Durable and Efficient Building Enclosures for Mid- to High-Rise Wood Buildings

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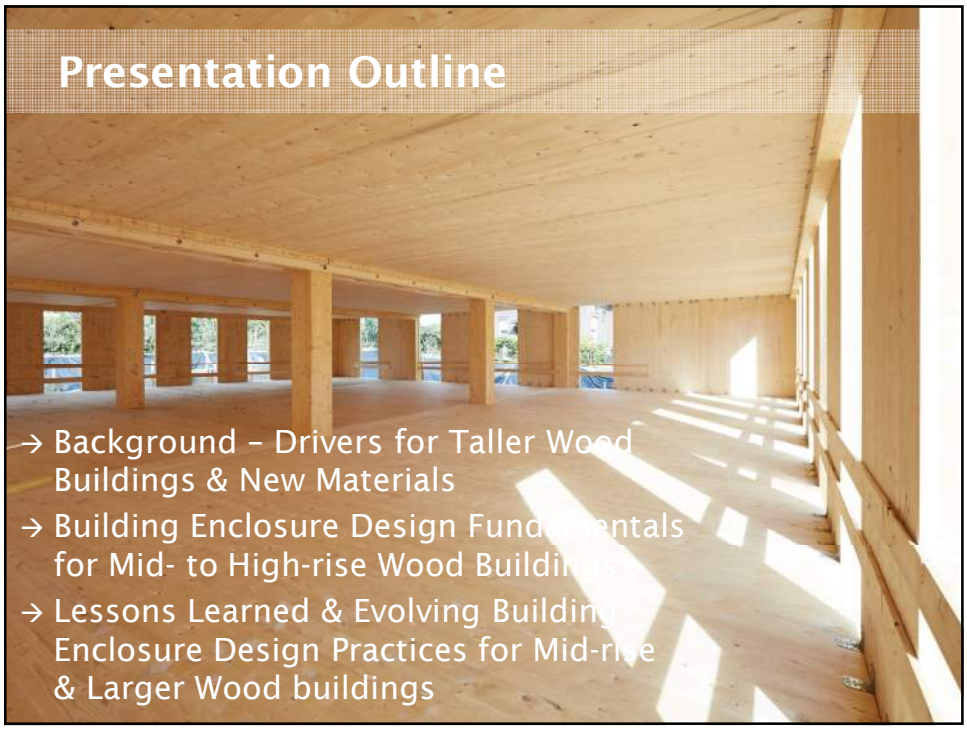
Presentation Outline



- → Background – Drivers for Taller Wood Buildings & New Materials
- → Building Enclosure Design Fundamentals for Mid- to High-rise Wood Buildings
- → Lessons Learned & Evolving Building Enclosure Design Practices for Mid-rise & Larger Wood buildings

What is New and Up With Wood Buildings?

- Building codes are rapidly changing to allow both larger and taller wood buildings across North America
  - 5&6 storey stick-built wood-frame "podium construction" becoming popular across many US States & Canadian Provinces
  - Even taller & larger buildings being constructed as alternate code solutions
- Significant research, testing, and current interest in taller & larger wood buildings
- Growing use of new wood products including Cross-Laminated Timber (CLT), Nail Laminated Lumber (NLL) and others
- Wood seen as a sustainable and renewable resource with bonus carbon sequestration

A Condensed History of Taller Wood Buildings

- Pre 1900s – many examples of tall mass timber buildings in North America up to ~10 storeys, many still around today
  - Mid 1900s – American/Canadian building/fire codes changed – restricting wood-buildings to 3-4 storeys
- Mid 1990s to early 2000s, Western States allow construction of 5 storeys stick built wood-frame
- Past decade – Mass timber buildings in Europe/UK/Oceania up to 15 storeys tall
- Several recent initiatives in Canada & US to allow for taller mass wood buildings up to 18 storeys (as alternate solutions under existing codes)

1900s era Tall Wood Buildings Across North America

2014 - Wood Innovation Design Centre, BC – 1st & currently tallest in North America

European Experience & Tall Mass Timber Buildings

8 storeys – LCT One, Austria, Hermann Kaufmann

9 storeys – Melbourne Australia, Land Lease

8 storeys – Finland, OOPEAA

14 storeys, Treet – Norway, Artec

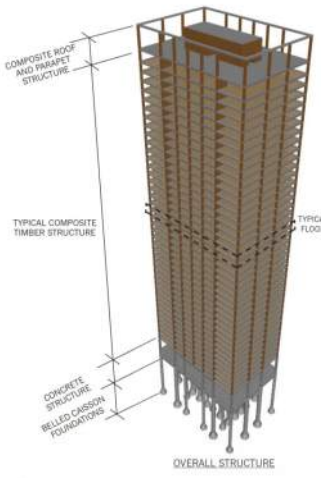
9 storeys – Murray Grove, UK, Waugh Thistleton Architects

Many Similarities:
- Mass Timber Components, CLT, Glulams etc.
- Pre-fabricated components (walls, floor panels)
- Hybrid wood & concrete structures

North American Tall Wood Buildings – The Future?

CEI Architecture

Michael Green Architecture



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The Future? North American Projects Underway

18 storey wood, Vancouver, BC

12 storey wood, Portland, OR

10 storey wood, New York

What is Unique About Taller & Larger Wood Buildings?

Building Enclosures for Taller Wood Buildings

- Taller buildings = increased exposure to wind and rain
  - Need for better site protection, use of more robust assemblies and materials: membranes, claddings, windows & roofing
  - Consideration for pre-fabrication
- More structural framing
  - Less space for insulation within studs
  - Unique wood/steel/concrete interfaces and details to consider
- Non-combustible claddings & enhanced fire-safety considerations during construction & in-service
- Emerging industry & requirements

Uniqueness of Larger Mass Timber Buildings?

- Greater use of engineered heavy timber components (panels, beams, columns)
  - Alternate structural systems (post/beam, tilt-up panels, infill systems)
  - Unique new connections, interfaces & details
- Longer & heightened exposure of wood components to rain and weathering during construction
- *Is not the same as stick built mid-rise wood-frame, but is also different from high-rise steel or concrete construction*

Mass Timber is Beyond Stick Framing

It Borrