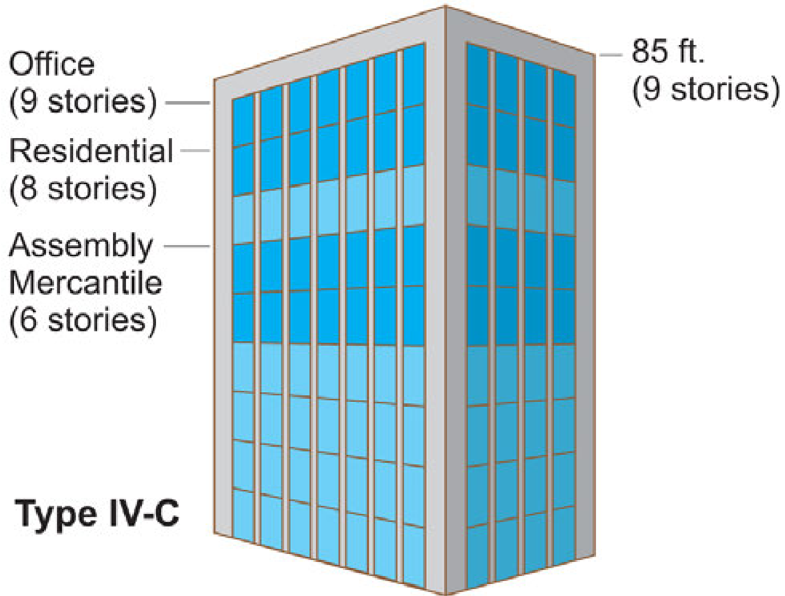
Type IV-C Building Size Limits

In most cases, Type IV-C height allowances = Type IV-HT height allowances, but additional stories permitted due to enhanced FRR

Type IV-C area = 1.25 * Type IV-HT area

Occupancy	# of Stories	Height	Area per Story	Building Area
A-2	6	85 ft	56,250 SF	168,750 SF
B	9	85 ft	135,000 SF	405,000 SF
M	6	85 ft	76,875 SF	230,625 SF
R-2	8	85 ft	76,875 SF	230,625 SF

Areas exclude potential frontage increase



Type IV-B

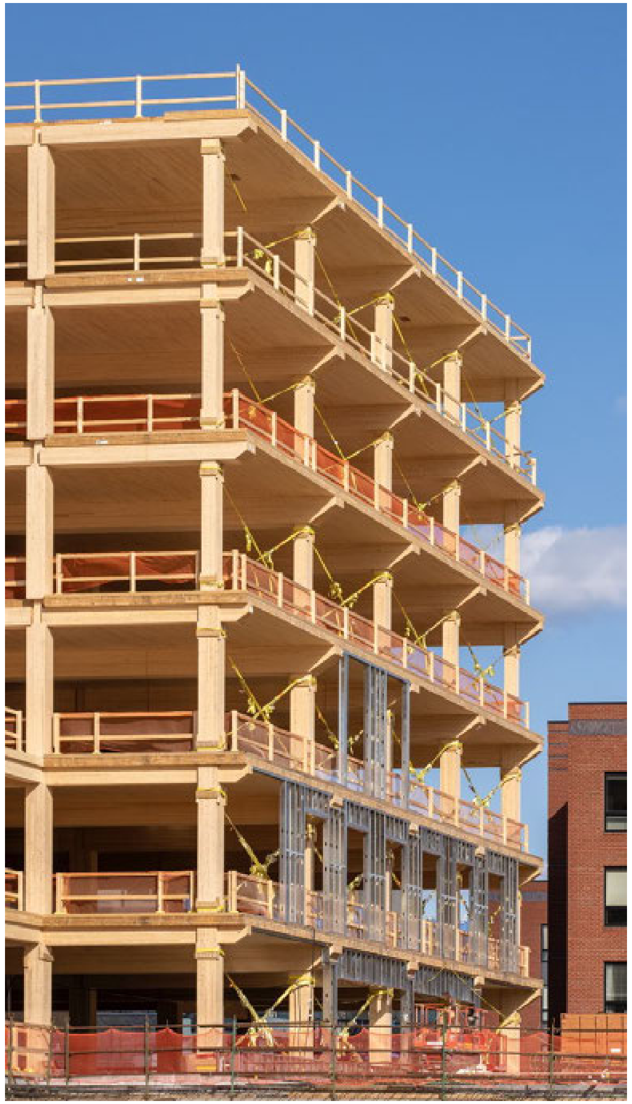
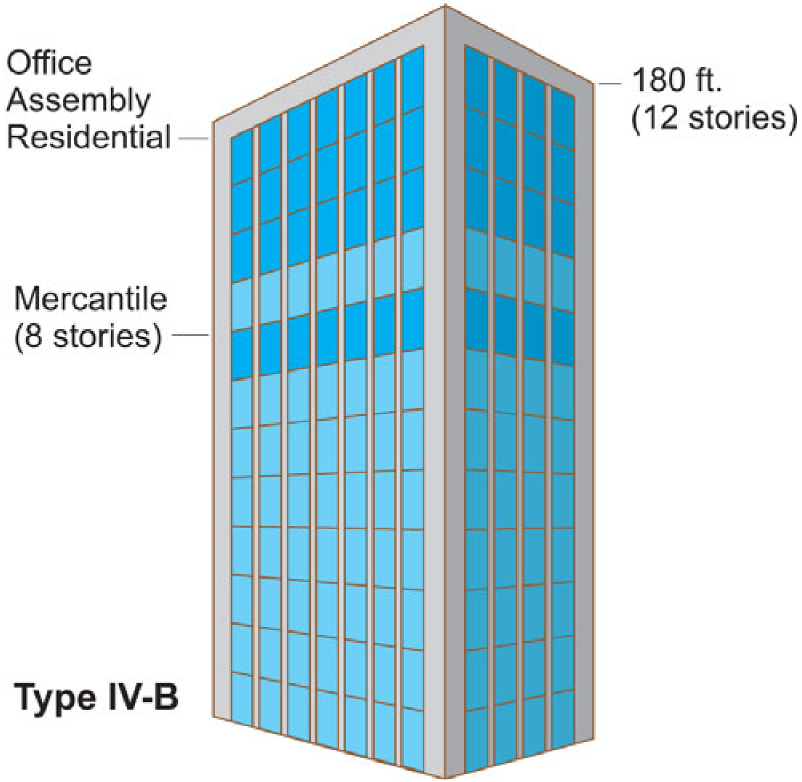


Photo: ©Prakash Patel

Photos: Nick Johnson, Tour D Space



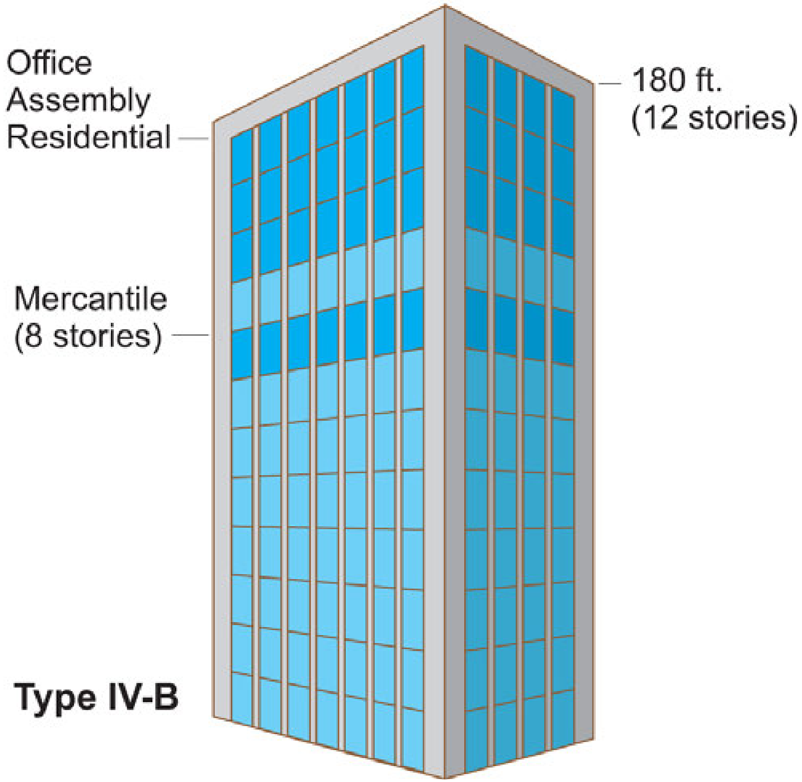
Type IV-B Exposure Limits

NC protection on some surfaces of Mass Timber

2021 IBC: 20% of ceilings or 40% of walls can be exposed

2024 IBC: 100% of ceilings or 40% of walls can be exposed

Photo: Nick Johnson, Tour D Space



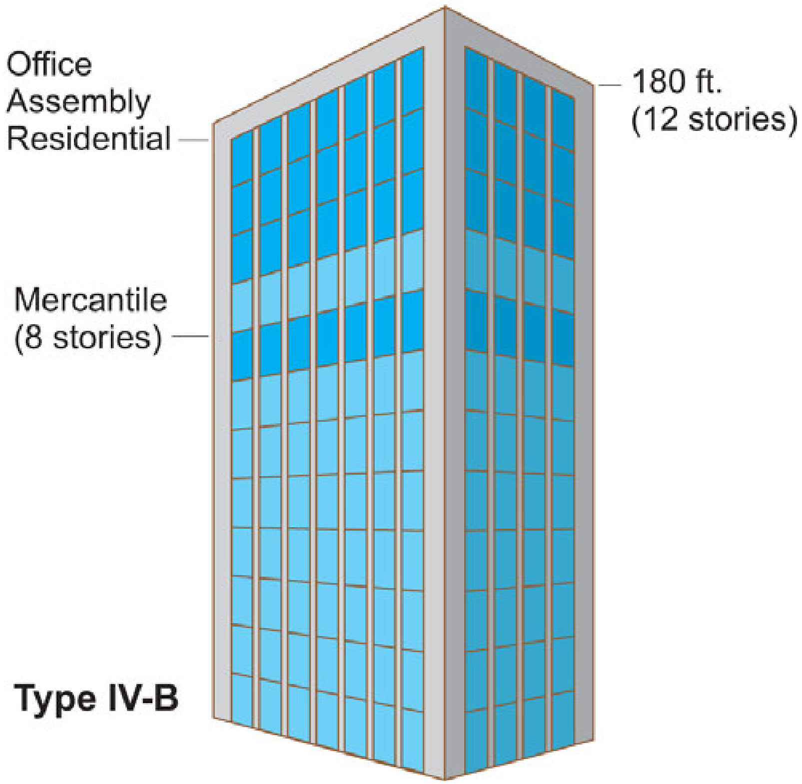
Type IV-B Building Size Limits

In most cases, Type IV-B height & story allowances = Type I-B height & story allowances

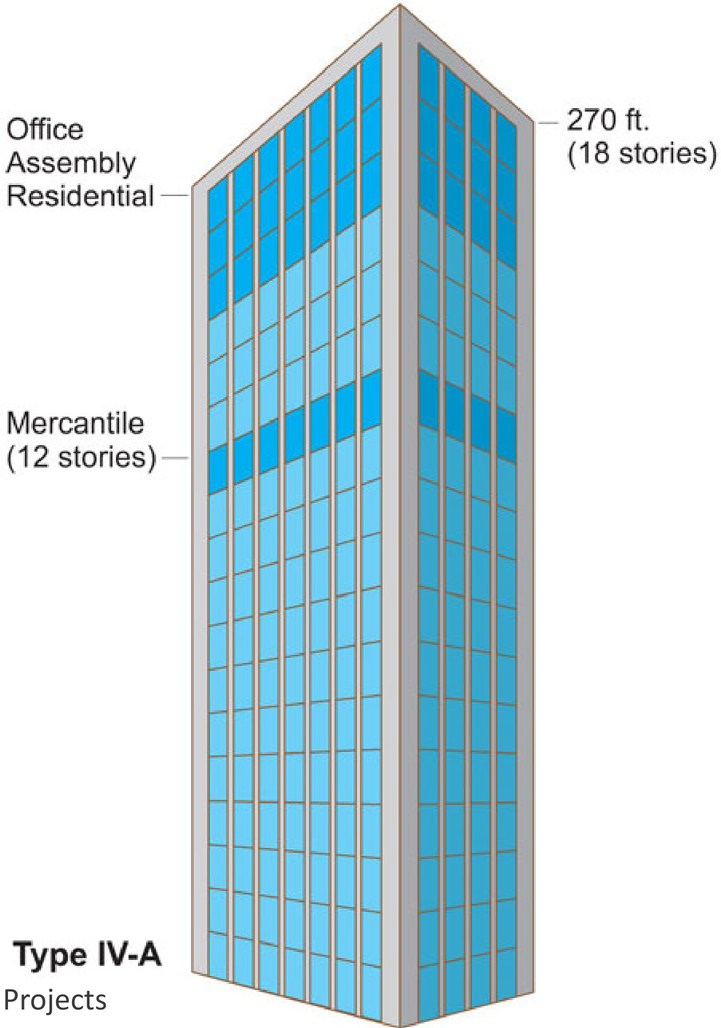
Type IV-B area = 2 * Type IV-HT area

Occupancy	# of Stories	Height	Area per Story	Building Area
A-2	12	180 ft	90,000 SF	270,000 SF
B	12	180 ft	216,000 SF	648,000 SF
M	8	180 ft	123,000 SF	369,000 SF
R-2	12	180 ft	123,000 SF	369,000 SF

Areas exclude potential frontage increase



Type IV-A

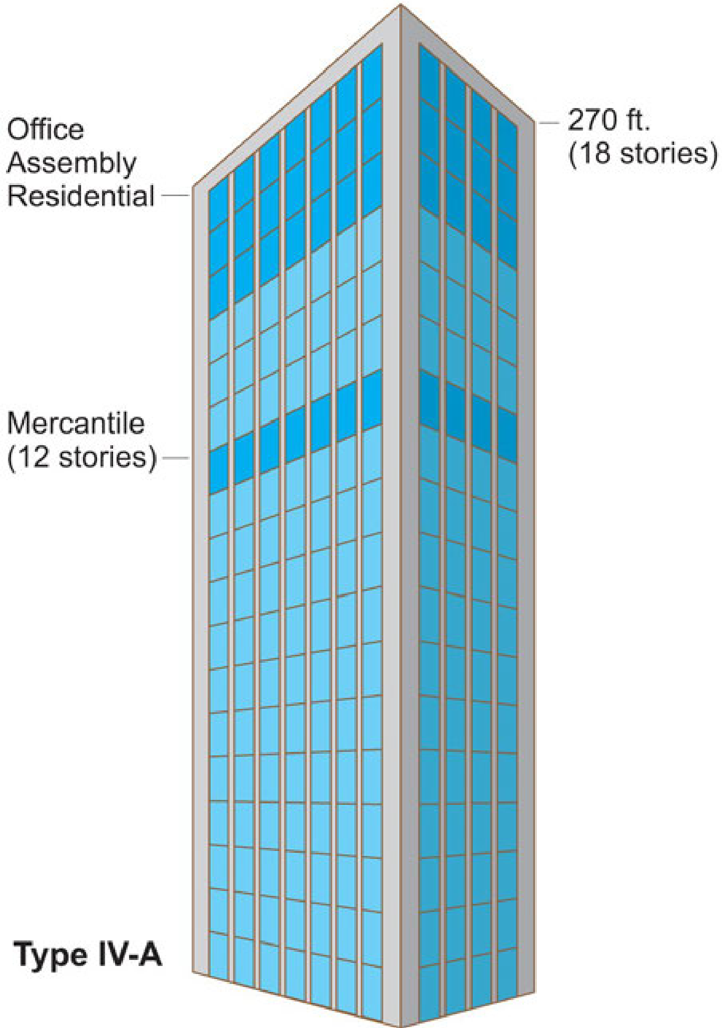


Photos: Flor Projects

Type IV-A Exposure Limits

100% NC protection on all surfaces of Mass Timber

Photo: Flor Projects



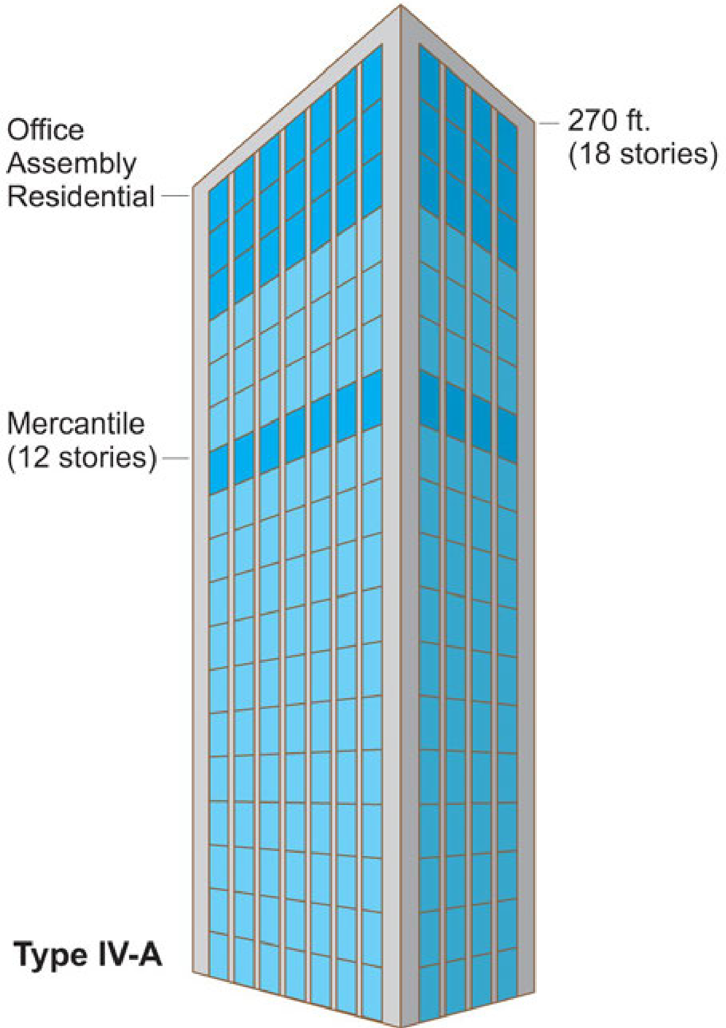
Type IV-A Building Size Limits

In most cases, Type IV-A height & story allowances = 1.5 * Type I-B height & story allowances

Type IV-A area = 3 * Type IV-HT area

Occupancy	# of Stories	Height	Area per Story	Building Area
A-2	18	270 ft	135,000 SF	405,000 SF
B	18	270 ft	324,000 SF	972,000 SF
M	12	270 ft	184,500 SF	553,500 SF
R-2	18	270 ft	184,500 SF	553,500 SF

Areas exclude potential frontage increase



Tall Mass Timber in the U.S.

How Did We Arrive Here?

INTRO, Cleveland, OH | Architect: Hartshorne Plunkard Architecture | Image Courtesy Harbor Bay Real Estate Advisors, Image Fiction

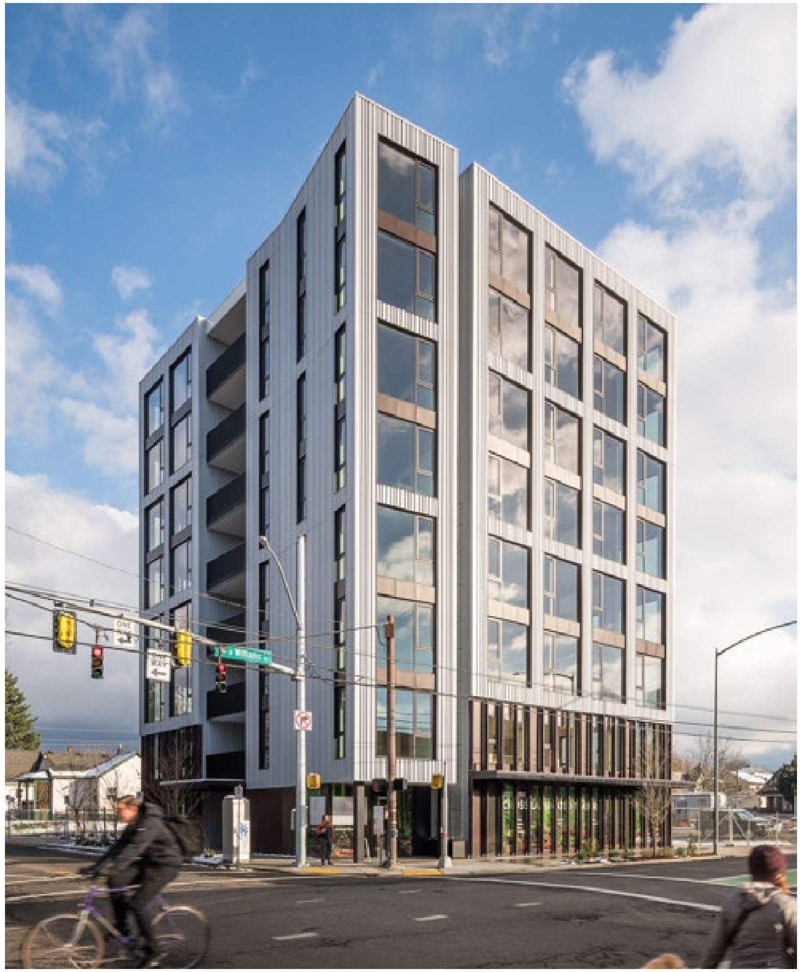
2008 – 2015: International Inspiration

8-18-Story Projects in Europe, Canada, Australia

Photos: Waugh Thisleton Architects | Bygg Mesteren | Voll Arkitekter | Michael Elkan | Naturally Wood | UBC

2015-2018: Domestic Innovation

Tall Wood Building Competition, 8-Story Carbon 12 in Portland, OR

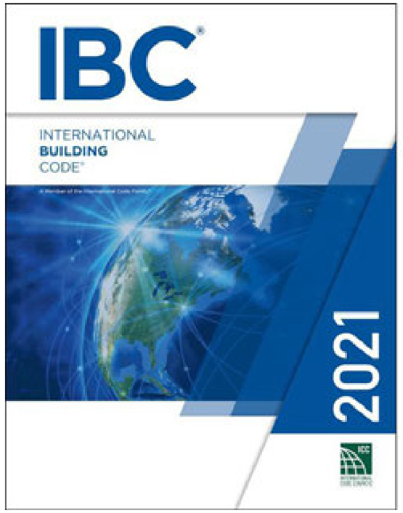


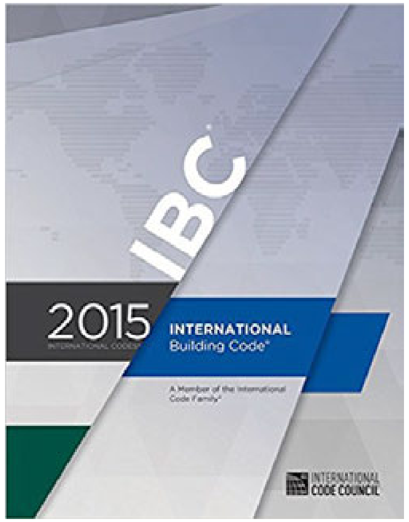
Photos: SHoP Architects | LEVER Architecture | Baumberger Studio/PATH Architecture

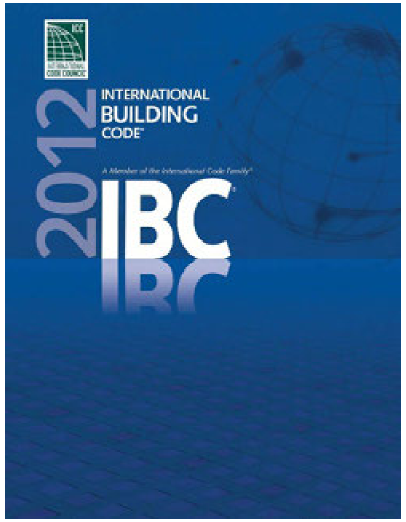
2015-2018: Building a Code Roadmap

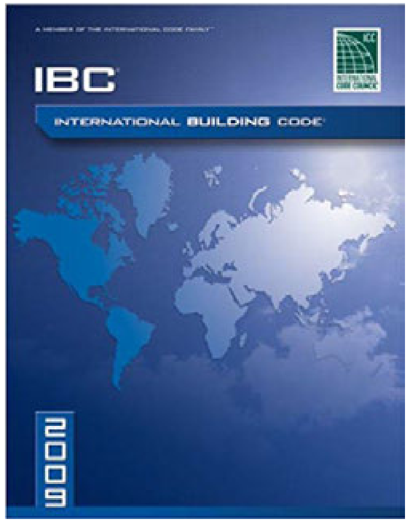
Photos: ICC

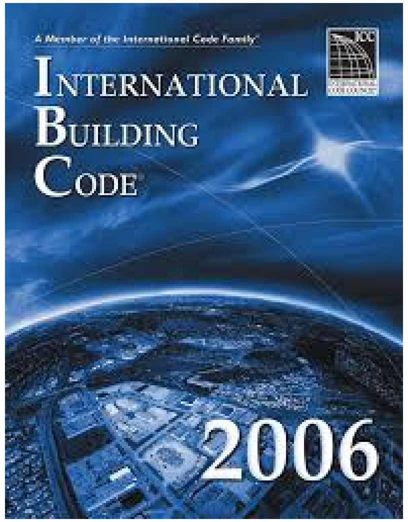
2015-2018: Building a Code Roadmap

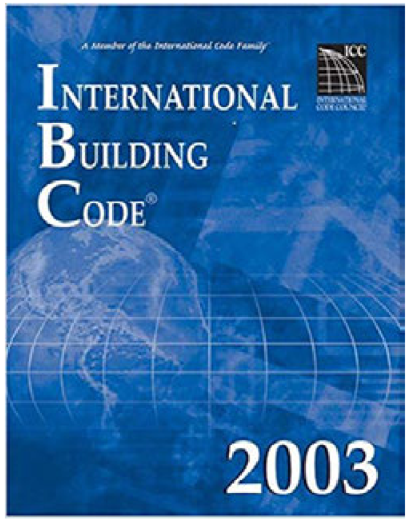


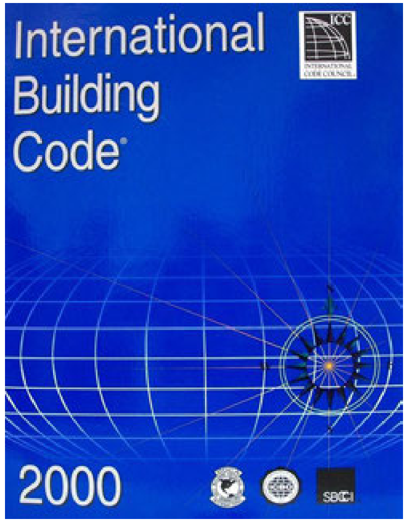












Images: ICC

2015-2018: Building a Code Roadmap

Photo: Lendlease

2015-2018: Building a Code Roadmap

Photo: Lendlease

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Photo: Lendlease

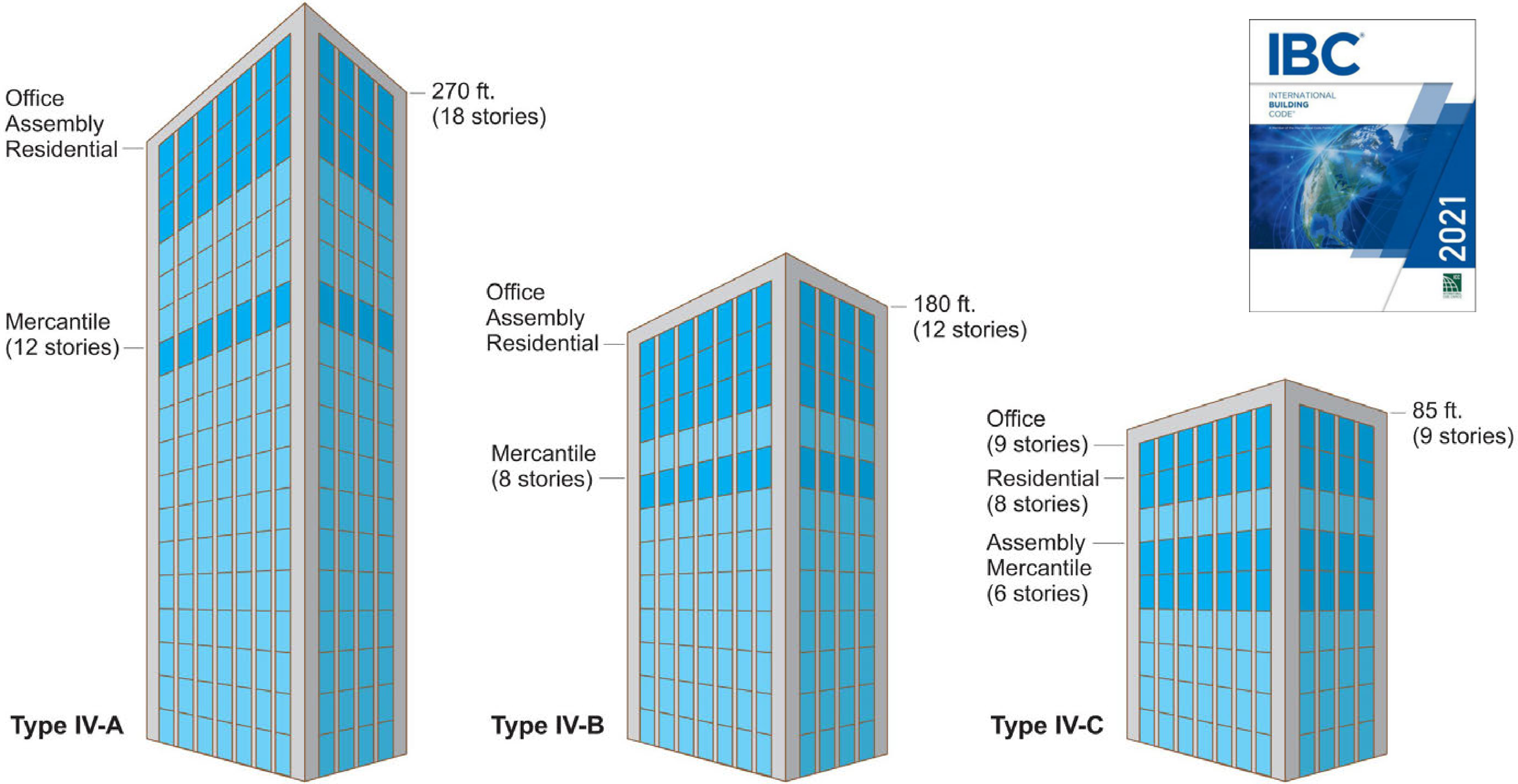
2015-2018: Building a Code Roadmap

Photo: Lendlease

2015-2018: Building a Code Roadmap

Photo: Lendlease

2018-2021: Rollout of a New Code Path



2021 IBC

CONSTRUCTION DEVELOPMENT SUSTAINABILITY

Denver Adopts Tall Mass Timber Codes

milehighcre — January 6, 2020

On December 23, the City of Denver voted to adopt the 2019 Denver Building Code, which includes the tall mass timber code provisions approved for the 2021 International Building Code (IBC).

As part of the adoption of the new code, there will be a four-month period where new projects can use either the 2016 Denver Building Code or the newly-adopted 2019 version. After four months, all building and fire code permits will be processed under the 2019 Denver Building Code.

"We congratulate the City of Denver on incorporating mass timber into its building codes, and recognizing the potential of this new category of wood products to revolutionize the way America builds," said American Wood Council president & CEO Robert Glowinski. "Mass timber offers the strength of historic building materials with lower weight, and, in the rare event of a fire, has inherent fire resistance. Beyond the aesthetic qualities of mass timber that building owners and designers are seeking, wood is among the most energy-efficient and environmentally friendly of all construction materials, storing carbon from the atmosphere for long periods of time."

The adopted proposal to recognize mass timber in the new code was submitted by Dr. Gregory R. Kingsley on behalf of the Structural Engineers Association of Colorado. The American Wood Council provided technical assistance to the city in support of the proposal.

The 2019 Denver Building Code will now recognize three new types of construction that also are included in the 2021 IBC:

AMENDMENTS TO THE BUILDING AND FIRE CODE FOR THE CITY AND COUNTY OF DENVER

The 2019 Denver Building and Fire Code includes the following codes except as amended herein.

APPENDIX U
TALL WOOD BUILDINGS

SECTION U101
GENERAL

U101.1 Purpose. The purpose of this appendix is to provide criteria for three new mass timber construction types: Type IV-A, Type IV-B, and Type IV-C. These building types expand the allowable use of mass timber construction to larger areas and greater heights than allowed for Type IV-HT construction.

U101.2 Scope. The provisions in this appendix are in addition to or replace the sections in the 2018 *International Building Code* where Types IV-A, IV-B, and IV-C construction are used. Where building Types IV-A, IV-B, or IV-C are not used, this appendix does not apply.

SECTION U102
AMENDMENTS TO THE INTERNATIONAL BUILDING CODE

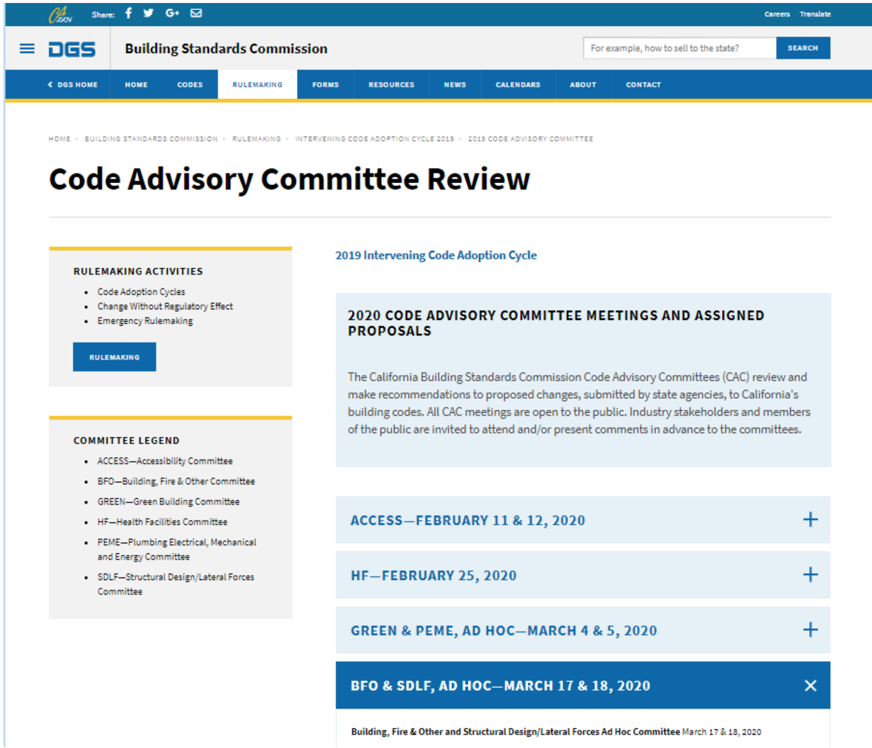
(Under use of this appendix chapter, the following sections shall be modified or added as follows and shall supersede the corresponding sections in the International Building Code or Denver amendments to the International Building Code)

Credit: City of Denver, Mile High CRE

Source: Softwood Lumber Board

On August 13, 2020 the California Building Standards Commission grouped the tall wood code change proposals into one agenda item and passed them unanimously.

The changes were published as an amendment to the 2019 CBC on January 1, 2021 and became effective on July 1, 2021



2019-2022: REFINING THE CODE ROADMAP

RI. SE

Fire Safe Implementation of Mass Timber In Tall Buildings

Research of the fire performance of CLT and Glued Laminated Timber buildings, with visible wood surfaces.

WOODWORKS WOOD PRODUCTS COUNCIL

The main aim of this research project was to identify safe limits of exposed mass timber surface areas that correspond with performance criteria used for previous U.S. Building Code Changes.

Source: RISE

2019-2022: REFINING THE CODE ROADMAP


USDA
United States Department of Agriculture

Compartment Fire Testing of a Two-Story Mass Timber Building

Samuel L. Zelinka
Laura E. Hasburgh
Keith J. Bourne
David R. Tucholski
Jason P. Ouellette

Forest Service | Forest Products Laboratory | General Technical Report FPL–GTR–247 | May 2018

Conservatism: ATF lab tests based on older generation CLT adhesives

2018 ATF tests were initiated before the 2018 version of ANSI/APA PRG 320 was published and the tested CLT was not compliant with the new product standard.

Source: RISE, USDA FS FPL & AWC

2019-2022: REFINING THE CODE ROADMAP

In tall buildings, preventing fire re-growth is key.

Fire re-growth is a phenomenon in which the heat-release rate of a fire intensifies following a decay phase. Fire re-growth can be initiated when delamination occurs, as this exposes un-charred wood surfaces, thereby resulting in an influx of fuel available for consumption by the fire.

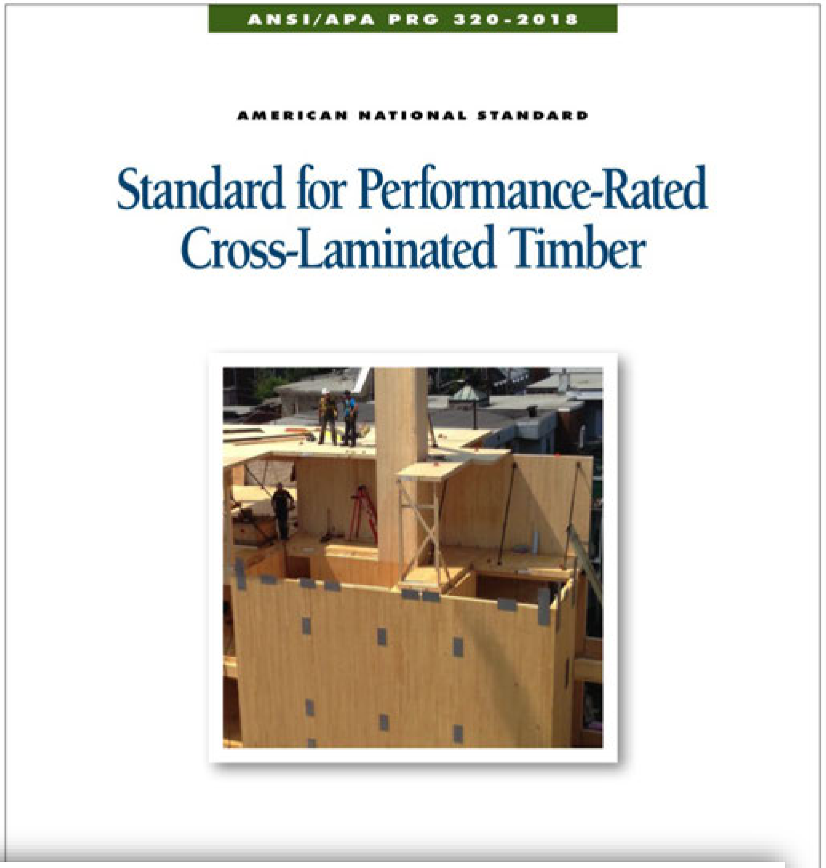

Photo: Urban One


Photo: ARUP

2019-2022: REFINING THE CODE ROADMAP

PRG 320 is manufacturing & performance standard for CLT

2019 edition (referenced in 2021 IBC) added new elevated temperature adhesive performance requirements validated by full-scale and medium-scale qualification testing to ensure CLT does not exhibit fire re-growth



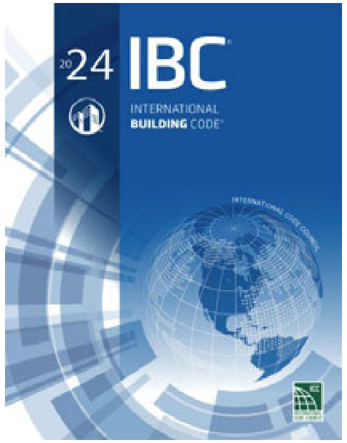
ANNEX B. PRACTICE FOR EVALUATING ELEVATED TEMPERATURE PERFORMANCE OF ADHESIVES USED IN CROSS-LAMINATED TIMBER (MANDATORY)

2019-2022: REFINING THE CODE ROADMAP

Photo: RISE

2019-2022: REFINING THE CODE ROADMAP

Change to 2024 IBC: IV-B Ceiling Exposure



602.4.2.2.2 Protected area.

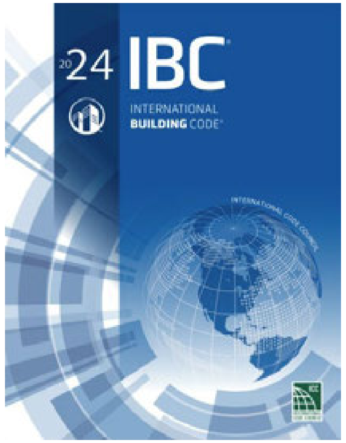
Interior faces of *mass timber* elements, including the inside face of exterior *mass timber walls* and *mass timber roofs*, shall be protected in accordance with Section 602.4.2.2.1.

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 complying 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. Unprotected portions of *mass timber* walls, including attached columns, limited to an area less than or equal to 40 percent of the floor area in any *dwelling unit* within a *story* or fire area within a *story*.
   1.3. Unprotected portions of both walls and ceilings of *mass timber*, including attached columns and beams, in any *dwelling unit* or fire area and in compliance with Section 602.4.2.2.3.
2. *Mass timber* columns and beams that are not an integral portion of walls or ceilings, respectively, without restriction of either aggregate area or separation from one another.

2019-2022: REFINING THE CODE ROADMAP

Change to 2024 IBC: IV-B Exposure Separation



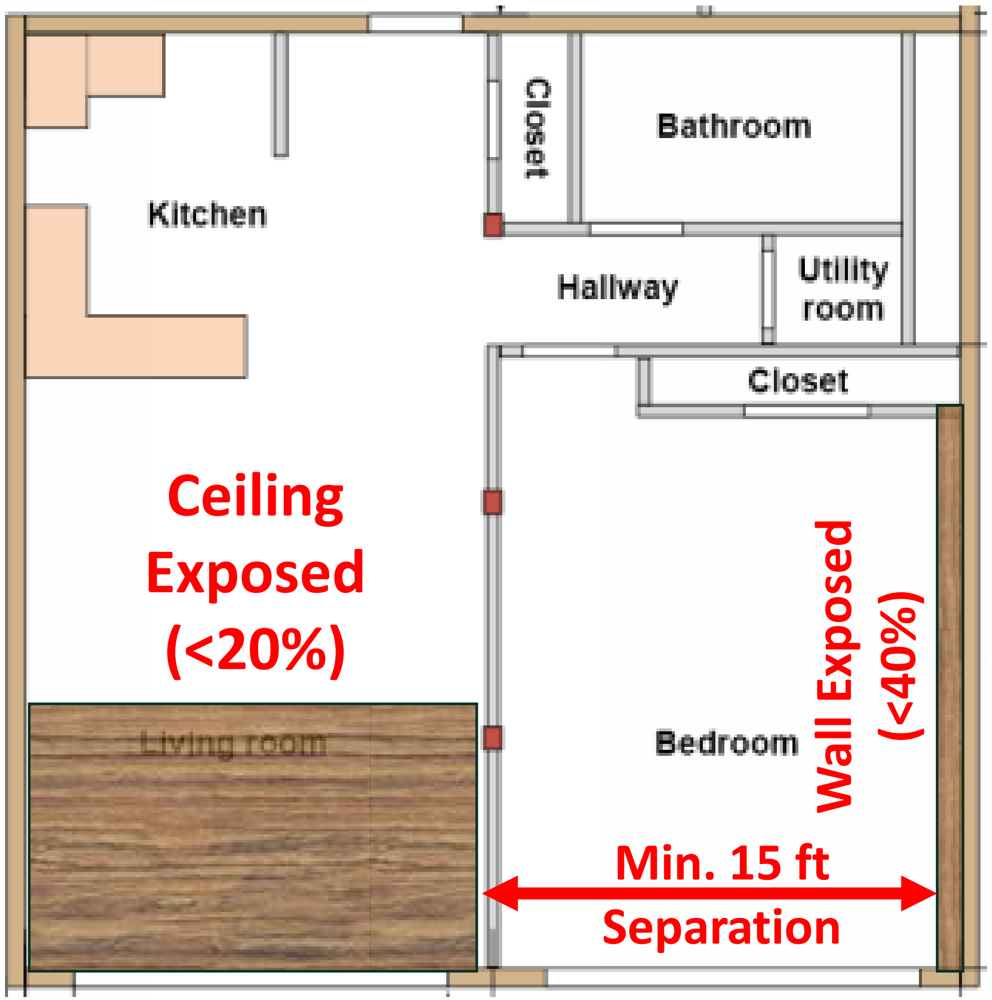
602.4.2.2.4 Separation distance between unprotected *mass timber* elements.

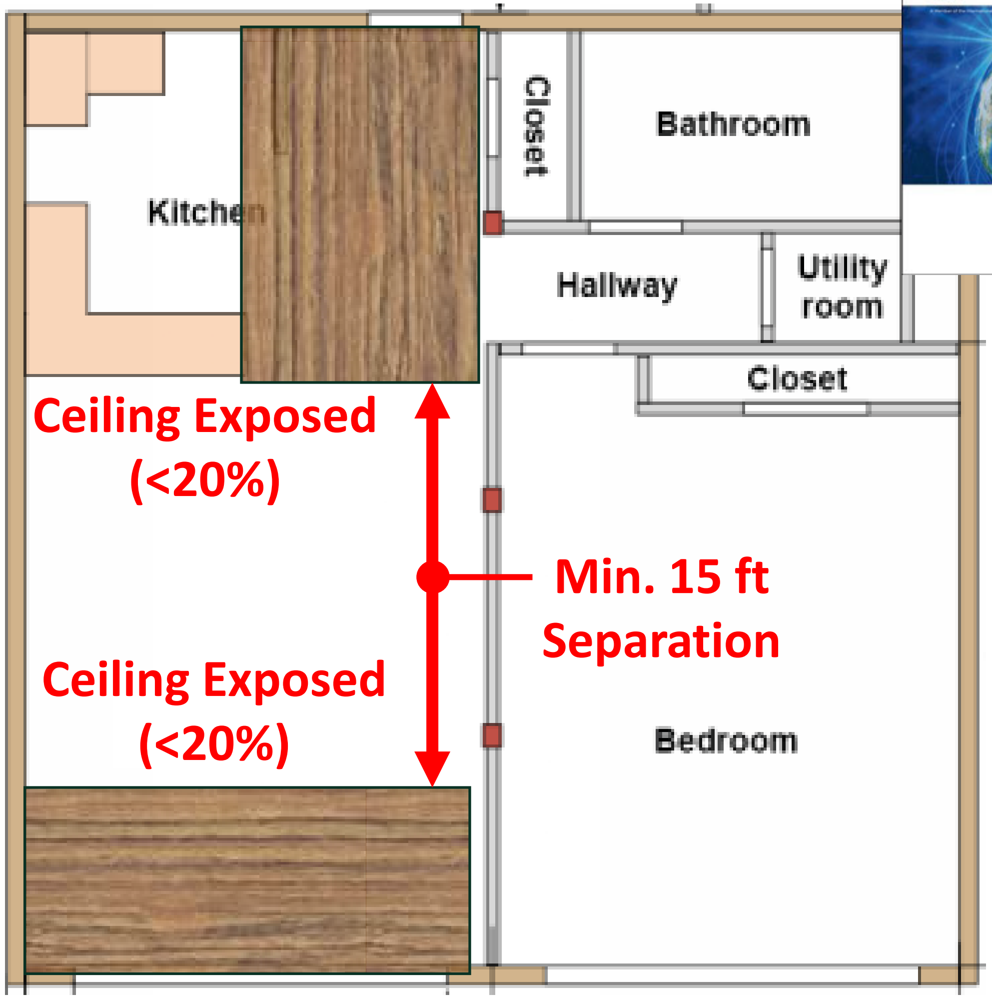
In each *dwelling unit* or *fire area*, unprotected portions of *mass timber* walls shall be not less than 15 feet (4572 mm) from unprotected portions of other walls measured horizontally along the floor.

2024 IBC eliminates need for 15 ft separation between exposed walls and ceilings, and between portions of exposed ceilings

2019-2022: REFINING THE CODE ROADMAP

2021 IBC Allowances

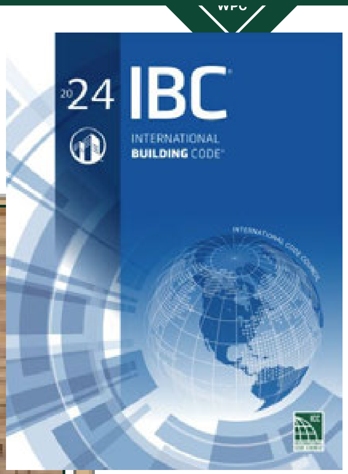


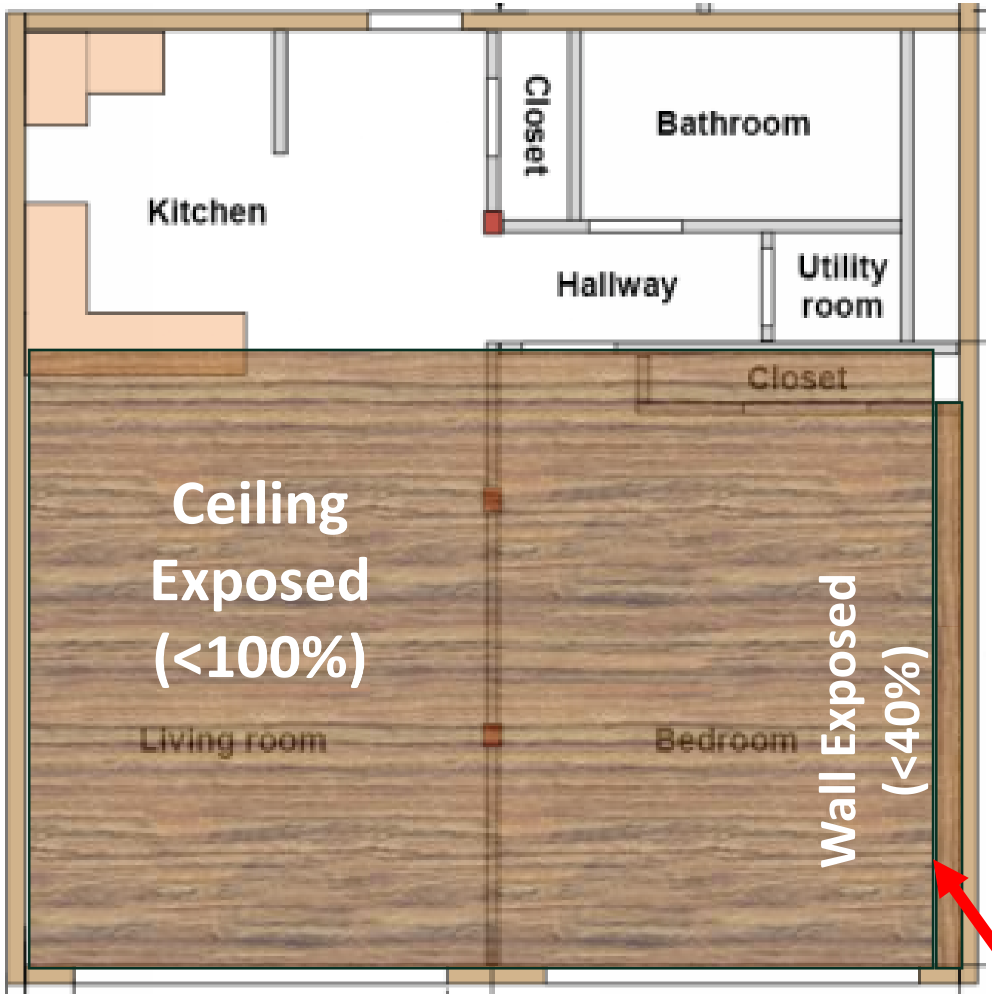


Credit: AWC

2019-2022: REFINING THE CODE ROADMAP

2024 IBC Allowances

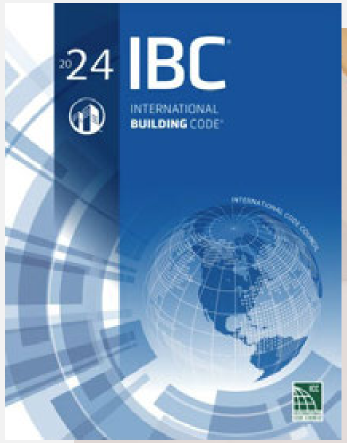




No separation req'd between wall & ceiling

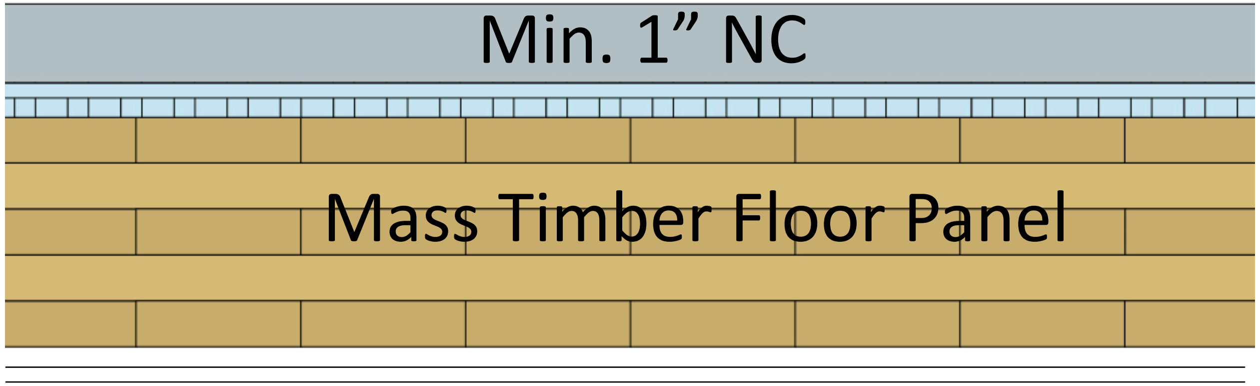
Credit: AWC

2019-2022: REFINING THE CODE ROADMAP



100% Timber Ceiling Exposure Up to 12 Stories

2019-2022: REFINING THE CODE ROADMAP



Min. 1” thick NC protection required on mass timber floors in IV-A and IV-B. Not required in IV-C

2019-2022: REFINING THE CODE ROADMAP

Change to 2024 IBC: Sequencing of NC topping install

F174-21

IFC: 3303.5

Proponents: David Tyree, representing AWC (dtyree@awc.org); Raymond O'Brocki, AWC, representing AWC (robrocki@awc.org)

2021 International Fire Code

Revise as follows:

3303.5 Fire safety requirements for buildings of Types IV-A, IV-B and IV-C construction. Buildings of Types IV-A, IV-B and IV-C construction designed to be greater than six stories above*grade plane* shall comply with the following requirements during construction unless otherwise *approved* by the *fire code official*:

1. Standpipes shall be provided in accordance with Section 3313.
2. A water supply for fire department operations, as *approved* by the *fire code official* and the *fire chief*.
3. Where building construction exceeds six stories above *grade plane* and noncombustible protection is required by Section 602.4 of the *International Building Code*, at least one layer of noncombustible protection shall be installed on all building elements on floor levels, including mezzanines, more than four levels below active mass timber construction before additional floor levels can be erected.

   ~~**Exception**~~ **Exceptions:**

   1. Shafts and vertical exit enclosures shall not be considered part of the active mass timber construction.
   2. Noncombustible material on the top of mass timber floor assemblies shall not be required before erecting additional floor levels.

4. Where building construction exceeds six stories above *grade plane*, required exterior wall coverings shall be installed on floor levels, including mezzanines, more than four levels below active mass timber construction before additional floor levels can be erected.

   Exception: Shafts and vertical exit enclosures shall not be considered part of the active mass timber construction.

Credit: ICC

2022 AND BEYOND: ADOPTING UPDATED CODES

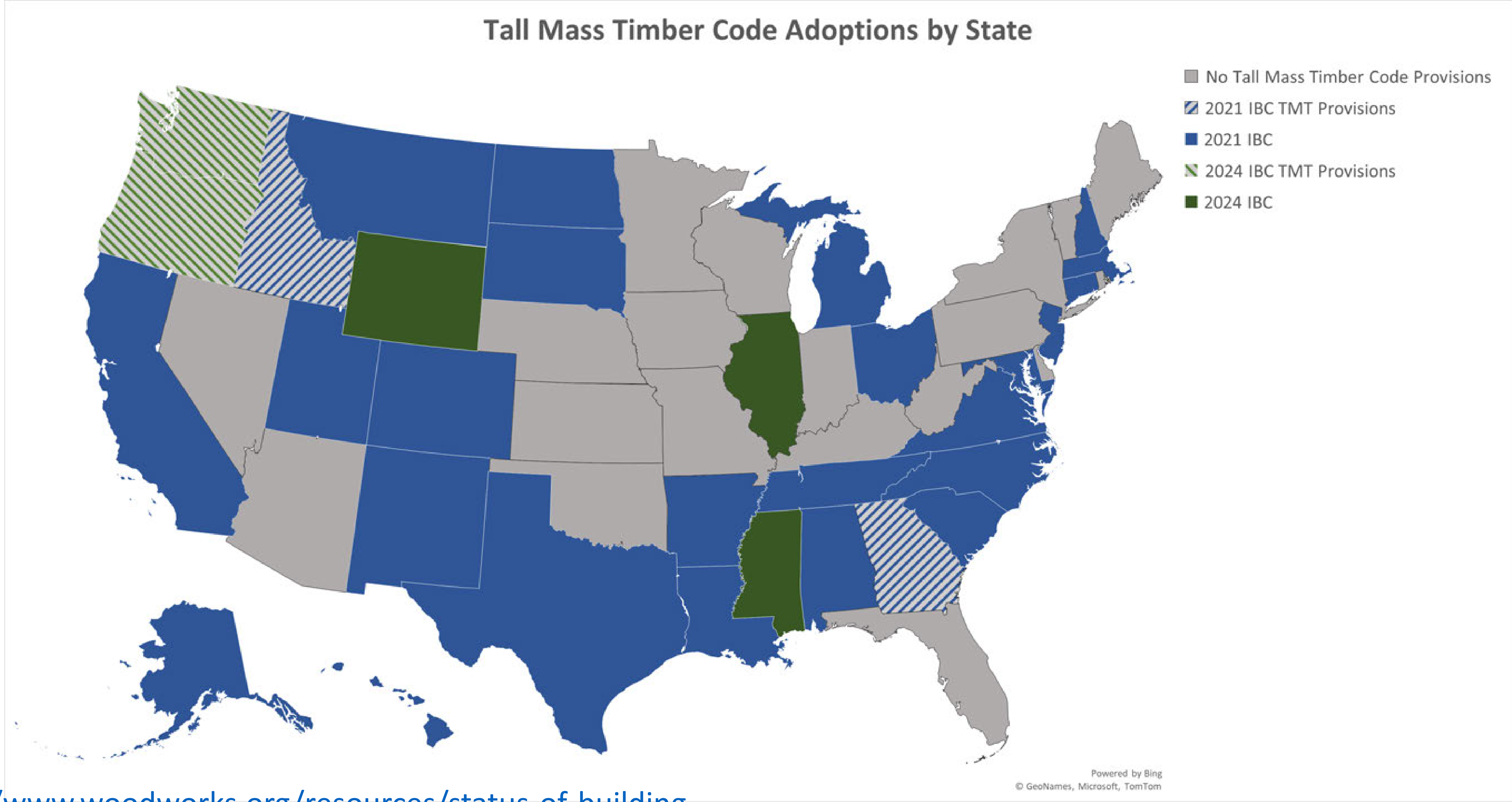
ORDINANCE NO. 32198

An ordinance amending Chapter 53, "Dallas Building Code," of the Dallas City Code by amending Sections 202, [F] 403.3.2, 406.5.2, 504.3, 504.4, 506.2.1, 506.2.3, 506.2.4, 507.3, 507.14,

1. Unprotected portions of *mass timber* ceilings, including attached beams, shall be permitted and shall be limited to an area less than or equal to 100 percent of the floor area in any dwelling unit or fire area; or
2. Unprotected portions of *mass timber* walls, including attached columns, shall be permitted and shall be limited to an area less than or equal to 40 percent of the floor area in any dwelling unit or fire area; or

Dallas
Denver
Oregon
Washington

TALL MASS TIMBER CODE ADOPTIONS

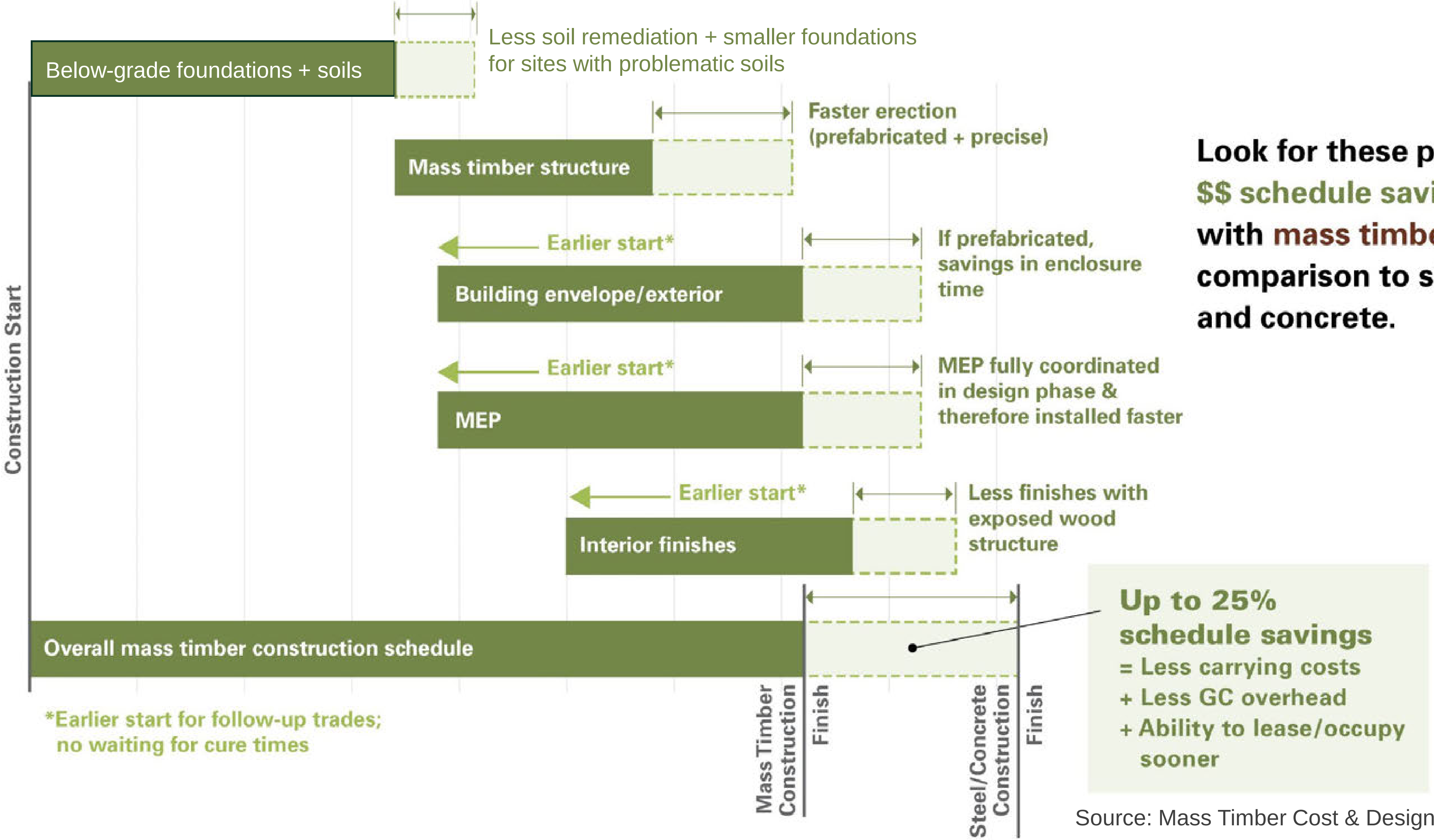


https://www.woodworks.org/resources/status-of-building-code-allowances-for-tall-mass-timber-in-the-ibc/

WHY ALL OF THE INTEREST?

Photo: WoodWorks
Architect/Developer: oWOW

Compressing the Typical Schedule



Look for these potential $$ schedule savings with mass timber in comparison to steel and concrete.

Source: Mass Timber Cost & Design Optimization, WoodWorks[2]

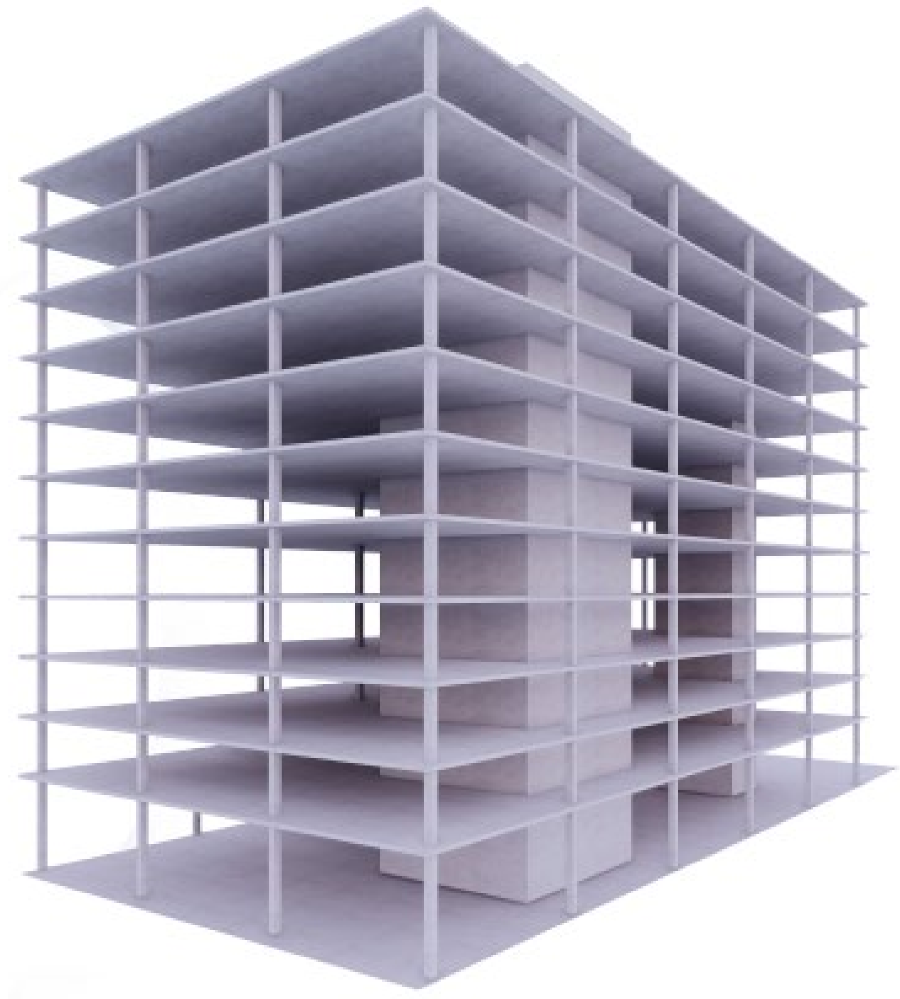
Construction Impacts: Labor Availability

Mass Timber: Structural Warmth is a Value-Add

TMBR (unbuilt) Minneapolis, MN | Images: D/O Architects

But is it cost competitive?

Need to Consider Holistic Costs, Not Structure Only



$/SF

$/SF

Image: GBD Architects

Risk Mitigation: Total Project Cost Analysis

CONSIDERATIONS:

- Ceiling Treatment
- Floor Topping
- HVAC System & Route
- Foundation Size
- Soil Improvements
- Exterior Skin Coordination
- Value of Time

Credit: Hacker Architects

Mass Timber Business Case Studies

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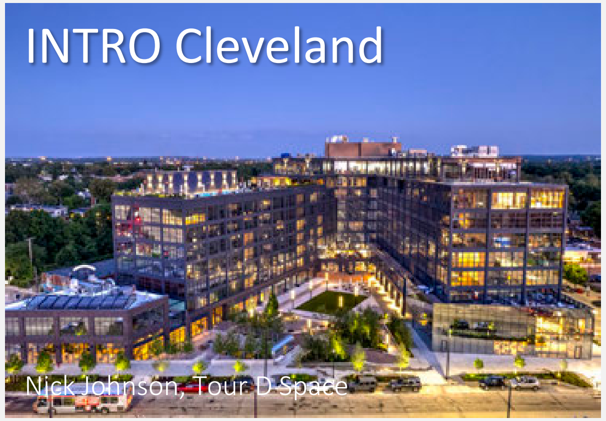

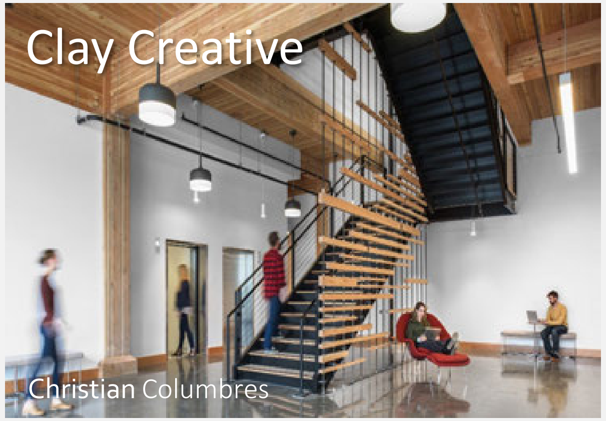

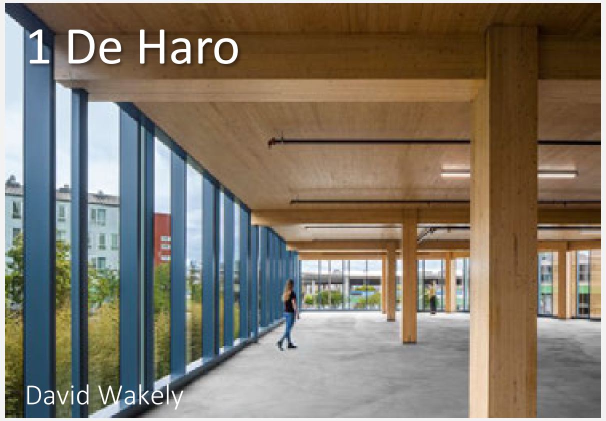

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$ Costs + $ Returns
Challenges,
Lessons Learned, Successes

Scan code here
to download the
current package

What’s the ‘Sweet Spot’ for Tall Mass Timber?

Depends on many factors:

- Project Use
- Site Constraints
- Local Zoning & FAR Limitations
- Budget
- Client Objectives for Sustainability, Exposed Timber
- And More…

But Some General Trends Could Be:

80 M Street, SE, Washington, DC
Photo: Hickok Cole | Architect: Hickok Cole

Type IV-C Tall Mass Timber

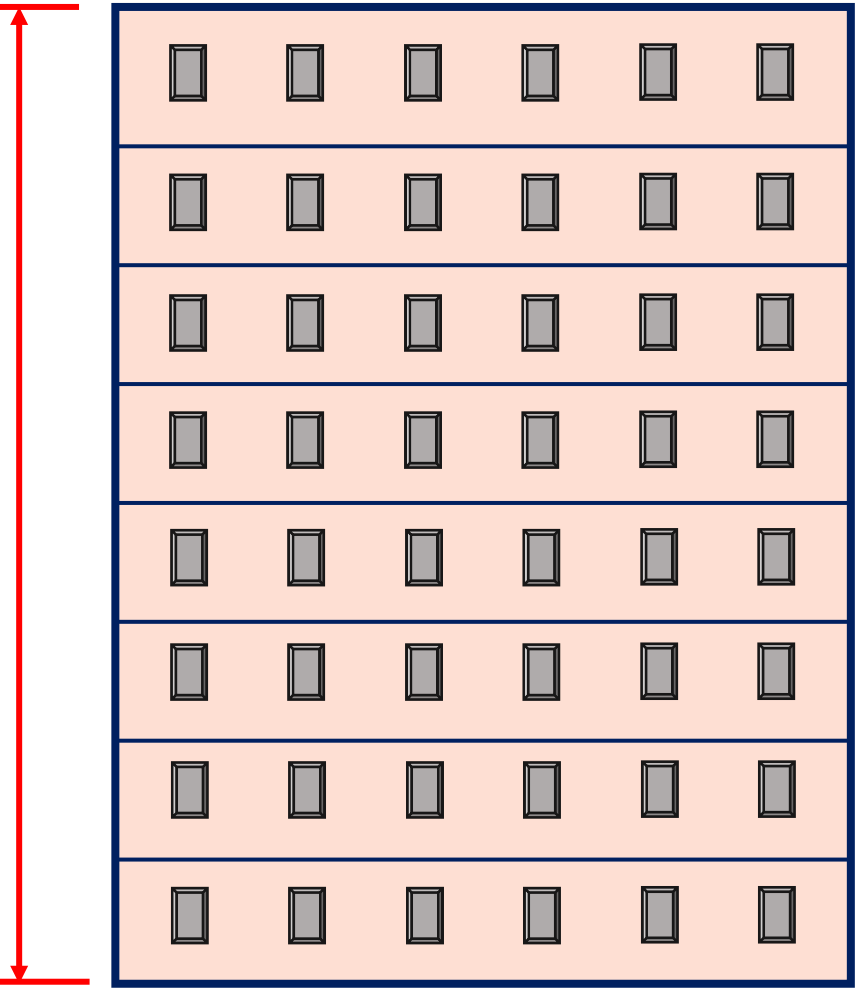
Example R-2, Type IV-C Building

8 Stories
85 ft

76,875 SF
max per floor

230,625 SF
bldg.

(areas noted
assume no frontage
increase)



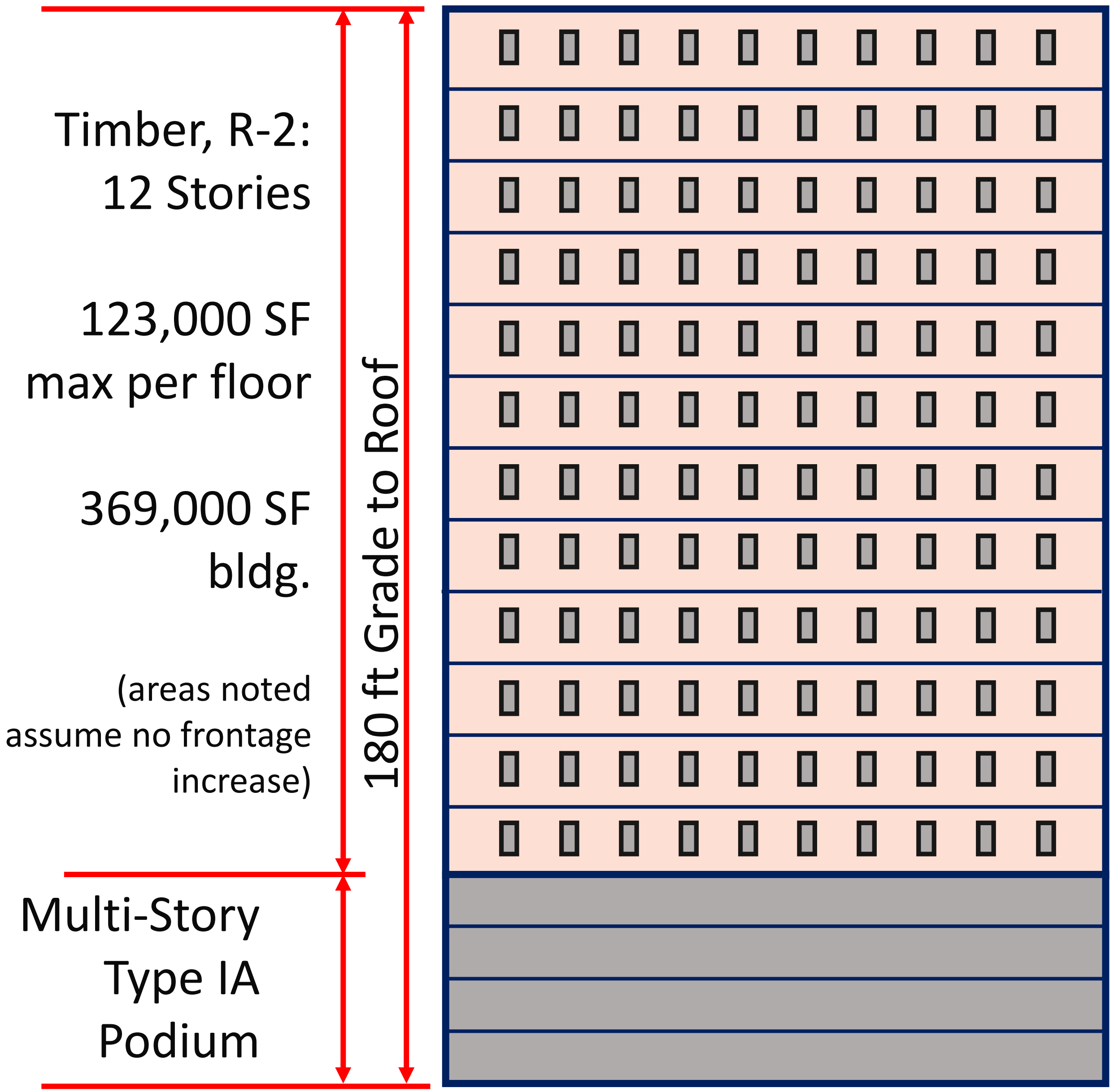
Not Likely to Utilize Podium Due to Overall Building Height Limit (85 ft) Relative to # of Timber Stories (8)

Same Overall Building Height Limit as IV-HT (85 ft) but higher Fire-Resistance Ratings Req'd

3 Additional Stories Permitted Compared to IV-HT

All Timber Exposed

Type IV-B Tall Mass Timber



Example Mixed-Use, Type IV-B Building

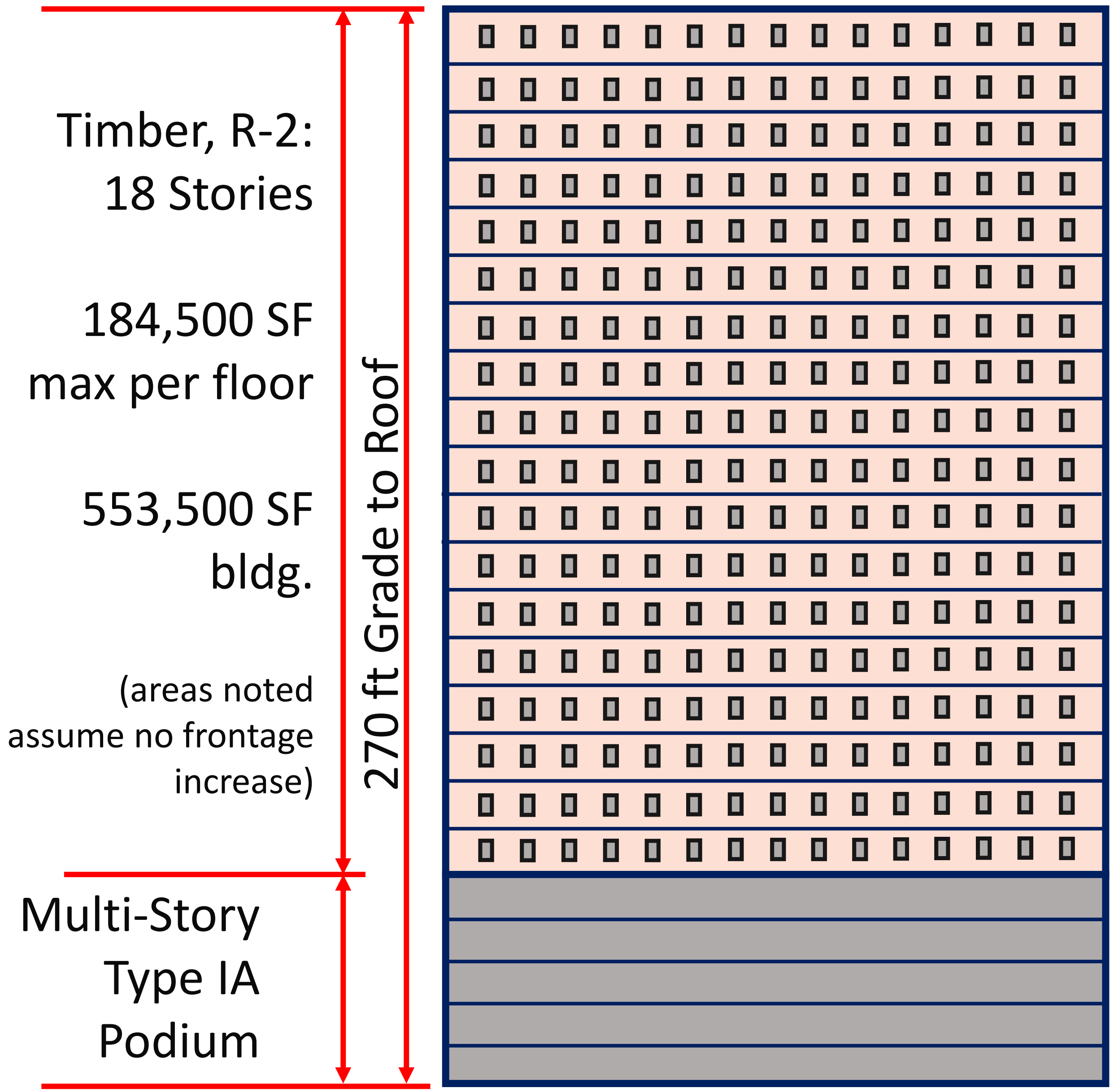
Likely to Utilize Podium Due to Overall Building Height Limit (180 ft) Relative to # of Timber Stories (12)

Same Fire-Resistance Ratings Req'd as IV-C But Limitations on Timber Exposed

4 Additional Stories Permitted Compared to IV-C

Limited Timber Exposed

Type IV-A Tall Mass Timber



Example Mixed-Use, Type IV-A Building

Likely to Utilize Podium Due to Overall Building Height Limit (270 ft) Relative to # of Timber Stories (18)

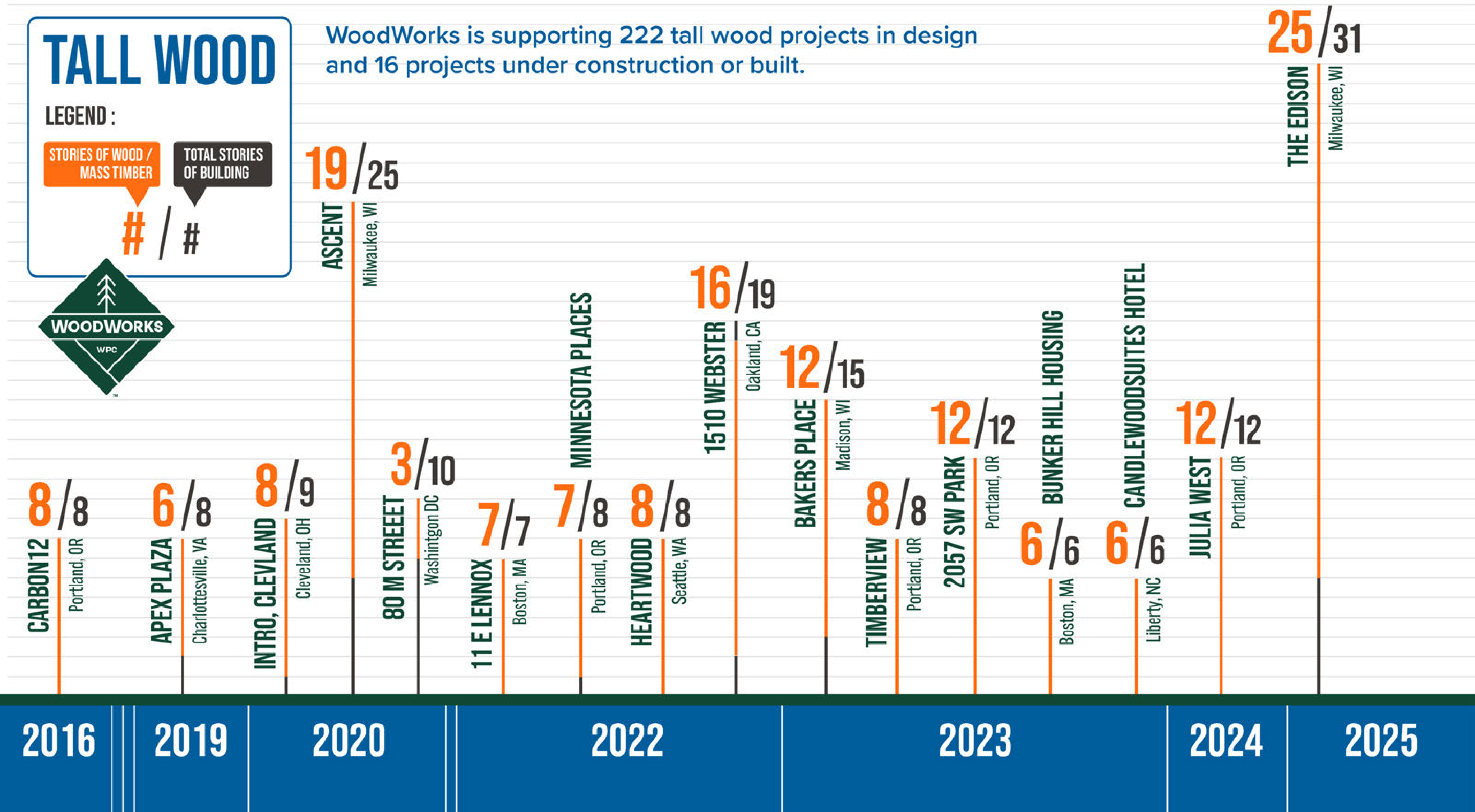
Higher Fire-Resistance Ratings Req'd than IV-B For Primary Frame

6 Additional Stories Permitted Compared to IV-B

No Exposed Timber Permitted

2025 AND BEYOND: PROJECTS RISING

Photo: Harbor Bay Real Estate Advisors, Image Fiction | Architect: Hartshorne Plunkard Architecture


TALL WOOD
LEGEND :
STORIES OF WOOD / MASS TIMBER
TOTAL STORIES OF BUILDING
/
WOODWORKS
WPC
WoodWorks is supporting 222 tall wood projects in design and 16 projects under construction or built.
8/8
CARBON12
Portland, OR
6/8
APEX PLAZA
Charlottesville, VA
8/9
INTRO, CLEVLAND
Cleveland, OH
19/25
ASCENT
Milwaukee, WI
3/10
80 M STREEET
Washintgon DC
7/7
11 E LENNOX
Boston, MA
7/8
MINNESOTA PLACES
Portland, OR
8/8
HEARTWOOD
Seattle, WA
16/19
1510 WEBSTER
Oakland, CA
12/15
BAKERS PLACE
Madison, WI
8/8
TIMBERVIEW
Portland, OR
12/12
2057 SW PARK
Portland, OR
6/6
BUNKER HILL HOUSING
Boston, MA
6/6
CANDLEWOODSUITES HOTEL
Liberty, NC
12/12
JULIA WEST
Portland, OR
25/31
THE EDISON
Milwaukee, WI
2016
2019
2020
2022
2023
2024
2025

11 E Lenox

Boston, MA

Monte French Design Studio
H+O Structural Engineers
Photo Jane Messinger

11 E Lenox

Boston, MA

43,000 sf, 7 stories wood

Type III-A with code modifications

Multi-Family

Completed 2023

Monte French Design Studio
H+O Structural Engineers
Photo Jane Messinger

Bunker Hill Housing Redevelopment – Stellata

Boston, MA

Architect: Stantec
Engineer: McNamara • Salvia
Photo: Courtesy Stantec

Bunker Hill Housing Redevelopment – Stellata

Boston, MA

- First of 15 residential buildings offering 2,699 units
- All buildings designed to Passive House standards
- Prefabricated Light Gauge metal and CLT panels

WOODWORKS

W | N PROFILE

Architect: Stantec
Engineer: McNamara • Salvia
Bryan Maltais with McNamara • Salvia

Ascent

Milwaukee, WI

Korb + Associates Architects
Thronton Tomasetti
Photo: C.D. Smith Construction

Ascent

Milwaukee, WI

493,000 sf, 25 stories total (19 mass timber)

Type IV-HT with code modifications

Multi-Family

Completed 2022

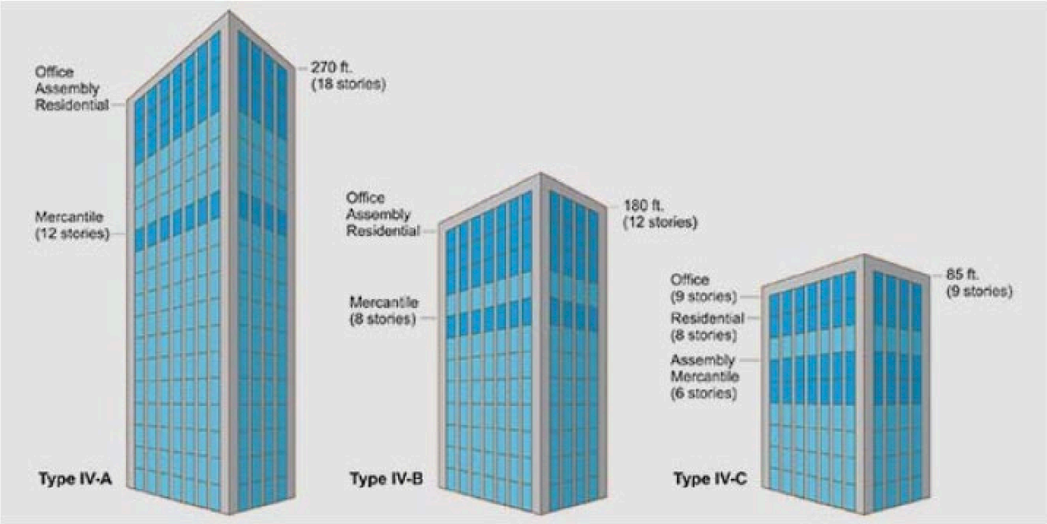
WN PROFILE

BUSINESS CASE STUDY

WOOD DESIGN AWARD WINNER

Korb + Associates Architects
Thronton Tomasetti
Photo: VRX Media Group

TALL MASS TIMBER RESOURCES



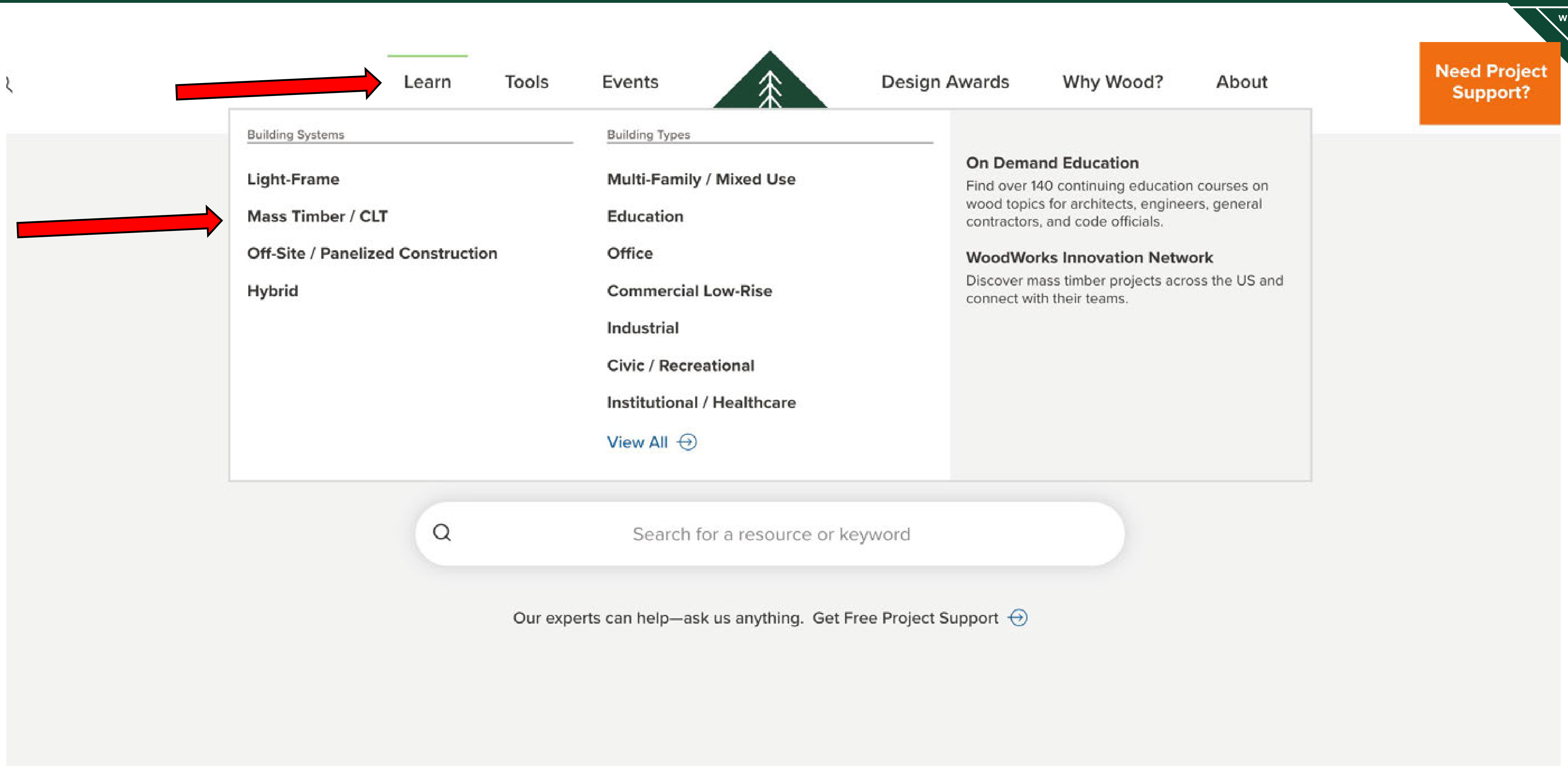
Tall Mass Timber

Code opportunities and requirements, FAQs, project examples and resources for teams interested in tall timber projects.

Learn More

www.woodworks.org/learn/mass-timber-clt/tall-mass-timber/

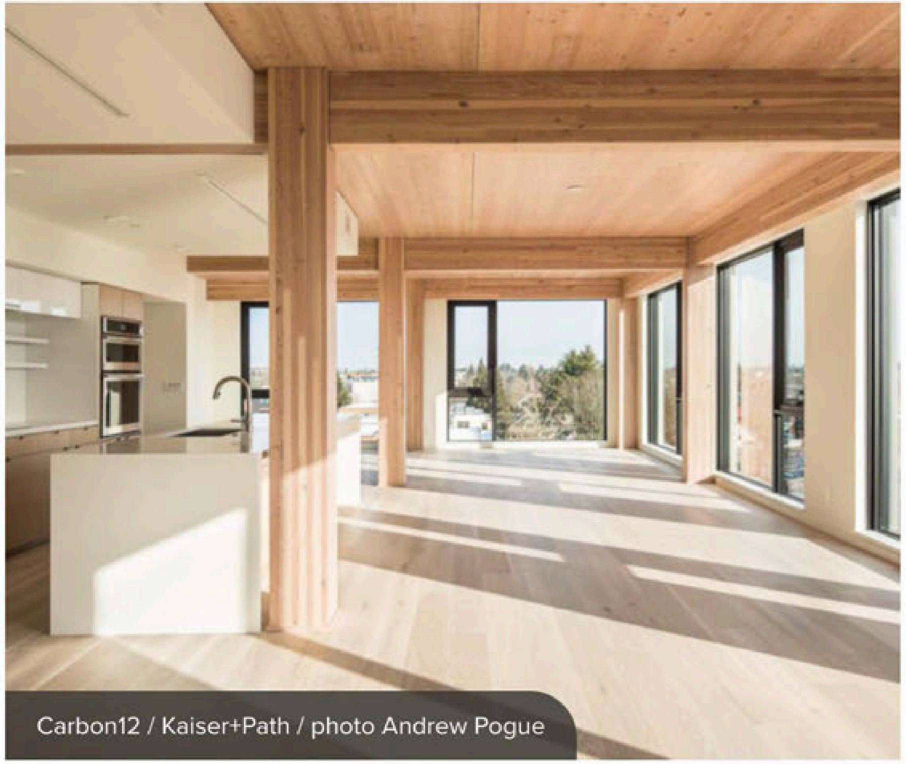
TALL MASS TIMBER RESOURCES



Woodworks.org > Learn > Mass Timber / CLT > Tall Mass Timber

TALL MASS TIMBER RESOURCES

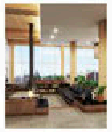
Technical Design Guidance from WoodWorks



Solution Papers

Tall Wood Buildings in the 2021 IBC – Up to 18 Stories of Mass Timber

Looking for information on the tall wood provisions in the 2021 International Building Code? This paper summarizes the provisions as well as the background and research that supported their adoption.

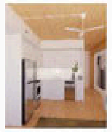


Demonstrating Fire-Resistance Ratings for Mass Timber Elements in Tall Wood Structures

Solution Papers

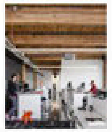
Shaft Wall Requirements in Tall Mass Timber Buildings

Solution Papers



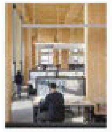
Concealed Spaces in Mass Timber and Heavy Timber Structures

Solution Papers



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

Solution Papers



Fire Design of Mass Timber Members: Code Applications, Construction Types and Fire Ratings

Solution Papers

TALL MASS TIMBER RESOURCES

Answers to Tall Mass Timber FAQs

5. How are design teams leveraging tall mas timber code provisions to maximize the amount of timber exposure?

Follow this link for an article that discusses how teams are utilizing the new code provisions to enhance the appearance of their tall mas timber structures with exposed timber framing.

6. I've heard that the 2024 IBC will allow 100% timber ceiling exposure in type IV-B, up to 12 stories tall. Is that code language finalized?

Yes, the 2024 IBC will include new code changes, which have been approved and will be incorporated, which allow timber ceiling exposure in Type IV-B construction up to 100%. The new code language as it will read in the 2024 IBC is available here. Several jurisdictions such as the City of Denver, City of Dallas, State of Oregon and State of Washington are already in the process of incorporating these new timber exposure limits in their building codes, and several design teams are looking to utilize the new limits in project-specific discussions with their local building officials. Reach out to your local WoodWorks Regional Director to see how projects in your area can approach these design topics.

TALL MASS TIMBER RESOURCES

Articles and Expert Tips

Learn Tools Events Award Gallery Why Wood? About

Need Project Support?

Expert Tips

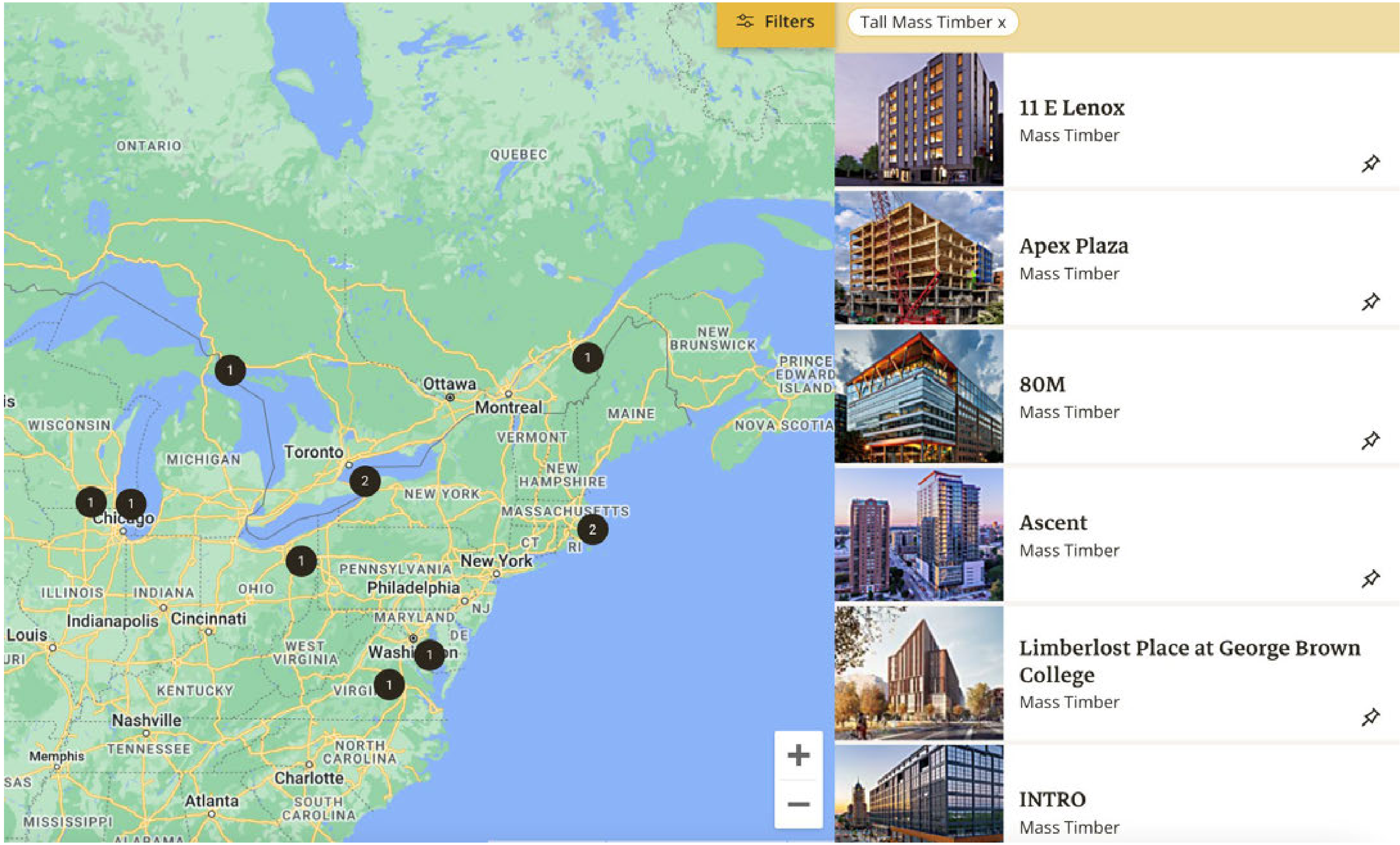
Tall Mass Timber Trends and Exposed Timber Allowances

Recent code changes and jurisdictional approvals provide for greater areas of exposed mass timber.

Share

TALL MASS TIMBER RESOURCES

Interactive Tall Mass Timber Project Map



TALL MASS TIMBER RESOURCES

Filter by Tall Mass Timber Projects

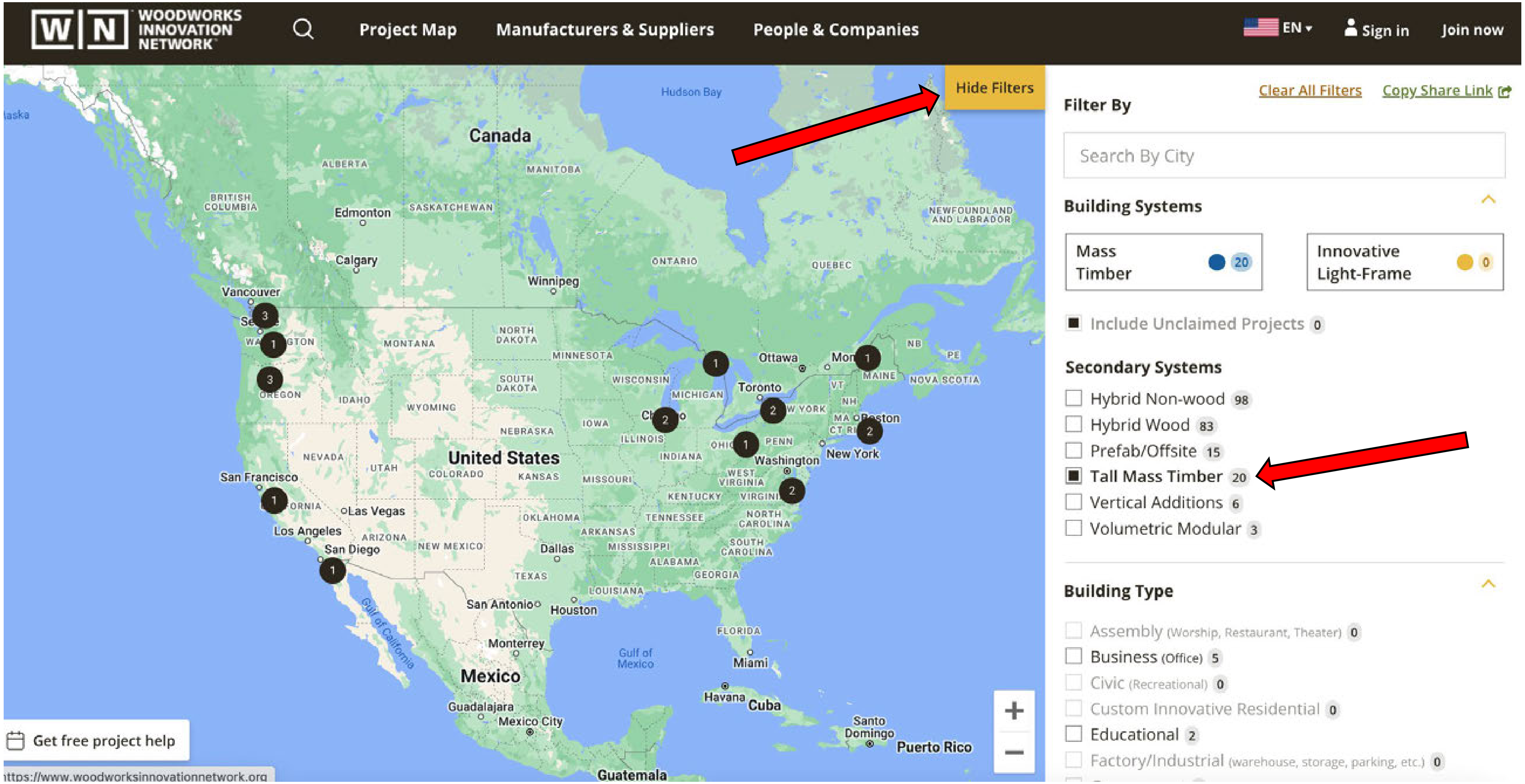



Photo: Harbor Bay Real Estate Advisors, Purple Film

WOODWORKS
WOOD PRODUCTS COUNCIL

Differential Material Movement in Tall Mass Timber Structures

Patrick Duffy, PE

Tall Mass Timber: New Opportunities, New Engineering Solutions

Vertical Movements of Timber Elements, Relative to Other Elements


Photo: H+O Structural Engineering, Kure Creative


Photo: Swinerton

Vertical Movements in Tall Mass Timber: Outline

- Codes & Referenced Standards
- Sources of Vertical Movement
- Detailing to Minimize & Accommodate Movements
- Calculations vs. On-site Measured Movements

INTRO, Cleveland, OH, Photo: Harbor Bay Real Estate Advisors, Purple Film

Building Codes and Standards

IBC

References Material Standards (NDS) and Product Standards (PRG 320, ANSI 190.1)

IBC 2304.3.3 requires assessment of shrinkage effects on systems such as roof drainage, electrical, mechanical, and other equipment

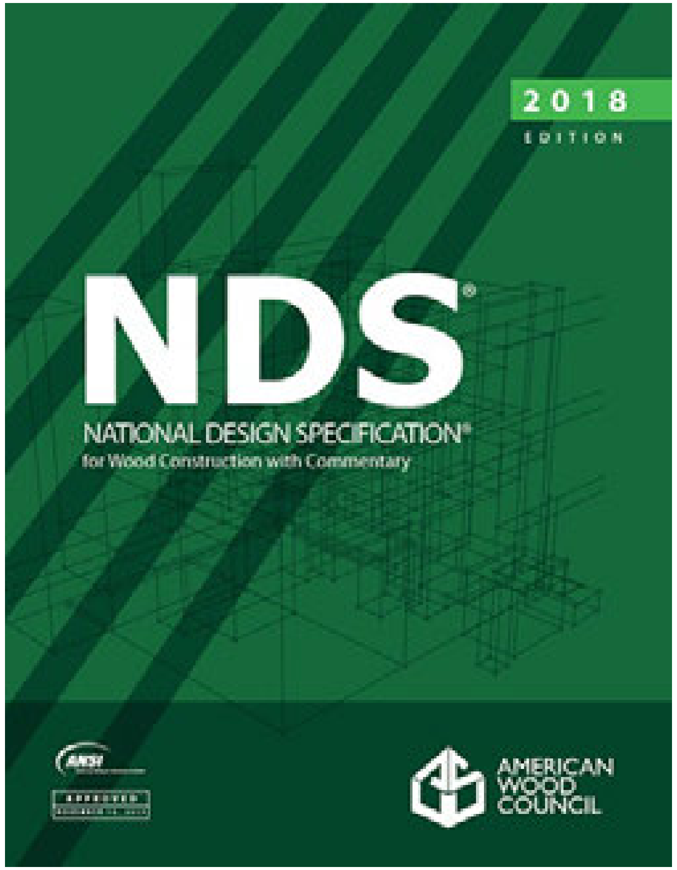
Building Codes and Standards

NDS

Design properties for wood members and connections

Includes properties for calculation of perpendicular to grain loading, resulting in crushing

Creep effects on bending members



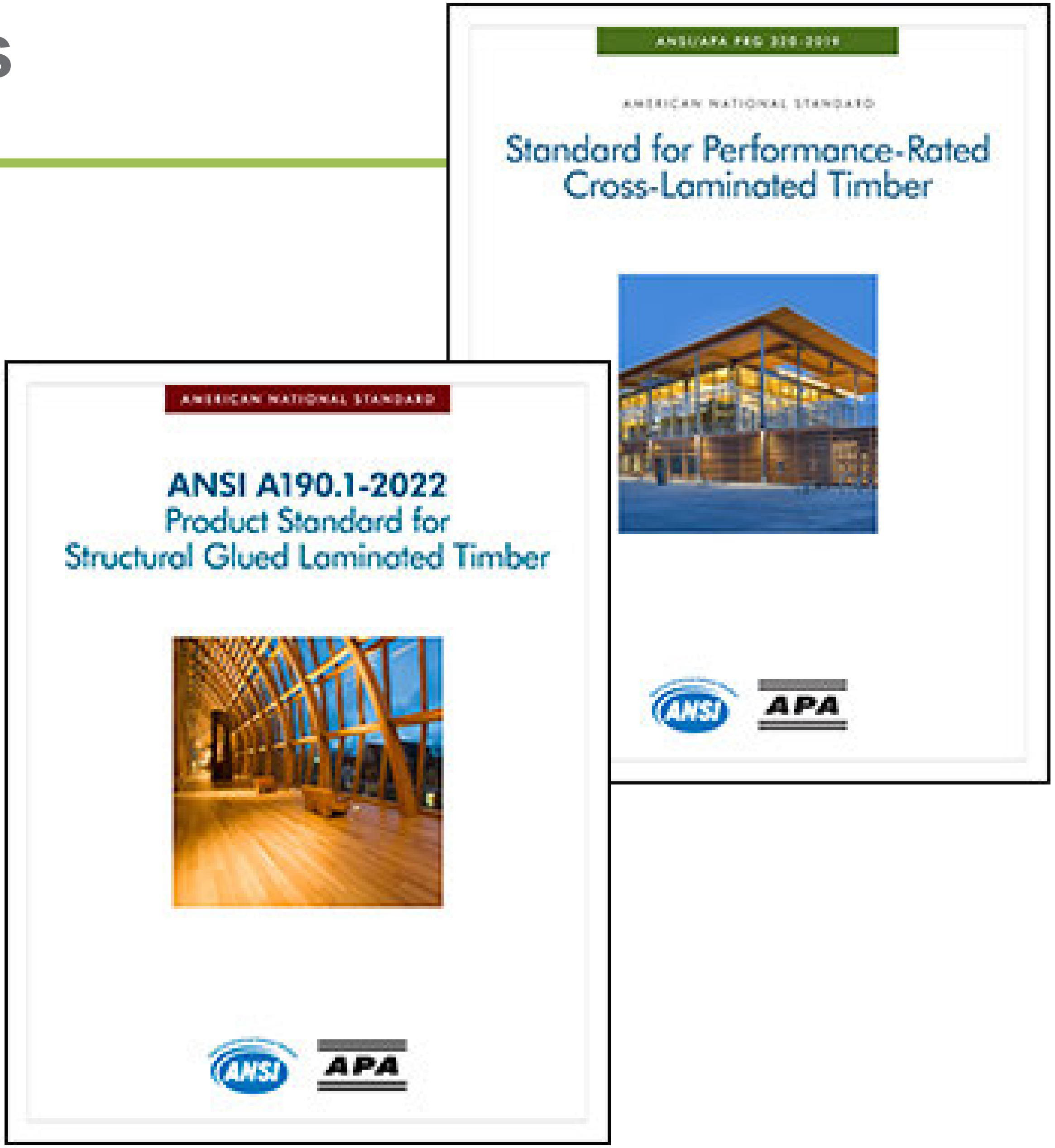
Building Codes and Standards

Mass Timber Product Standards

Product tolerances & MC at time of manufacturing

EG. CLT panel width +/- 1/8”
CLT panel length +/- ¼”
Glulam columns up to 20 ft long +/- 1/16”

ANSI A190.1: lumber used in glulam max MC = 16% at the time of bonding

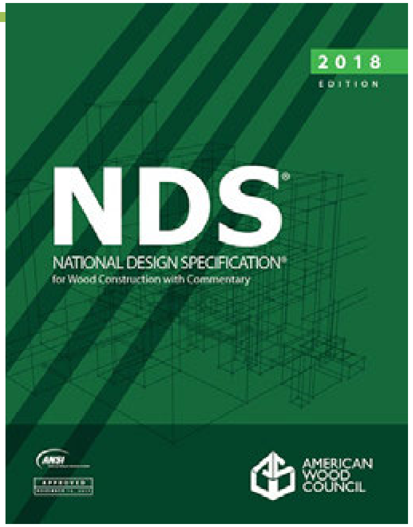


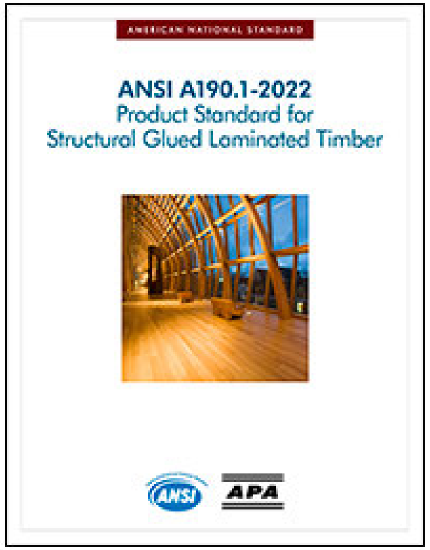
Building Codes and Standards

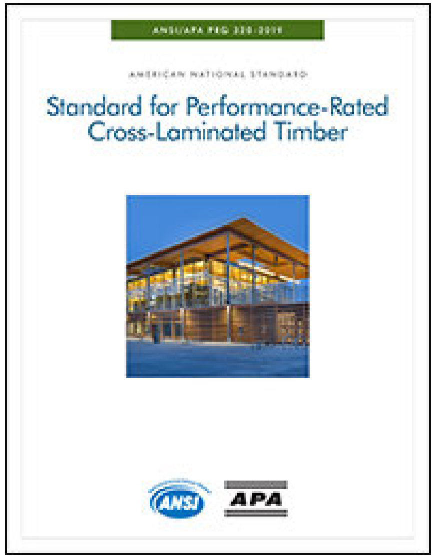
What’s not addressed?

- Calculations for shrinkage
- Creep factor for column axial shortening
- Connection settlements

Engineering judgement is necessary. The following information notes several possible methods, it is not intended to cover all options or solutions







Quantifying Vertical Movement

Movement Types

- Column Axial Shortening including Creep
- Column Axial Shrinkage
- Panel & Beam Shrinkage
- Panel & Beam Crushing
- Beam Shortening
- Tolerances & Joint Settlements

Photo: Alex Nye

Quantifying Vertical Movement

Column Axial Shortening

$$\Delta_{as} = PL/AE$$

Where:

- Δ_{as} = column axial shortening (in.)
- P = axial load supported by the column (lbs)
- L = length of the column (in.)
- A = cross sectional area of the column (in.^{2})
- E = modulus of elasticity of the column (psi)

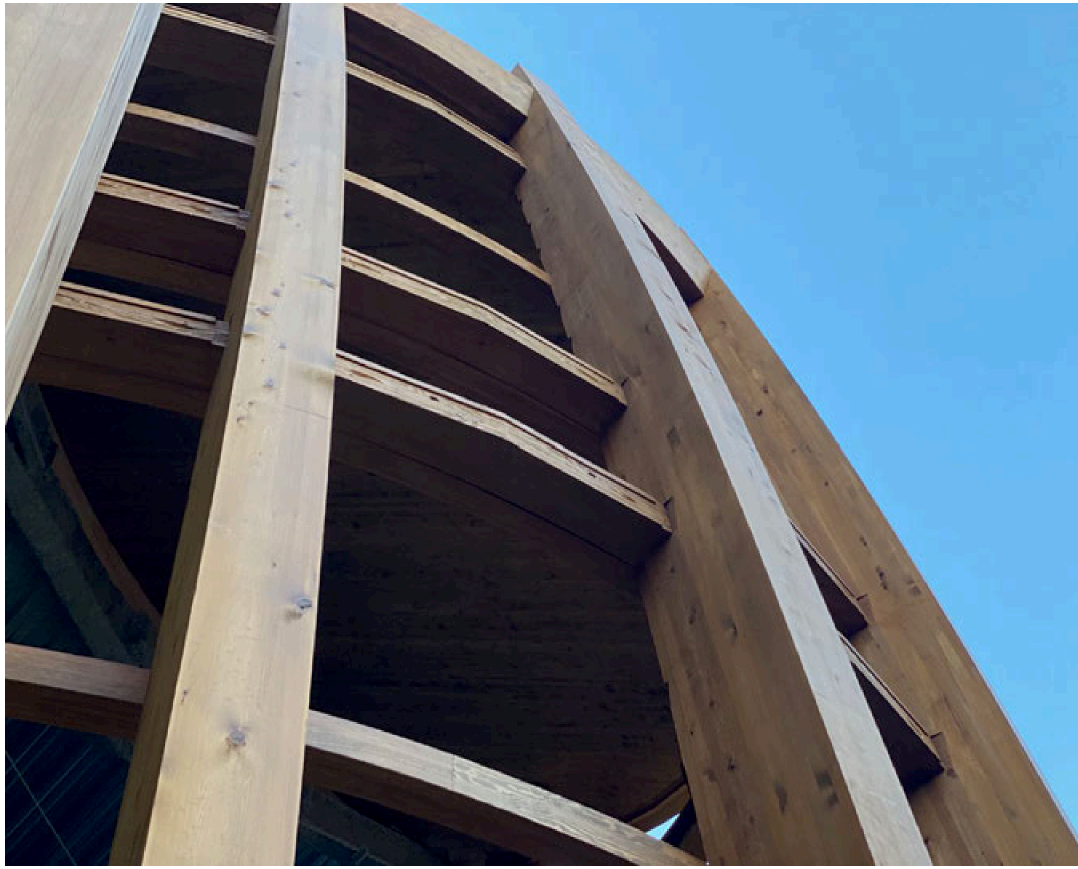


Photo: WoodWorks

Quantifying Vertical Movement

Column Axial Shortening

Design example:

- Axial load of 45,000 lbs (20,000 lbs dead load, 25,000 lbs live load, duration of load factor = 1.0)
- Assume an 8-3/4-in. x 9-in. Douglas-fir glulam column, layup combination 2
- Column length = 15 feet
- F'_c = 1,950 psi
- E = 1,600,000 psi

$\Delta_{as} = PL/AE$ = (45,000)(15*12)/(8.75*9)(1,600,000) = 0.06 in.

Photo: WoodWorks

Not accounting for creep effects

Quantifying Vertical Movement

Column Axial Shortening Including Creep Effects

Equation 3.5-1 in the NDS provides a method of quantifying the deformation effects of long-term loading on bending members.

$$\Delta_{as,T} = K_{CR}\,\Delta_{LT} + \Delta_{ST}$$

Where:

- $\Delta_{as,T}$ = column axial shortening including creep effects (in.)
- K_{CR} = time-dependent deformation creep factor
  - If we assume the creep factor for axial compression is the same as for bending, K_{CR} = 1.5 for seasoned timbers, glulam or SCL used in dry service conditions.
- Δ_{LT} = immediate deformation due to long-term loading (in.)
- Δ_{ST} = deformation due to short-term loading (in.)

Quantifying Vertical Movement

Column Axial Shortening Including Creep Effects

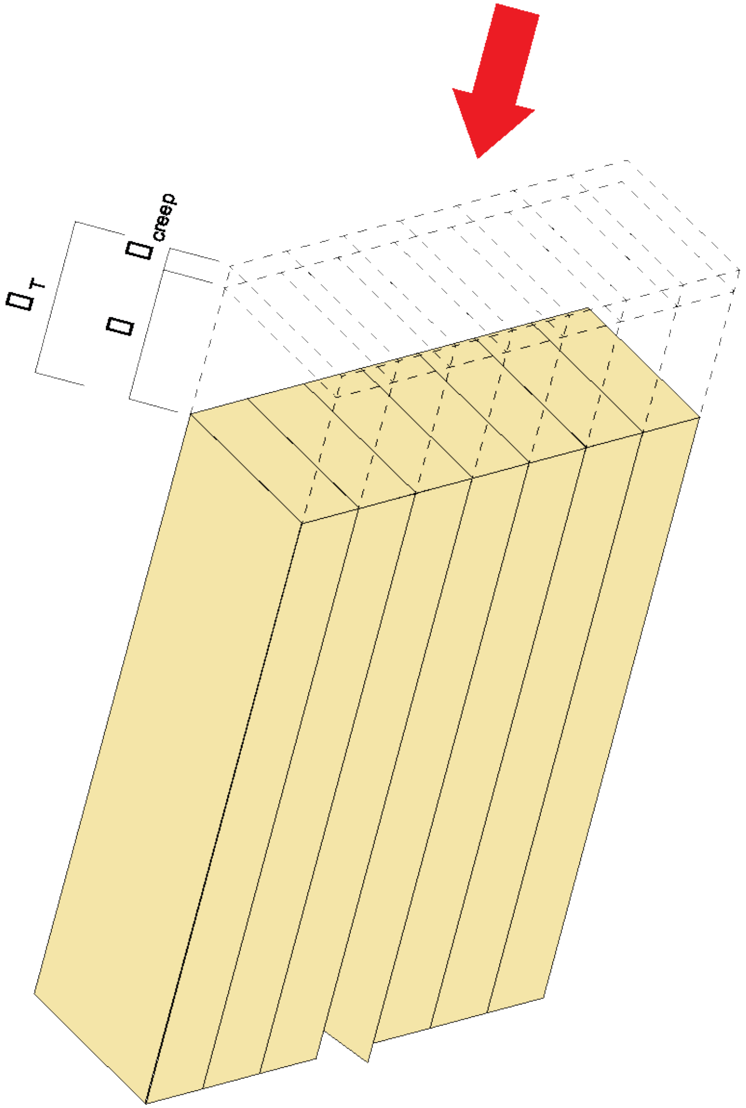
For the column in the above example, the 20,000 lbs axial dead load on the column is the long-term load, and the 25,000 lbs axial live load is the short-term load. If one applies this creep deformation equation to axial column shortening, accounting for long-term creep effects, the total anticipated axial column shortening in this example would be:

$$\Delta_{as,T} = (1.5)(0.06)(20{,}000/45{,}000) + (0.06)(25{,}000/45{,}000) = 0.07 \text{ in.}$$

(0.01 in of this total is from creep)

Quantifying Vertical Movement

Figure 3
Shortening of glulam columns



Column Axial Shortening Including Creep Effects

0.01 in creep
0.06 in non-creep
0.07 in total

Quantifying Vertical Movement

Column Axial Shortening

Impact of fire-resistance ratings

$$\Delta_{as} = PL/AE$$

A column that is ‘oversized’ to provide a FRR will have a larger cross section for the same load, resulting in less axial shortening

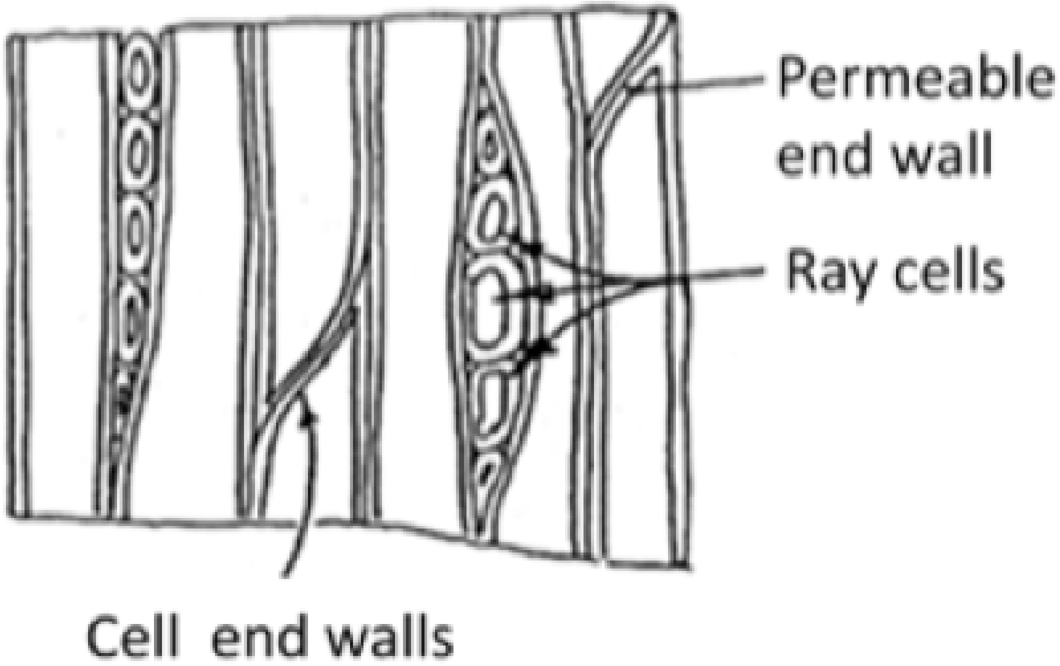
Photo: David Barber, Arup

Quantifying Vertical Movement

Column Axial Shrinkage

Wood is a hygroscopic material

- Has the ability to take on or give off moisture – acclimates to its surrounding conditions



Quantifying Vertical Movement

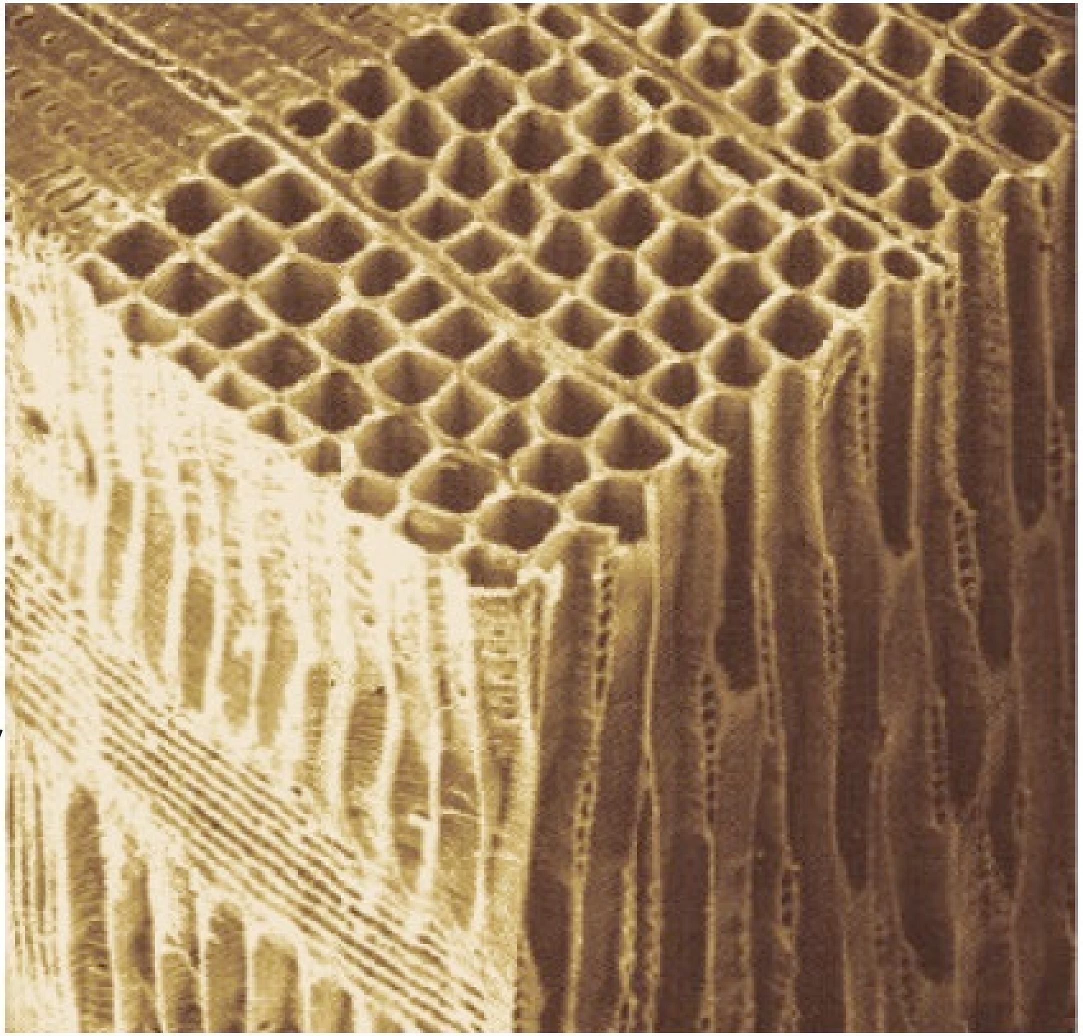
Column Axial Shrinkage

Water exists in wood in two forms:

- Free Water – water in cell cavity
- Bound Water – water bound to cell walls

Fiber Saturation Point (FSP):

- Point at which cell walls are completely saturated but cell cavities are empty (i.e. no free water but still has all its bound water)

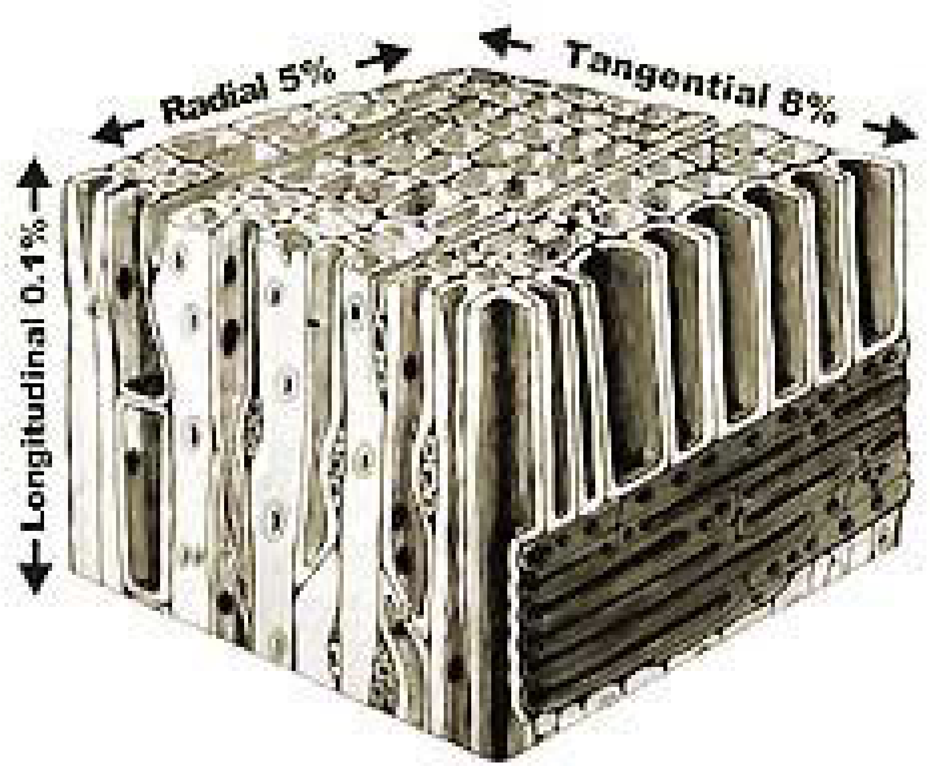


Southern yellow pine cellular makeup

Source: USDA Forest Service Agricultural Handbook (1972)

Quantifying Vertical Movement

Column Axial Shrinkage



When does wood shrink?

- After MC drops below FSP – bound water is removed

Why does wood shrink?

- Loss of moisture bound to cell wall changes thickness of cell wall

Is shrinkage uniform across all dimensions of a piece of lumber?

- No…

Quantifying Vertical Movement

Column Axial Shrinkage

Wood is orthotropic, meaning it behaves differently in its three orthogonal directions: Longitudinal (L), Radial (R), and Tangential (T)

- Longitudinal shrinkage is usually considered negligible in low- and mid-rise wood buildings
- In tall mass timber structures, effects can accumulate, should consider impacts

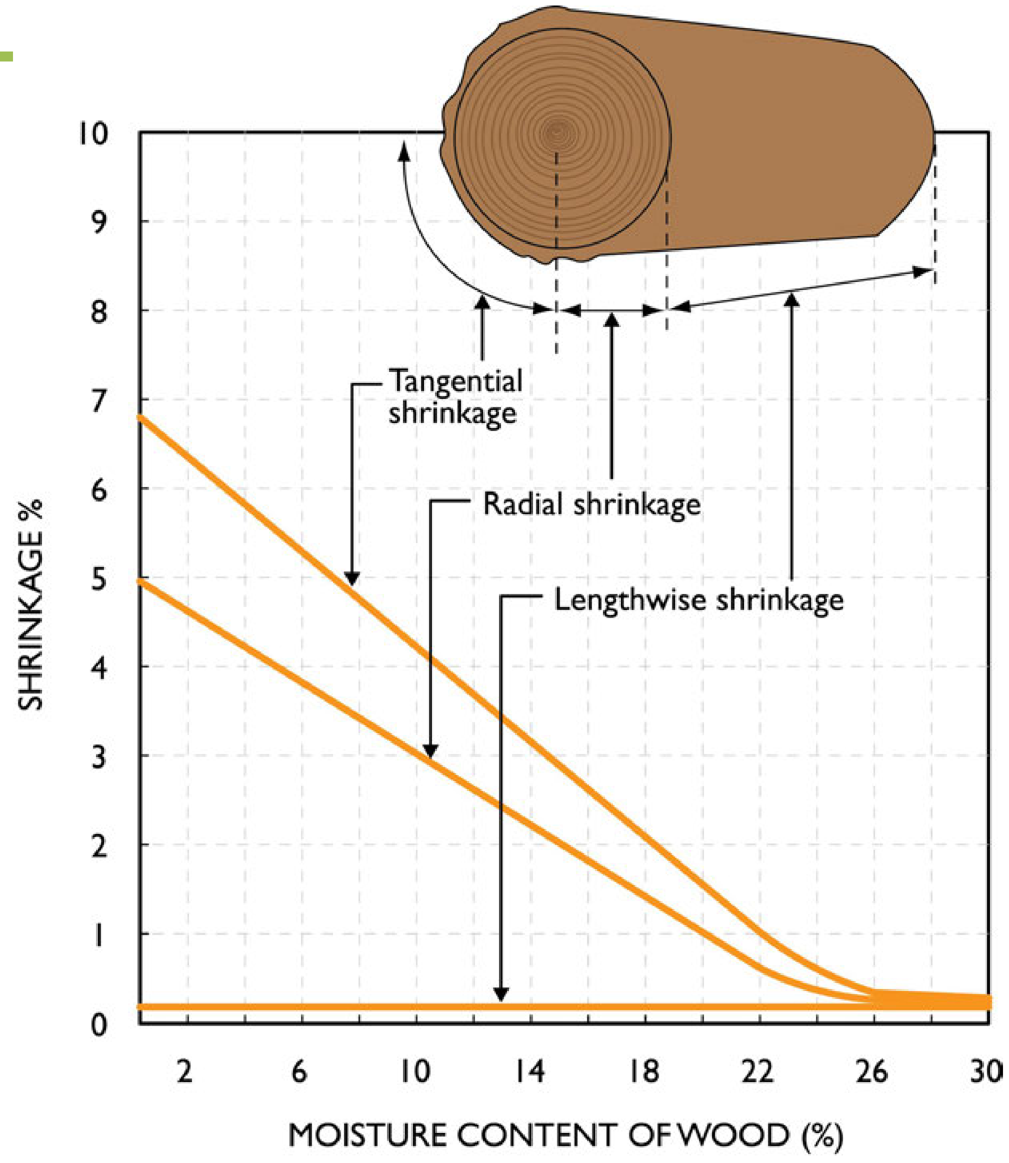


Image: RDH Building Science, Inc.

Quantifying Vertical Movement

Column Axial Shrinkage

Longitudinal shrinkage approximately 0.1% to 0.2%

Assuming an avg. of 0.15%, and a fiber saturation point (FSP) of MC = 28%, this results in a coefficient of longitudinal shrinkage of:

0.0015 / 28 = 0.000054

INTRO, Cleveland, OH, Photo: Harbor Bay Real Estate Advisors, Purple Film

Quantifying Vertical Movement

Column Axial Shrinkage

0.000054 is the amount of longitudinal shrinkage per inch of column length per % of MC change.

Using the column from the example earlier in this document, assume an 8-3/4-in. x 9-in. column, 15 ft long, with installed MC of 19% and EMC of 12%. Calculated longitudinal column shrinkage is:

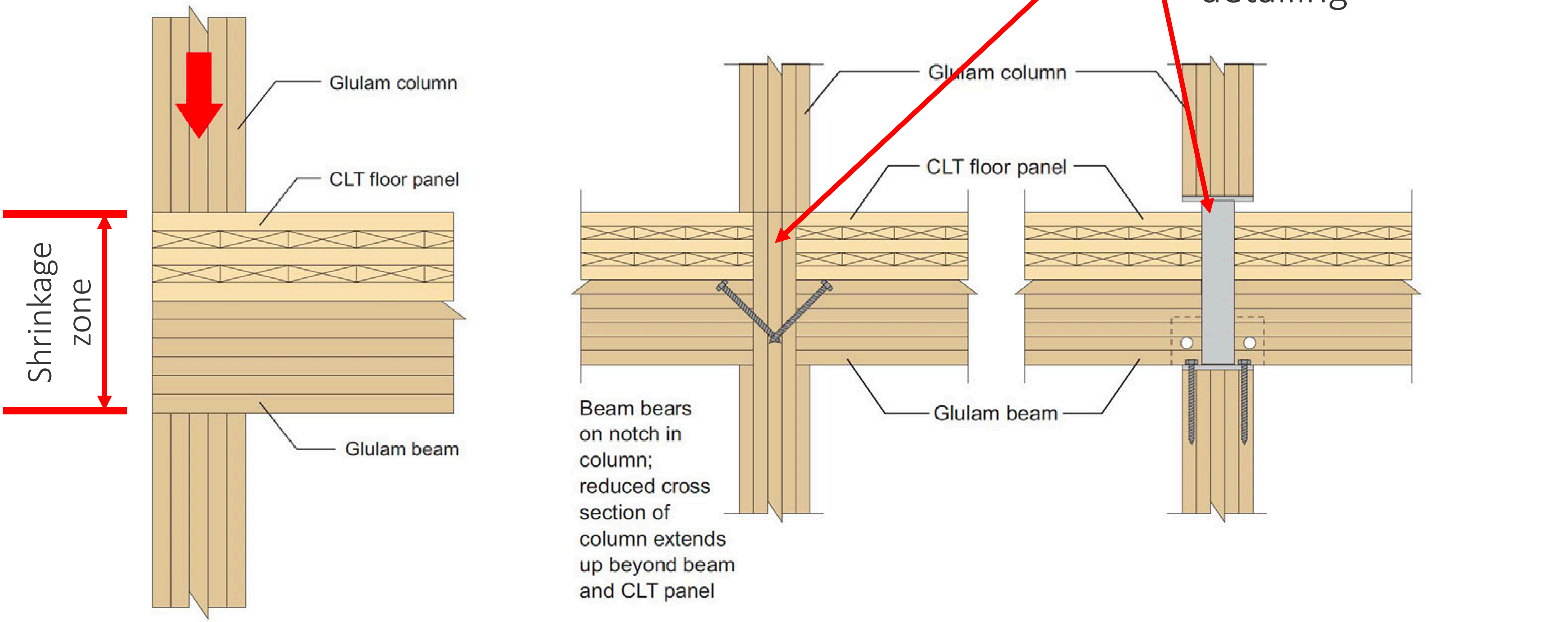
Column Length:

$$\Delta_{shrinkage} = (15\text{ ft})(12\text{ in./ft})(0.000054)(19-12) = 0.07\text{ in.}$$

Quantifying Vertical Movement

Beam Shrinkage

Beam shrinkage zone eliminated by detailing



Quantifying Vertical Movement

Beam Shrinkage

Longitudinal shrinkage approximately 0.1% to 0.2%

Radial & Tangential (cross-grain) shrinkage approximately 5% to 7%

Coefficient of cross-grain shrinkage = 0.07 / 28 = 0.0025

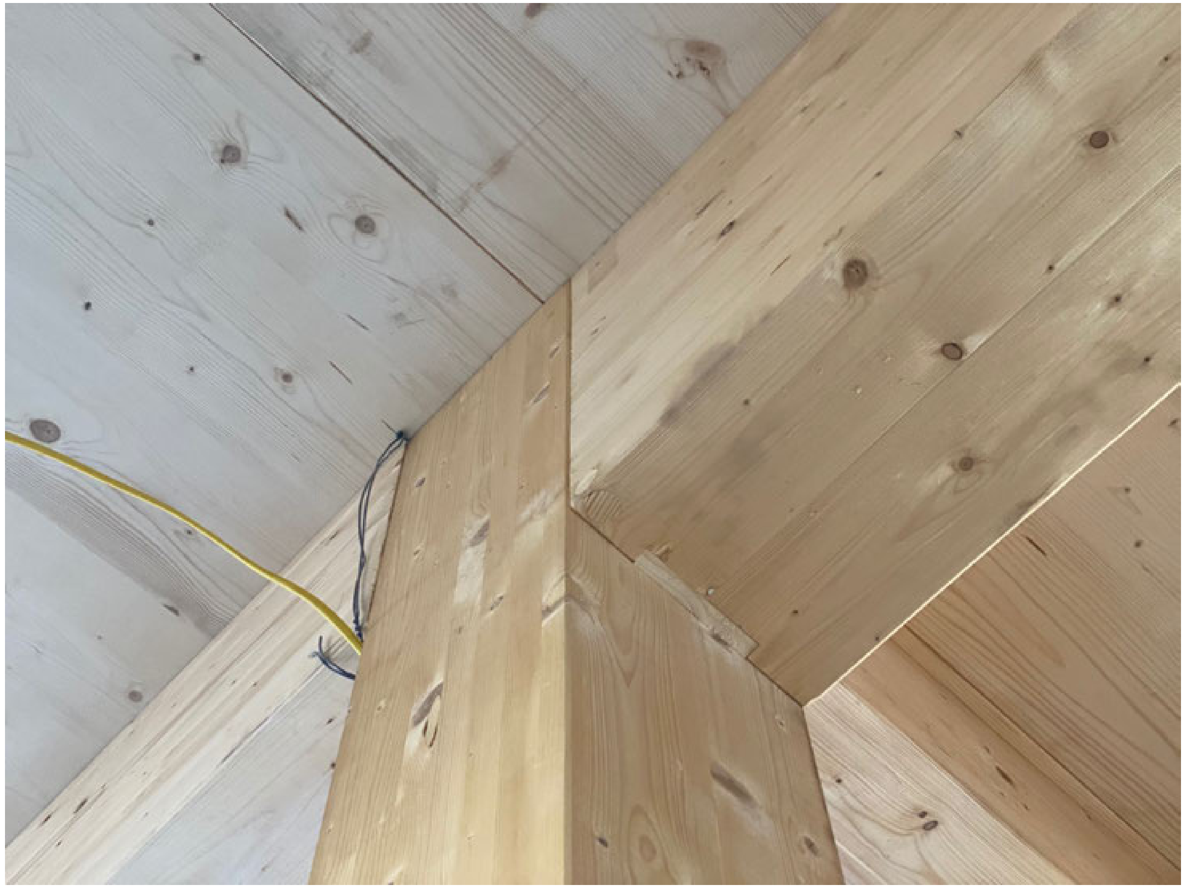


Photo: WoodWorks

Quantifying Vertical Movement

Beam Shrinkage

Beam to column connection not detailed to eliminate shrinkage:

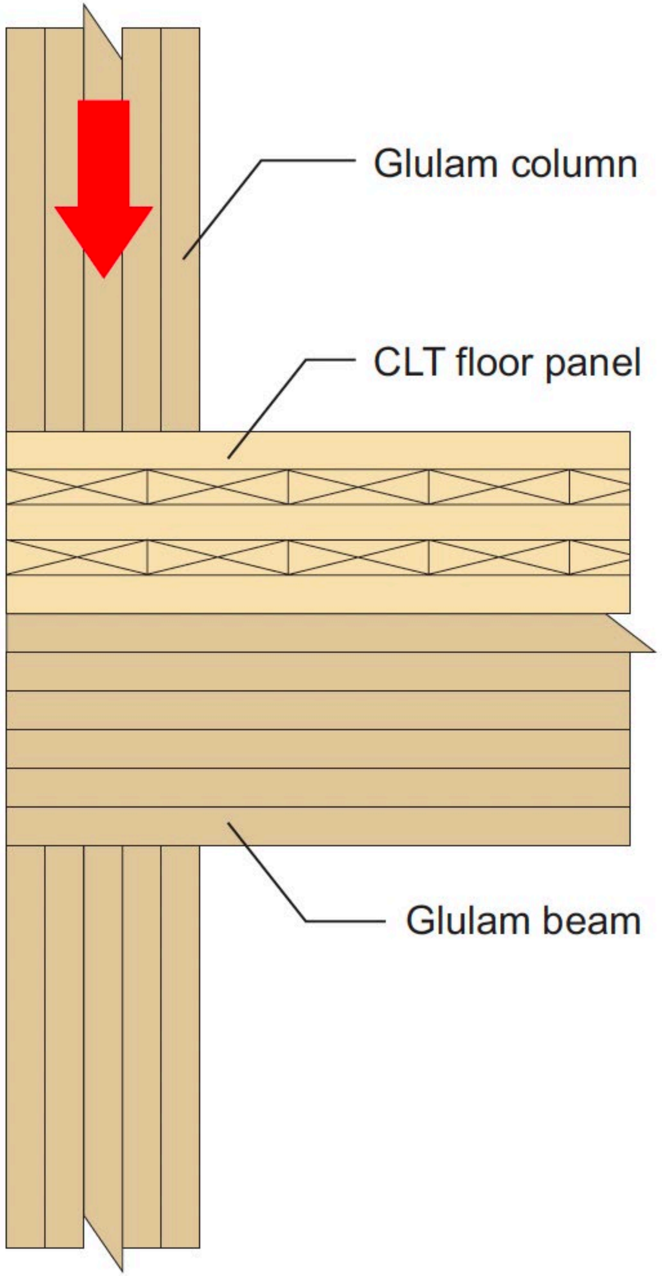
For example, an 8-3/4-in. x 24-in. glulam beam with an installed MC of 19% and EMC of 12% would have an anticipated shrinkage of:

Beam depth:

$\Delta_{shrinkage}$ = (24 in.)(0.0025)(19-12) = 0.42 in.

Beam width:

$\Delta_{shrinkage}$ = (8.75 in.)(0.0025)(19-12) = 0.15 in.



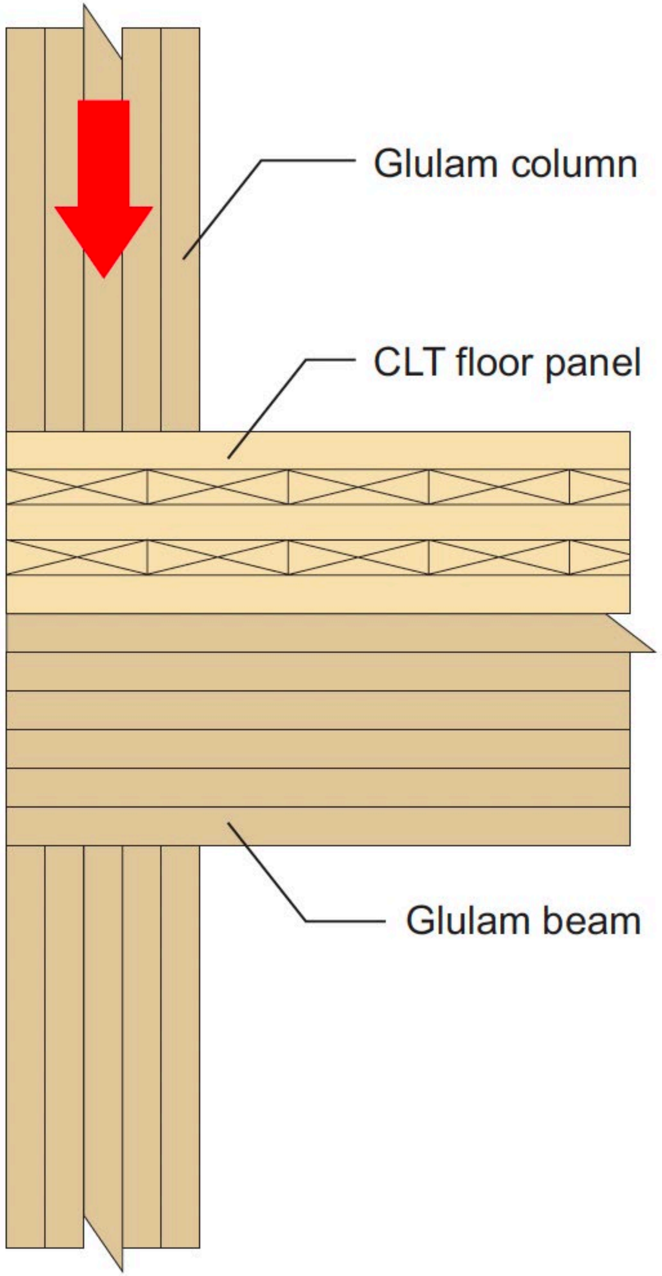
Quantifying Vertical Movement

Panel Shrinkage

Some engineers may also choose to account for panel shrinkage if not isolated from shrinkage zone:

Assume 5-ply mass timber panel, 6-7/8" thick:

$\Delta_{shrinkage}$ = (6.875 in.)(0.0025)(19-12) = 0.12



Quantifying Vertical Movement

Beam & Panel Shrinkage

On-site moisture protection measures directly impact column & beam shrinkage

Recall that one of the variables in the shrinkage equation is installed MC. The lower this is, the closer it will be to equilibrium MC, which results in less shrinkage

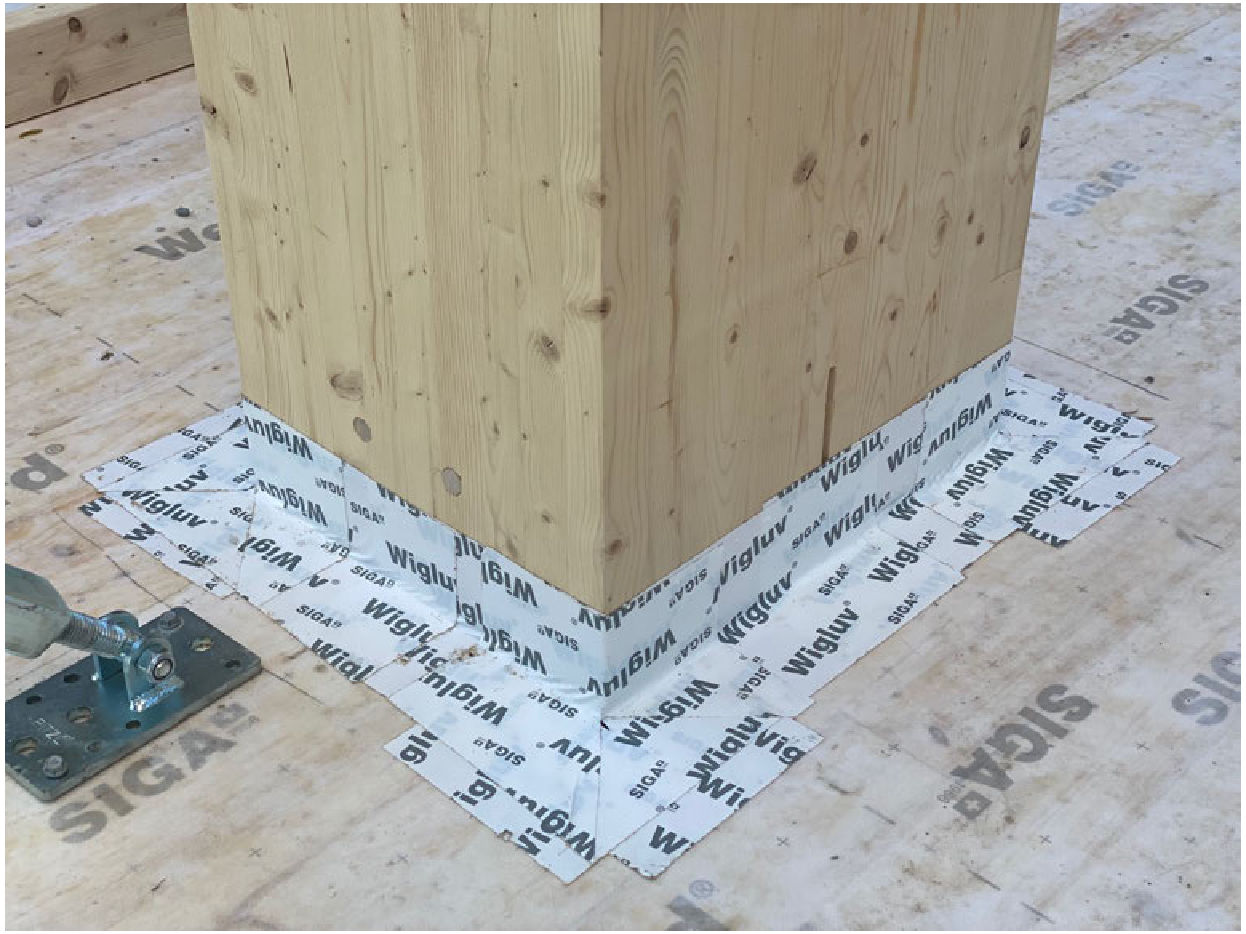


Photo: WoodWorks

Quantifying Vertical Movement

On-Site Moisture Protection Strategies to Minimize Column, Beam & Panel Shrinkage

- Plan Early
- Risk Evaluation
- Develop Construction Phase Plan
- Execute the Design and Moisture Management Plan
- Monitor

RDH Moisture Management Guide 1st Ed

Photo: Swinerton

Material Environmental Exposure and Moisture Management

Enroute
Onsite
Post-Install
Other Material

Photo: Alex Schreyer

Quantifying Vertical Movement

On-Site Moisture Protection Strategies to Minimize Column, Beam & Panel Shrinkage

Quantifying Vertical Movement

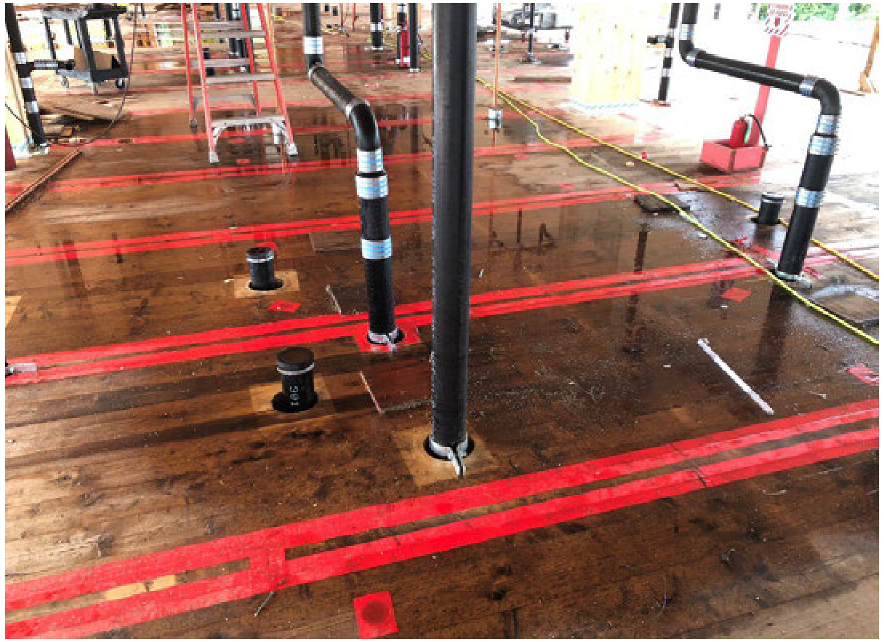
On-Site Moisture Protection Strategies to Minimize Column, Beam & Panel Shrinkage

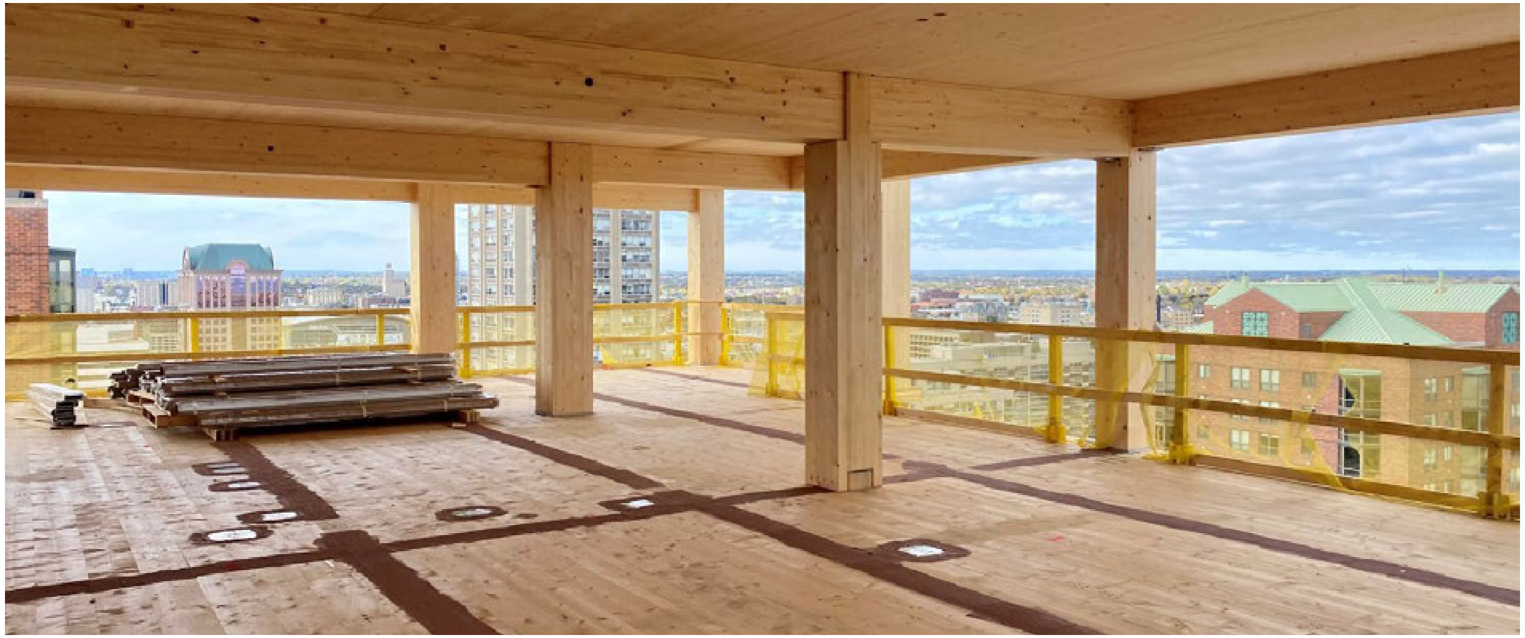

On-Site Considerations

On Site Considerations

Quantifying Vertical Movement

On-Site Moisture Protection Strategies to Minimize Column, Beam & Panel Shrinkage





Quantifying Vertical Movement

Faster timber & enclosure install aids in minimizing moisture increase

Photo: WoodWorks

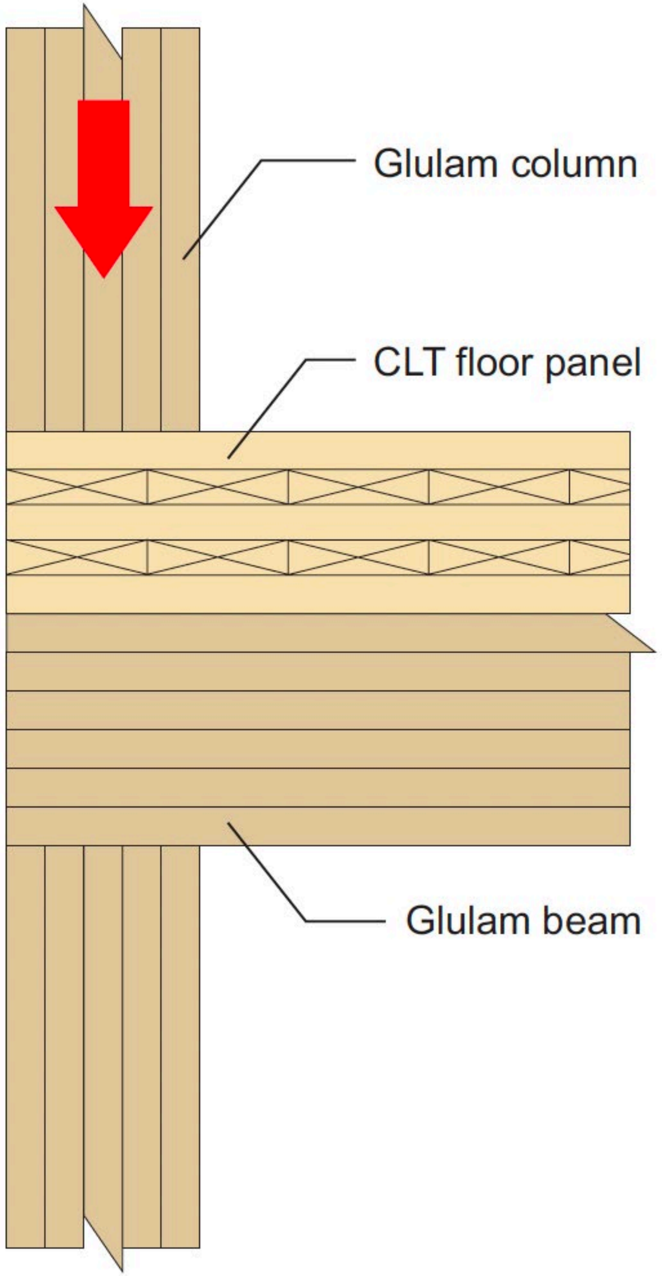
Quantifying Vertical Movement

Beam Crushing

Limiting perp to grain stresses in bearing (eg. column bearing top of beam or panel) results in small amounts of localized crushing

Crushing at 73% of allowable perpendicular-to-grain stress is 0.02 in.

Crushing at 100% of allowable perpendicular-to-grain stress is 0.04 in.



Quantifying Vertical Movement

Beam Crushing

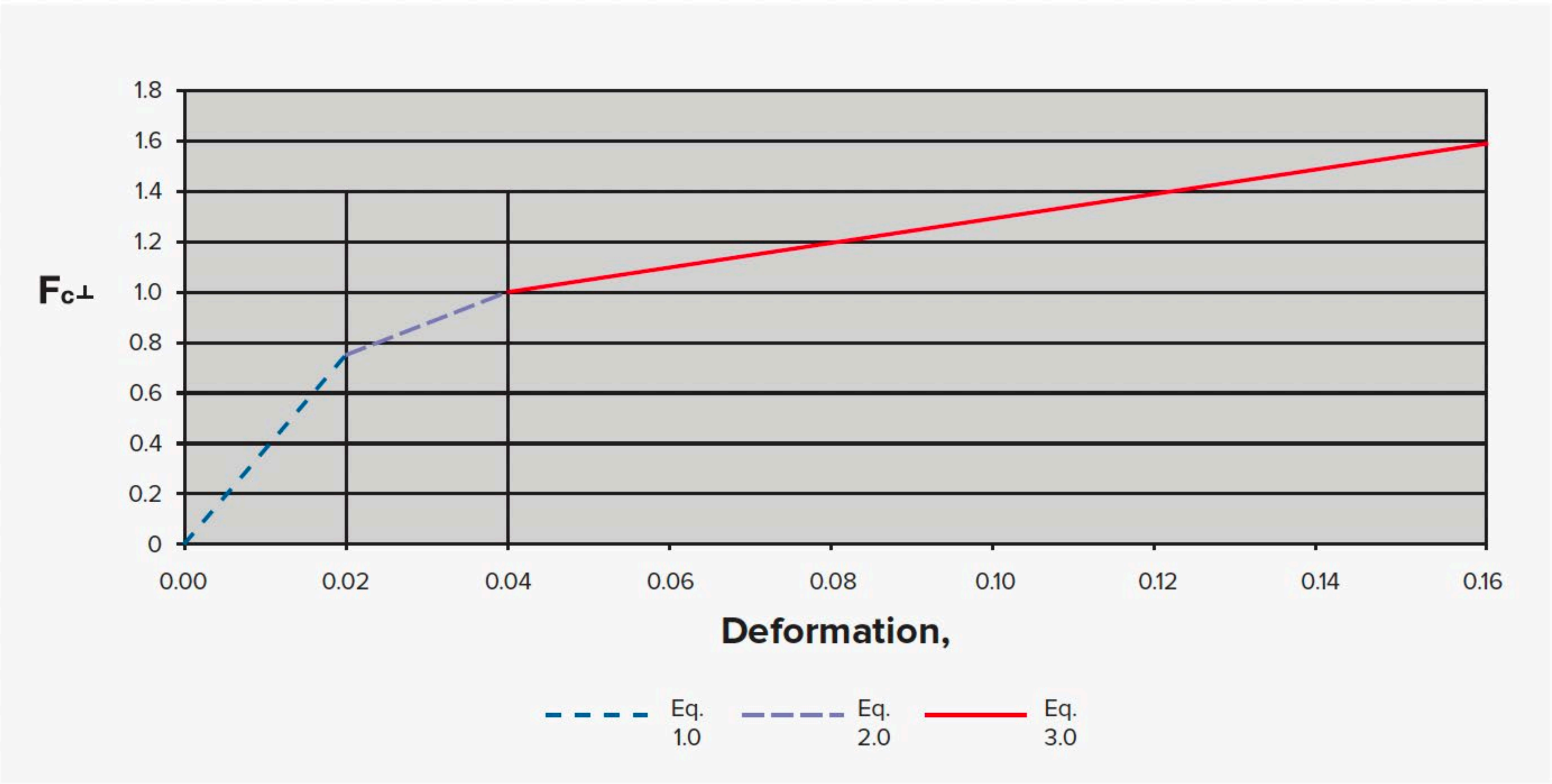


FIGURE 7: Fc⊥ load deformation curve
SDPWS Commentary Example C4.3.4-2 and SDPWS Commentary Reference 67

Quantifying Vertical Movement

Beam Crushing

Where: $f_{c\perp} \leq F_{c\perp 0.02\text{ in}}$

$$\Delta = 0.02 \text{ x} \left(\frac{f_{c\perp}}{F_{c\perp 0.02\text{ in.}}}\right)$$

Where: $F_{c\perp 0.02\text{ in.}} < f_{c\perp} < F_{c\perp 0.04\text{ in.}}$

$$\Delta = 0.04 - 0.02 \text{ x} \frac{1 - \left(\frac{f_{c\perp}}{F_{c\perp 0.04\text{ in.}}}\right)}{0.27\text{ in.}}$$

Where: $f_{c\perp} > F_{c\perp 0.04\text{ in.}}$

$$\Delta = 0.04 \text{ x} \left(\frac{f_{c\perp}}{F_{c\perp 0.04\text{ in.}}}\right)^3$$

Where:

Δ = deformation, in.

$f_{c\perp}$ = induced stress, psi

$F_{c\perp 0.04\text{ in.}} = F_{c\perp}$ = reference design value at 0.04 in. deformation, psi ($F_{c\perp}$)

$F_{c\perp 0.02\text{ in.}}$ = reference design value at 0.02 in deformation, psi ($0.73\, F_{c\perp}$)

Quantifying Vertical Movement

Beam Crushing

Assume the column in this design example bears on top of an 8-3/4-in. wide x 24-in. deep glulam beam. $F'_{c,perp}$ = 650 psi. The perpendicular-to-grain stress on top of the beam is:

$F_{c,perp}$ = 45,000 lbs/(8.75)(9) = 571 psi

And the resulting crushing is:

Stress ratio = 571/650 = 0.88. Therefore, use equation 2.0 to calculate crushing:

$\Delta_{crushing}$ = (0.04 - (0.02)((1-(571/650))/0.27)) = 0.03 in. ← Per bearing interface

$\Delta_{crushing}$ = (0.03)(2) = 0.06 in. ← 2x bearing interfaces

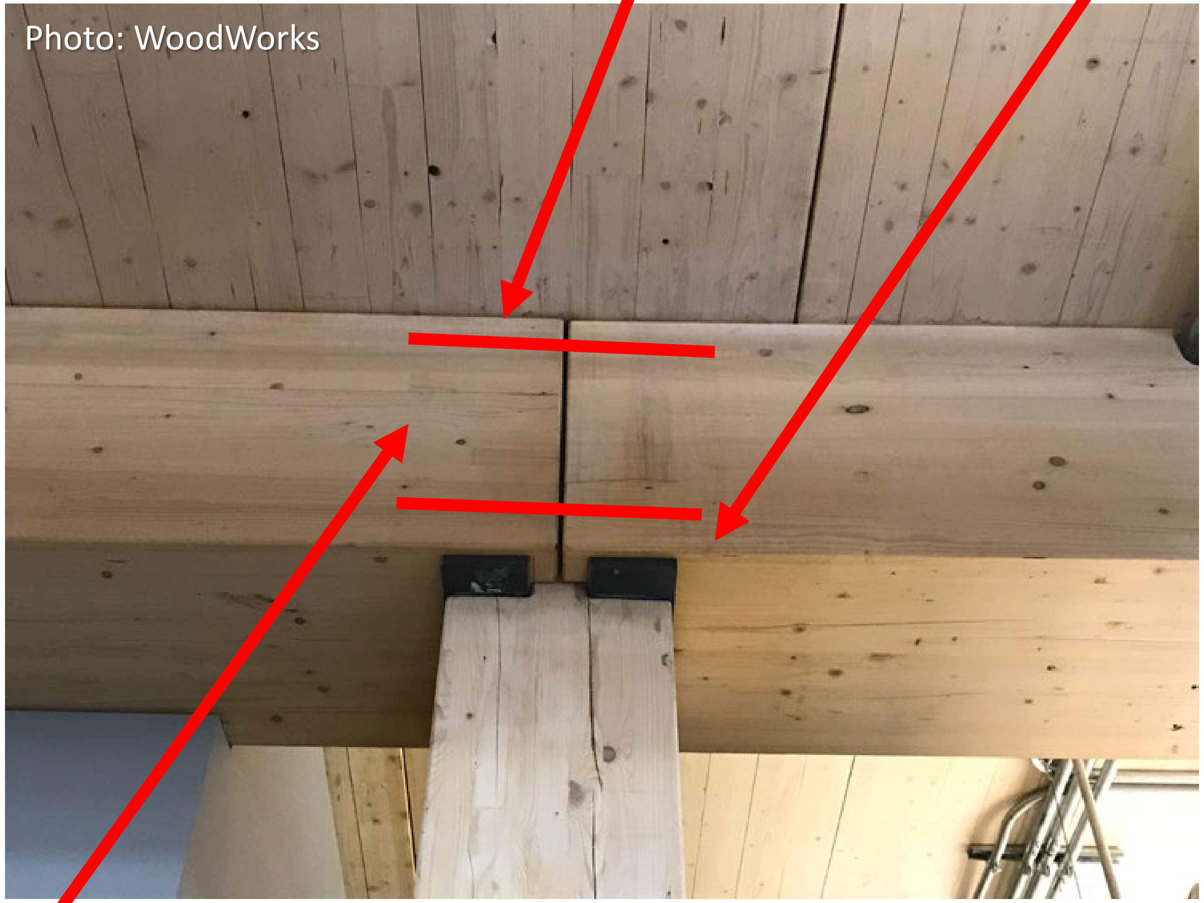
Quantifying Vertical Movement

Beam Shrinkage, Crushing & Shortening

Crushing commonly assumed to occur within 2” of top and bottom of beam

What about the short “column” in between?

Can still be subject to shortening in a similar manner to PL/(AE) of columns



Beam Shortening

PL/(AE):

- P is the applied load
- L is the remaining core beam depth (total beam depth minus 2-in. each top and bottom)
- A is the area of the column bearing on the beam (influenced area of the beam core may be increased 2-in. each direction, not to exceed beam edges)
- E is E of the beam divided by 30
    - E/30 term is an estimate derived from ASTM D2555 for clear wood

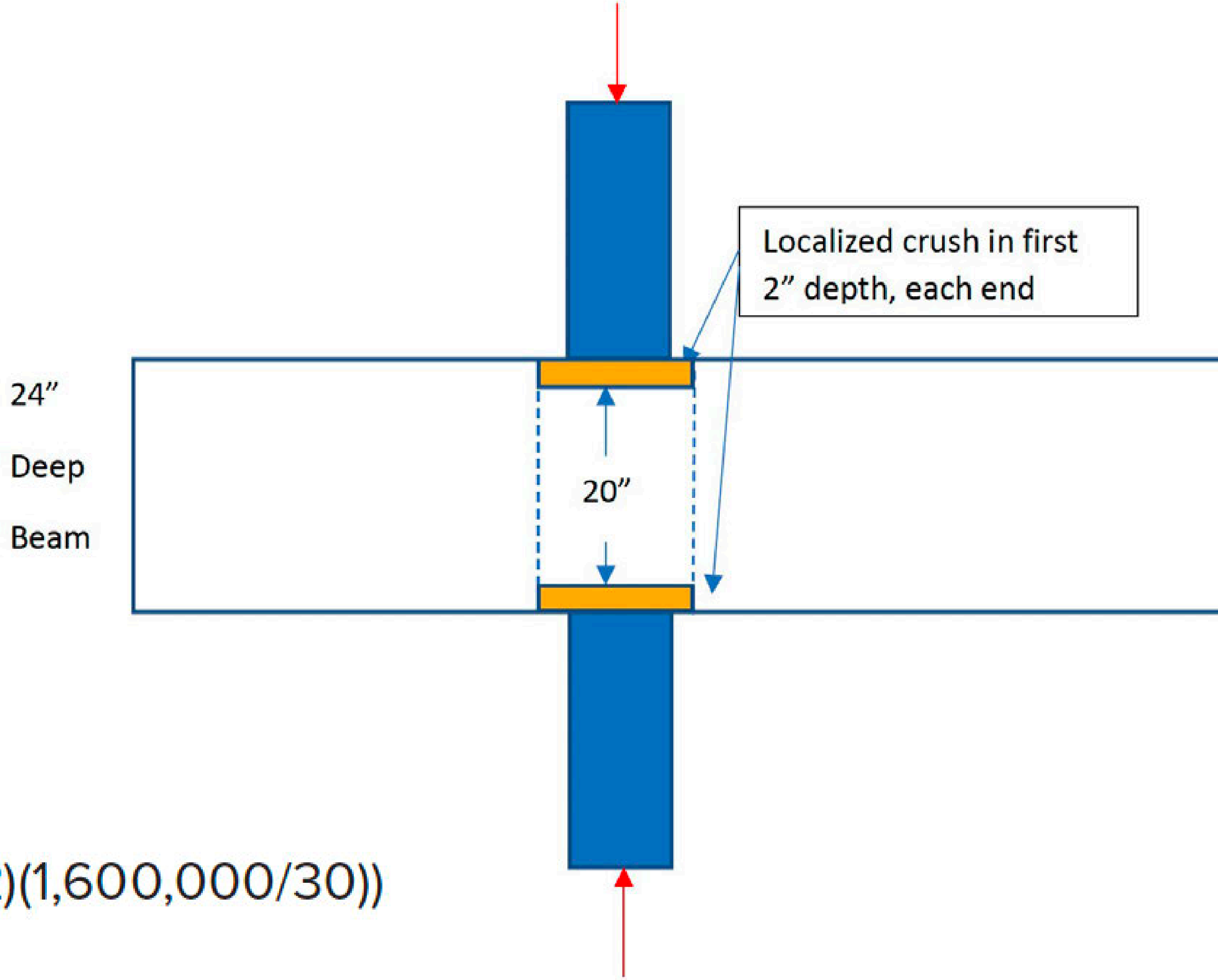
Quantifying Vertical Movement

Beam Shortening

For the beam and column example above, this would result in a beam core depth shortening of:

Column is 8.75”x9”

Beam is 8.75”x24”



$PL/(AE) = (45{,}000)(24\text{-}2\text{-}2)/((8.75)(9+2+2)(1{,}600{,}000/30))$

$= 0.15$ in.

Quantifying Vertical Movement

Tolerances & Joint Settlements

Material tolerances and small amounts of vertical settlement at connections can result in additional vertical movements

Some engineers include this additional movement in total building shrinkage calculations (1/16-in. per floor for example) while others choose to ignore it

Photo: WoodWorks

Quantifying Vertical Movement

Summing all Vertical Movements

$$\Delta_{column} = \Delta_{as,T} + \Delta_{shrinkage} + \Delta_{crushing} + \Delta_{settlement}$$

Using the detail shown in Figure 5 where the beam **is not** isolated from the shrinkage and crushing zone, the net vertical movement per level is:

$\Delta_{column} = 0.07 + 0.42 + 0.07 + 0.06 + 0.06 = 0.68$ in. x 12 story building = 8.2 in

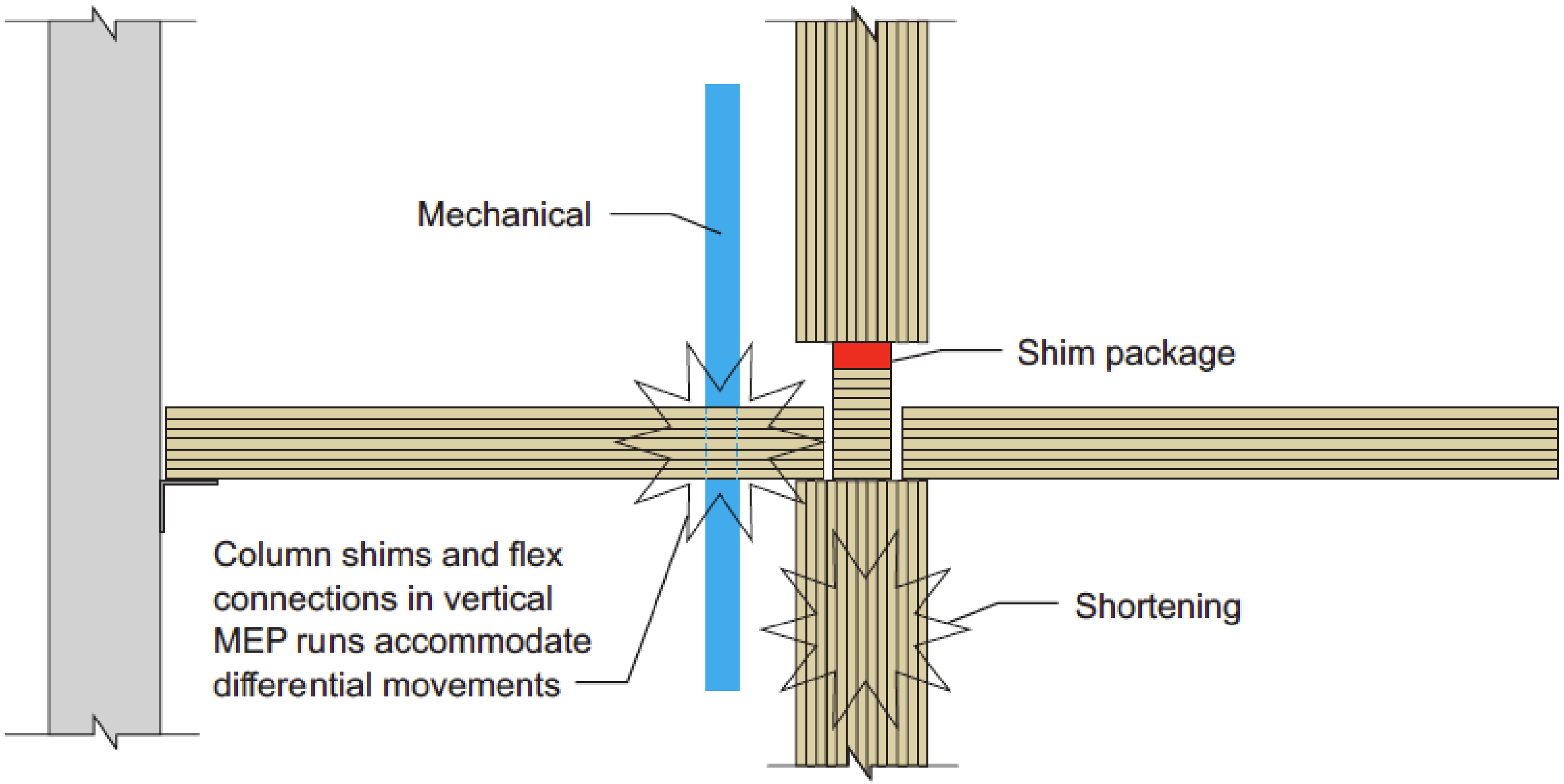
Using the detail shown in Figure 6 where the beam **is** isolated from the shrinkage and crushing zone, the net vertical movement per level is:

$\Delta_{column} = 0.07 + 0 + 0.07 + 0 + 0.06 = 0.2$ in. x 12 story building = 2.4 in

Minimizing Vertical Movement

Now we know how to calculate anticipated movements:

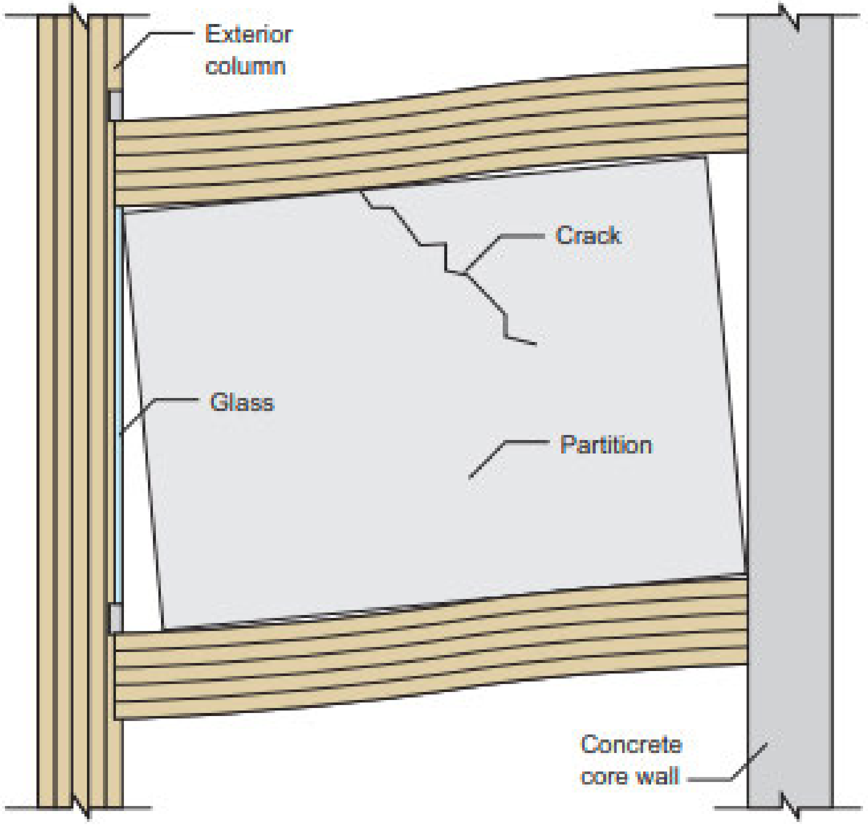
- What do those movements affect?
- It isn't necessarily the vertical movements alone that can cause issues, it is the differential movements than can

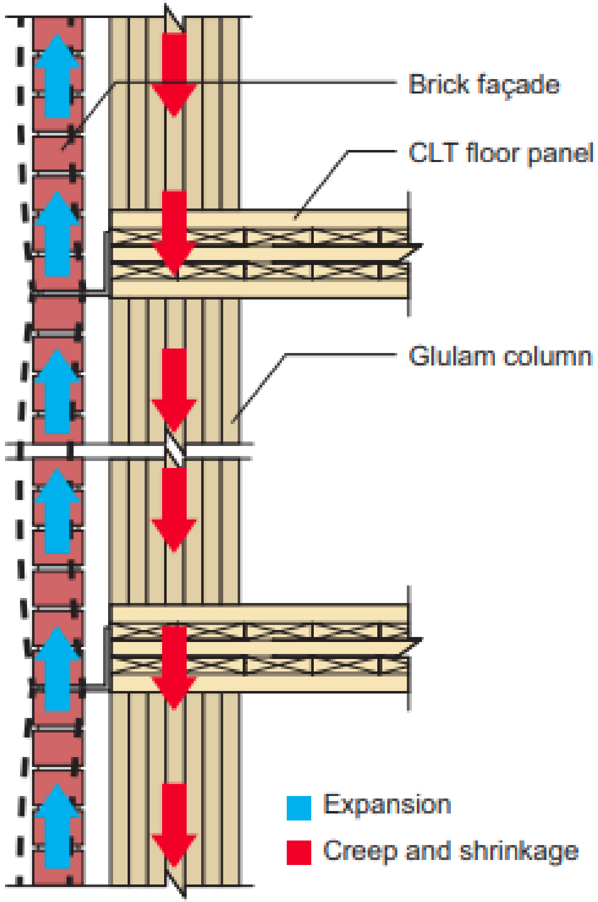


Minimizing Vertical Movement

Impact of Differential Vertical Movements on Non-Structural Components

- Interior Partitions
- Exterior Cladding
- Mechanical Equipment
- Roof Drainage

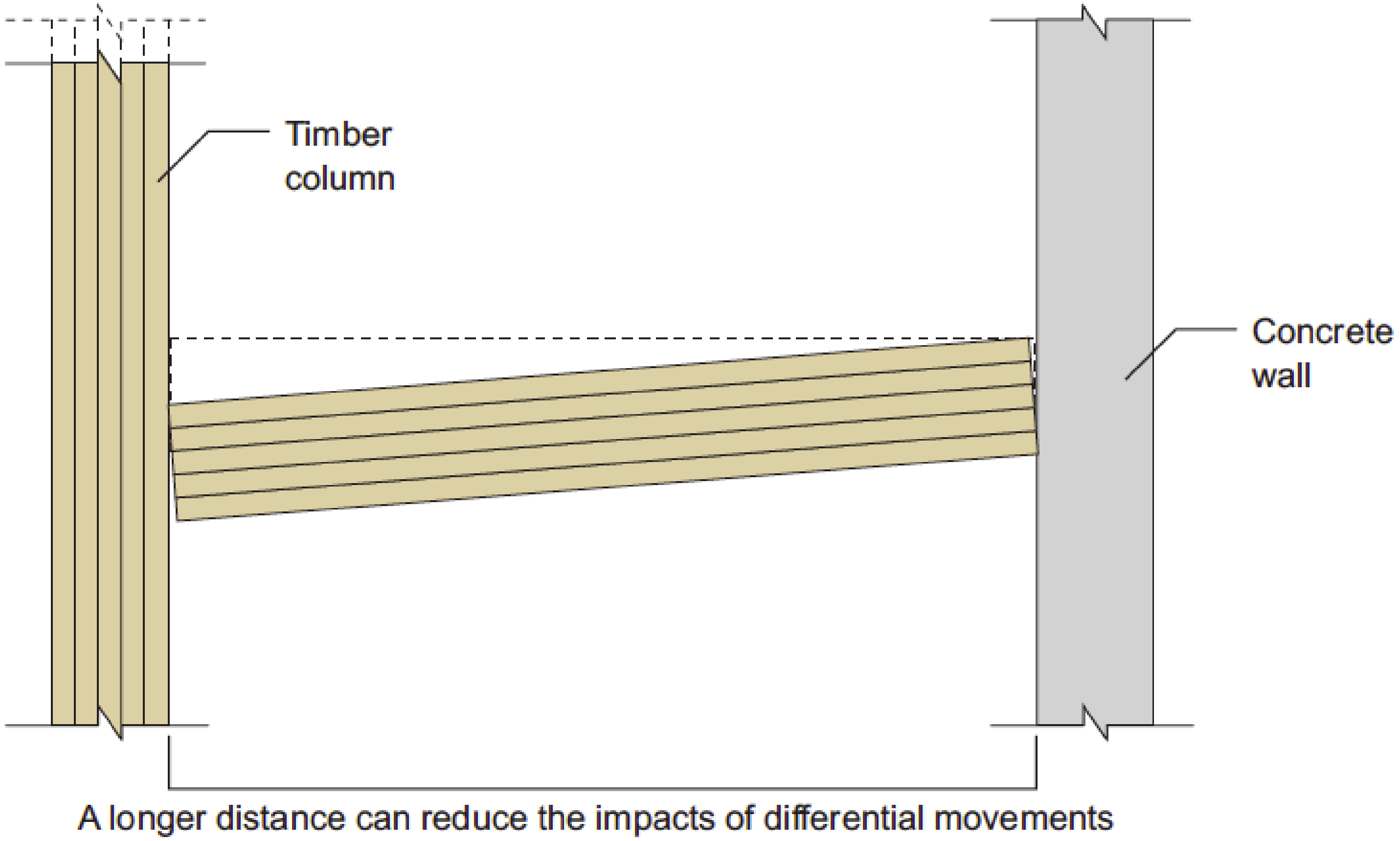




Minimizing Vertical Movement

Impact of Differential Vertical Movements on Structural Components

- Connections to concrete cores, steel braced frames
- Differential gravity support (eg. mix of beams & bearing walls)

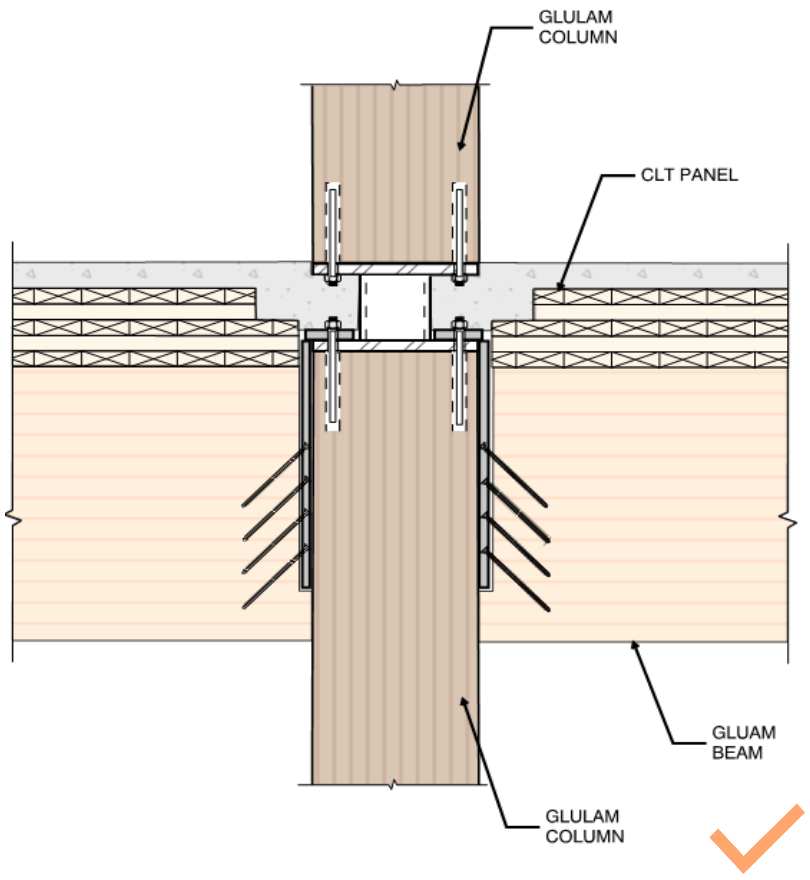


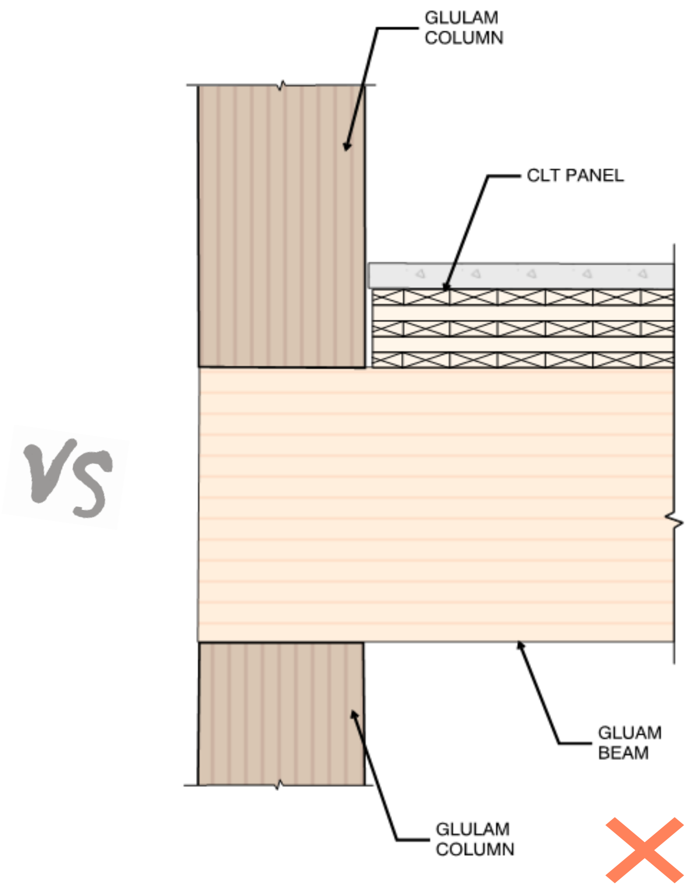
Minimizing Vertical Movement

Beam to beam, beam to column and column to column connections are key in minimizing vertical movements

Minimize movements by:

Isolating perp-to-grain shrinkage & crushing



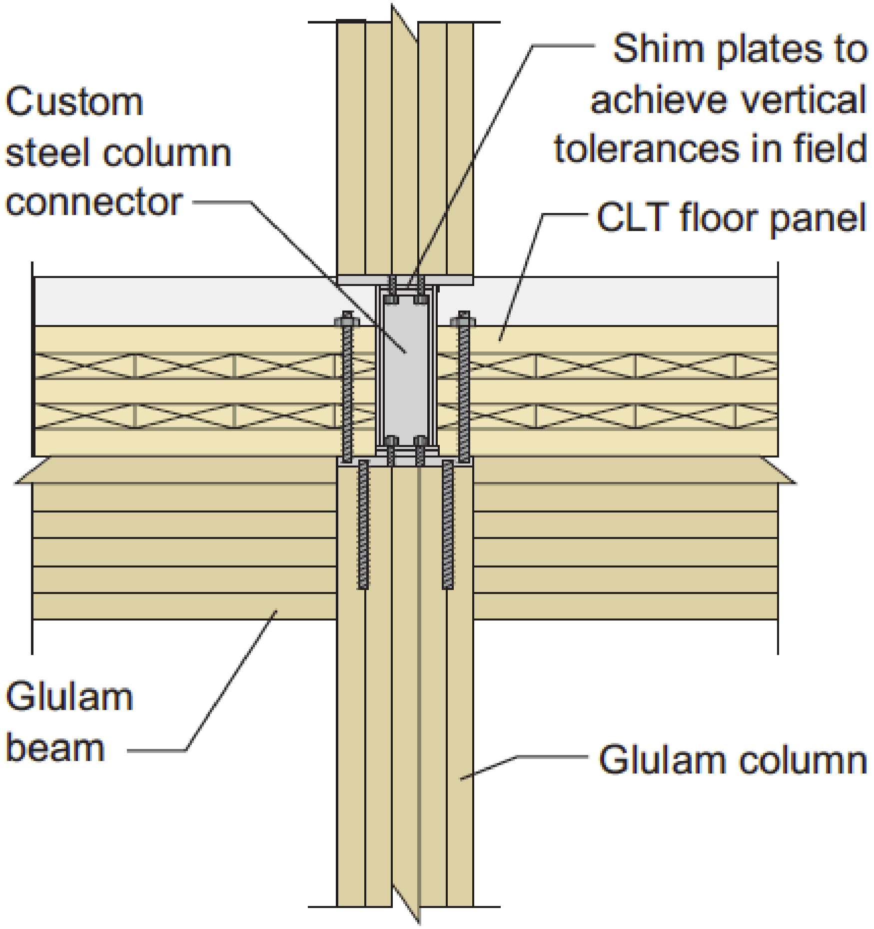


Minimizing Vertical Movement

Beam to beam, beam to column and column to column connections are key in minimizing vertical movements

Minimize movements by:

Shimming column connections

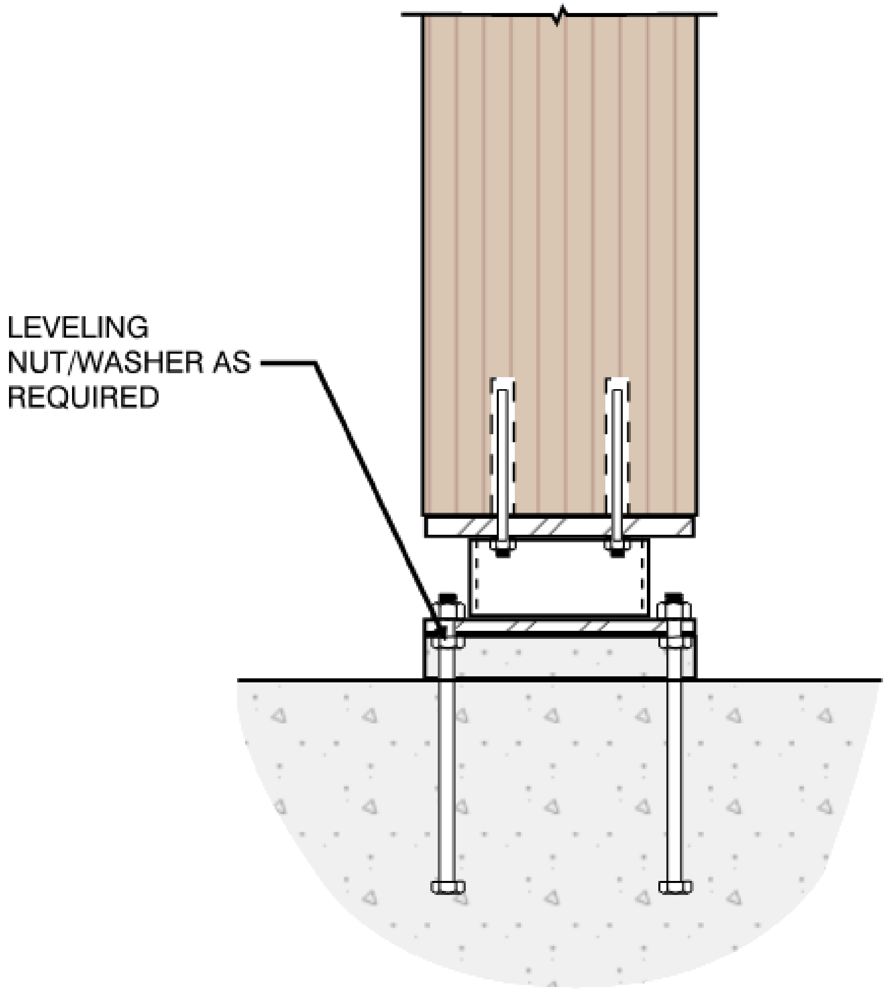


Minimizing Vertical Movement

Beam to beam, beam to column and column to column connections are key in minimizing vertical movements

Minimize movements by:

Adjustments at base with leveling nuts & grout

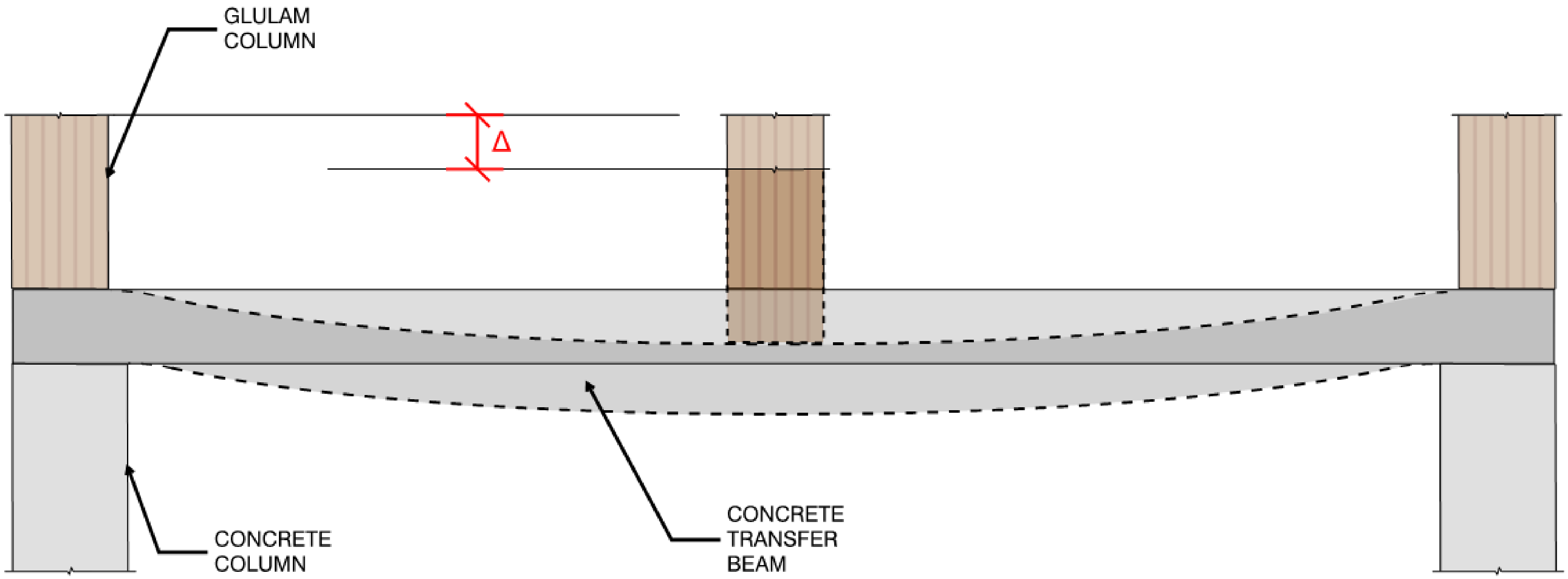


Minimizing Vertical Movement

Consider differential stiffness & deflections of supports

Minimize movements by:

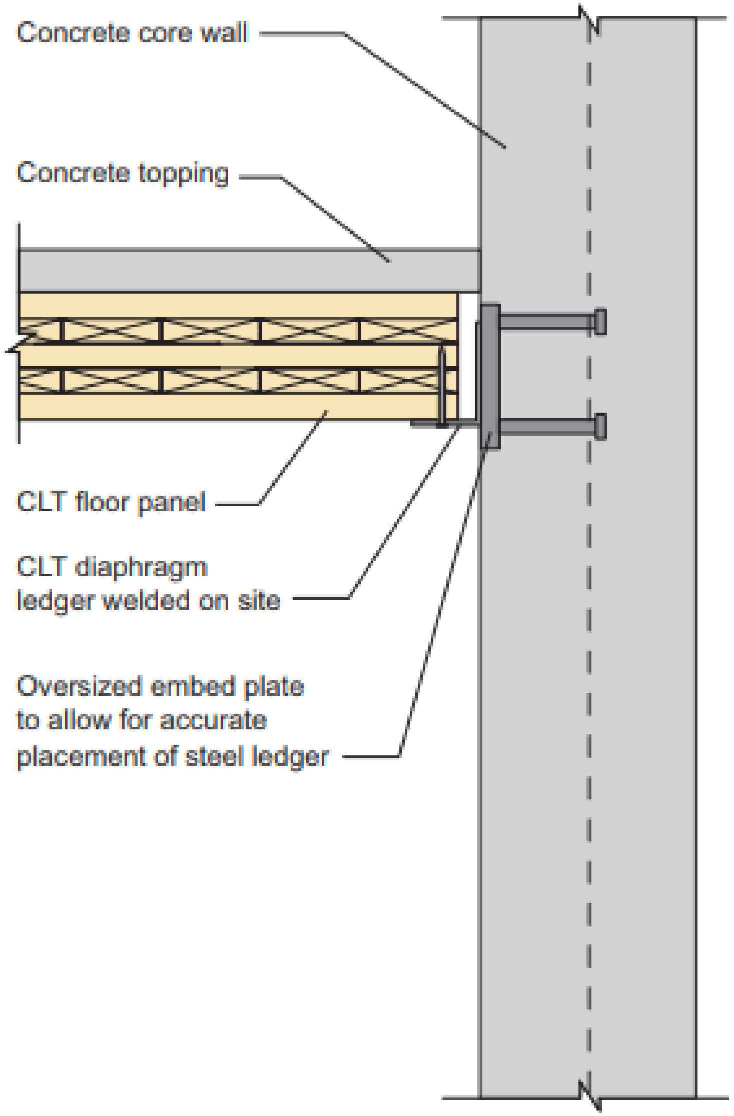
Providing equivalent support stiffnesses or connection details that accommodate differential deflections

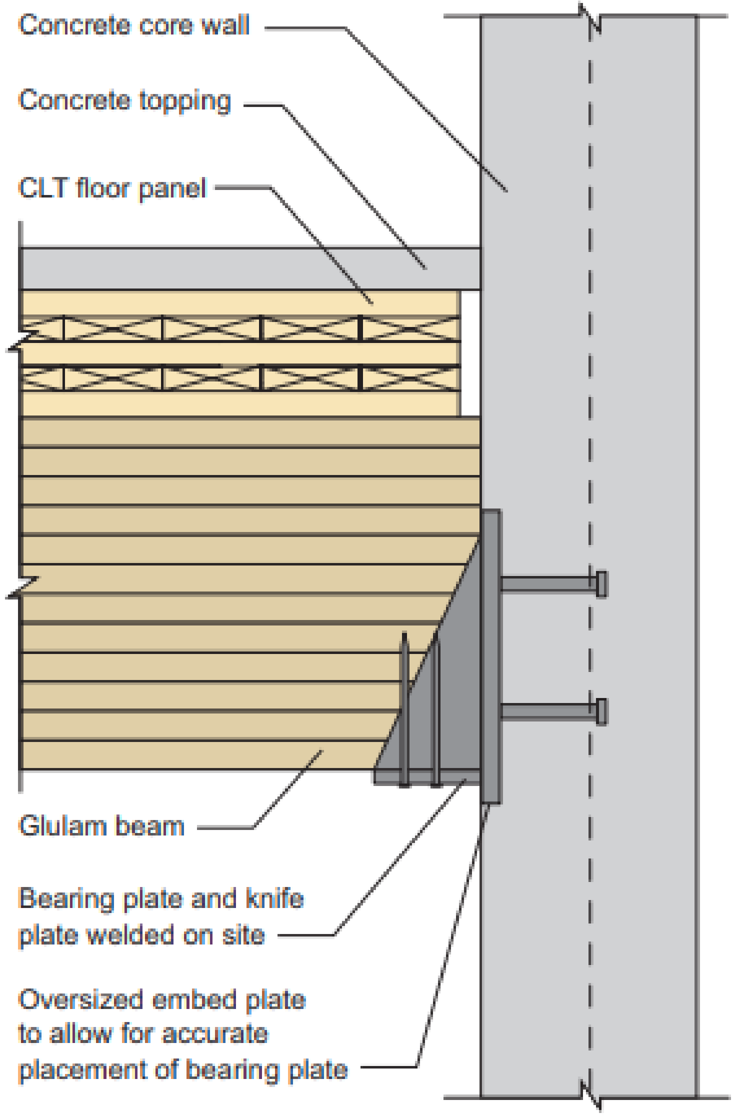


Accommodating Vertical Movement

Accommodate movement at timber to concrete cores

Example: embedded, oversized steel plate in concrete. Steel angle field welded to plate once final elevations are determined (and ideally once some initial shrinkage and settlement has occurred)





Accommodating Vertical Movement

Accommodating Vertical Movement

Beyond structural connections, consider movement impacts on MEPF services. Flex/compression connections

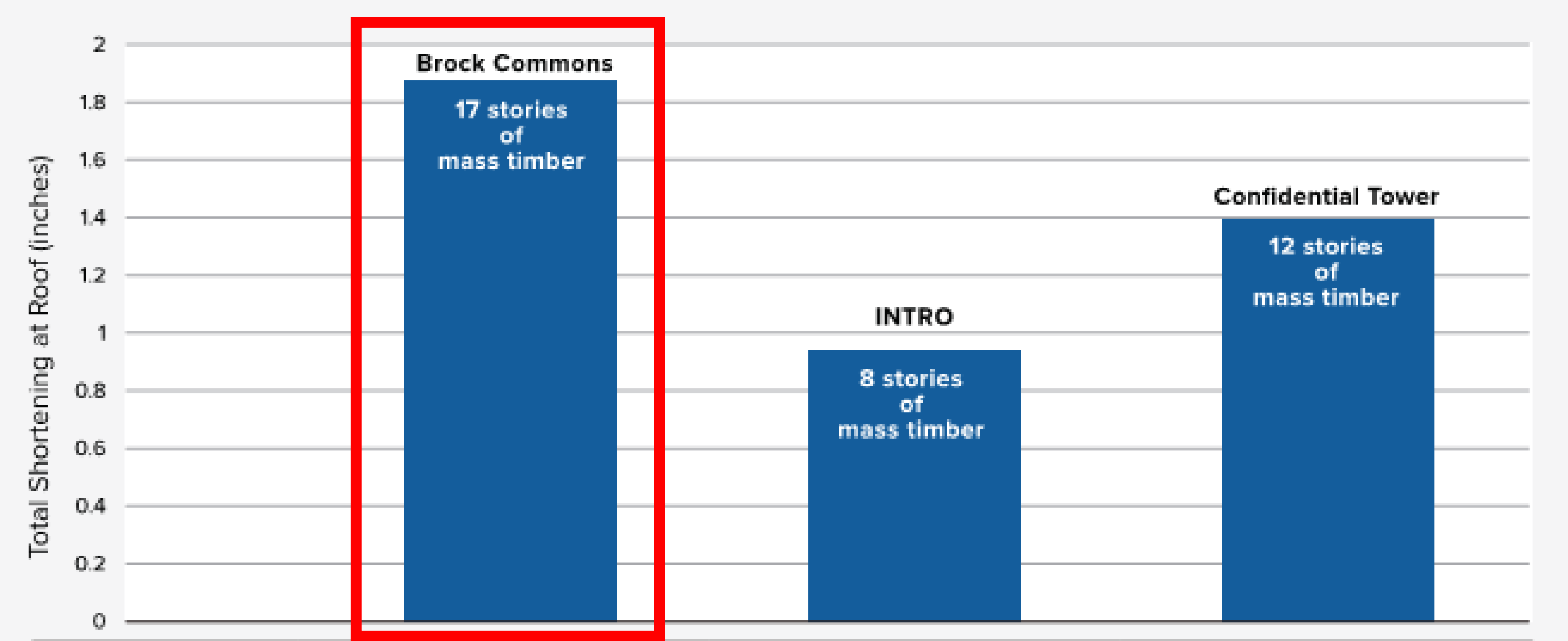
Accommodating Vertical Movement

Also consider other continuous non-bearing elements such as exterior walls, shafts. Include deflection tracks, control joints

Calculated vs. Actual Vertical Movement

Calculations may overestimate actual movements on site

Examples of calculated vertical movement for several North American tall timber projects:



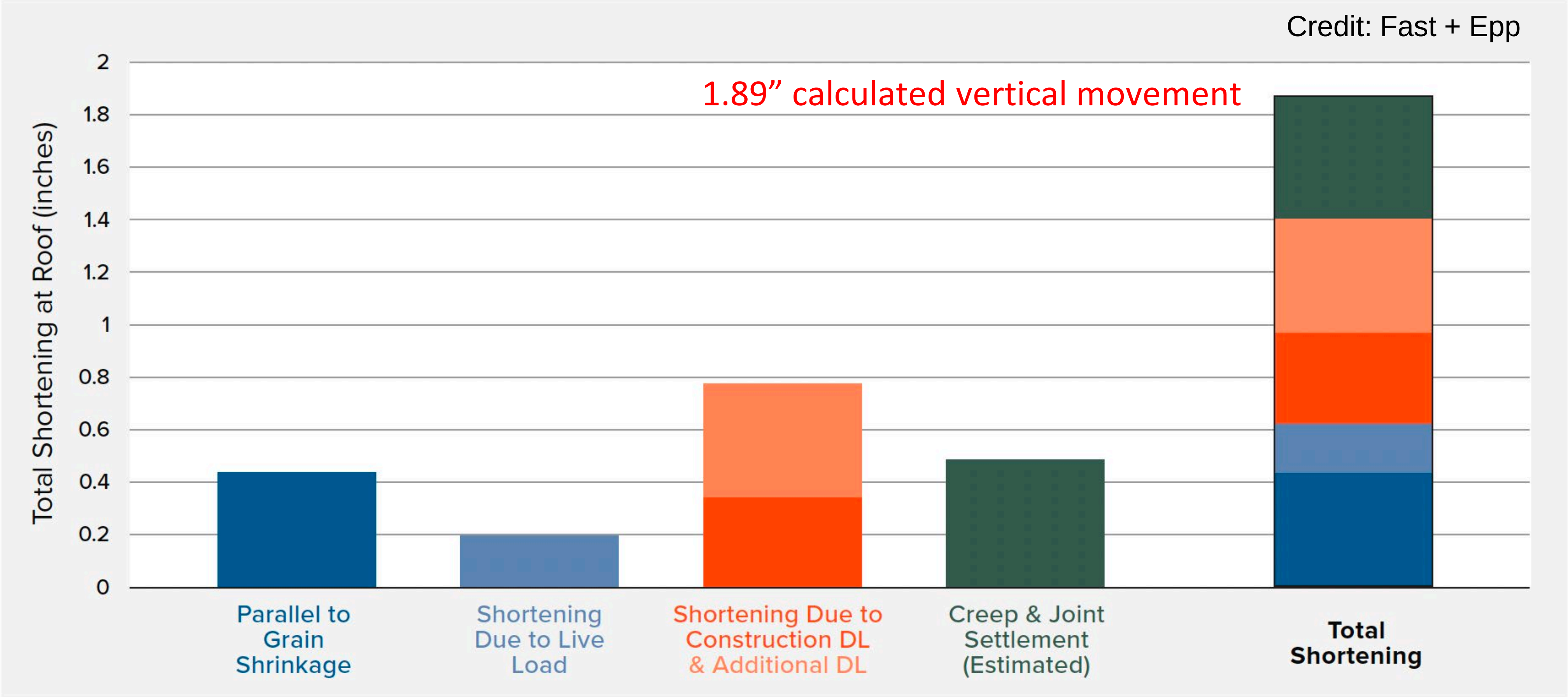
FFR & Exposure	2 hrs - Fully encapsulated	2 hrs - Exposed	2 hrs - Partially encapsulated
Grid	13' x 9'	20' x 22' average	10' x 12'
Structural system	Point-supported CLT	CLT on glulam beams	10' x 12'
Main story height	9'-2"	11'-5"	9'-8"

Credit: Fast + Epp

Calculated vs. Actual Vertical Movement

Calculations may overestimate actual movements on site

Calculated vertical movement at Brock Commons: 18 story (17 over 1) mass timber residence hall in Vancouver, BC.

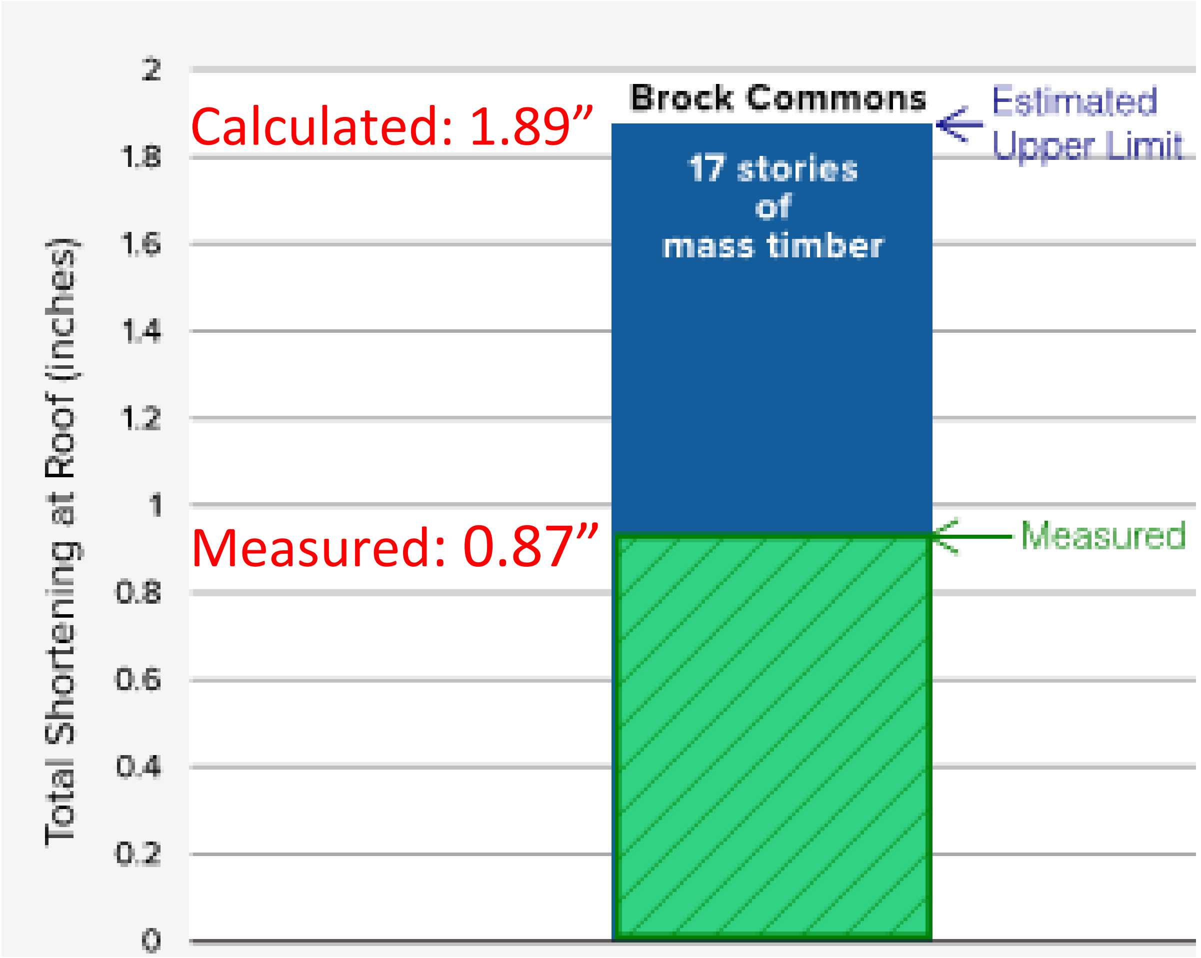


Calculated vs. Actual Vertical Movement

Calculations may overestimate actual movements on site

Brock Commons: Measured movements were ~50% of calculated movements

Values used for elastic modulus, live load, creep, joint settlement, and moisture variation among others can compel designers to overestimate the total shortening and lead to over-shimming. Engineering judgement and experience in mass timber buildings are important to balance theoretical study.

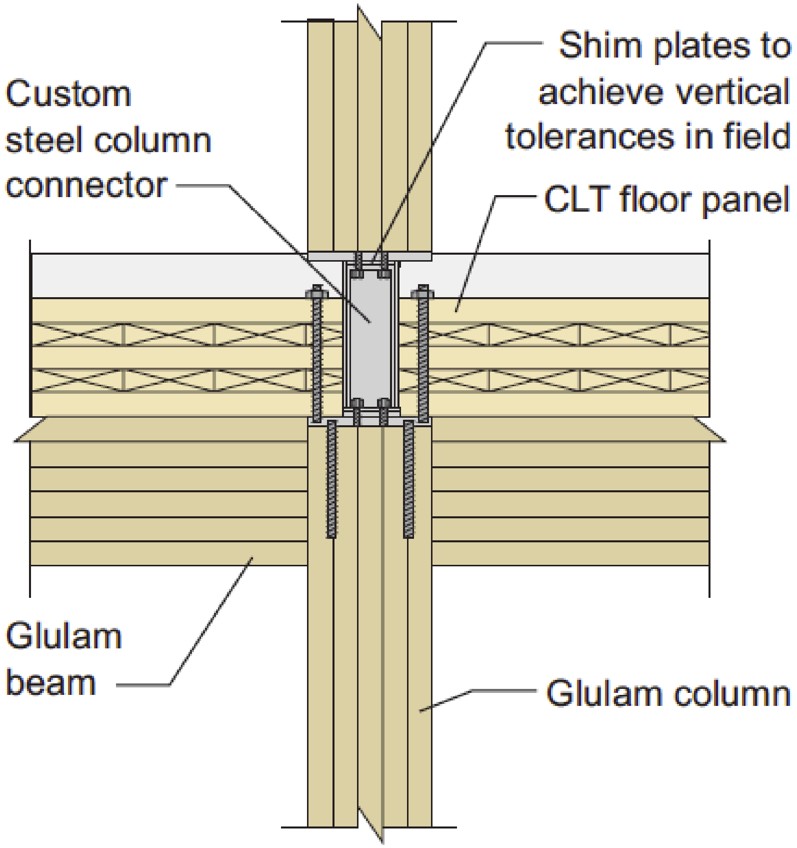


Credit: Fast + Epp

Calculated vs. Actual Vertical Movement

Calculations may overestimate actual movements on site

Takeaways: calculations are important in setting detailing conditions, but don’t overshim. Verify on site



Conclusions

- Critical to consider axial column shortening and other vertical movements in tall mass timber buildings
- Precautions should be taken to address estimated shortening due to the uncertainties that lie within assumptions
- Know impacts of movements on structural connections & non-structural components


Photo: H+O Structural Engineering, Kure Creative

Conclusions

- When properly accounted for, shortening should not negatively affect the construction, use, or long-term performance of the building
- Negative impacts can be avoided through a combination of proper detailing and effective moisture management strategies
- Involve all members of the design and construction team in understanding vertical movements

Photo: WoodWorks

Conclusions

- On site observations and inspections help to ensure that performance matches design intent
- Proper detailing must lead to proper installation
- Once fully understood, accommodating vertical movement simply becomes another design criteria

Vertical Movement in Mass Timber Design Resource

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WOODWORKS
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Differential Material Movement in Tall Mass Timber Structures

An Overview of Column Movement Types and How to Address Them

It is a common narrative that tall mass timber buildings are relatively new to the U.S., and wood structures between seven and 24 stories have been built successfully in other countries for more than a decade. However, while there are dozens of timber buildings over eight stories tall worldwide, the suggestion that America is new to these types of projects is fast becoming out of date.

U.S. interest in tall timber buildings, i.e., buildings that exceed height and area limits for wood construction prescribed in the 2018 and previous versions of the International Building Code (IBC), has steadily increased over the past several years. With the introduction of three new construction types in the 2021 IBC—Types IV-A, IV-B and IV-C, which allow up to 18, 12 and nine stories of mass timber construction respectively—these projects are also getting built. Currently, about 10% of the mass timber buildings in design or built in this country exceed the 2018 prescriptive height limits. In 2021 alone, tall projects such as INTRO in Cleveland, Ascent in Milwaukee, 11 E Lenox in Boston, 80M in Washington DC, and Apex Plaza in Charlottesville, VA either started or completed the mass timber portion of construction. At the time of writing, several others are set to break ground.

As the height of mass timber buildings continues to grow, a new set of design and detailing challenges arises, creating the need for new engineering solutions to

INTRO in Cleveland, OH

Photo: Harbor Bay Real Estate Advisors

Free download at woodworks.org

Questions? Ask us anything.

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901 East Sixth, Thoughtbarn-Delineate Studio, Leap!Structures, photo Casey Dunn

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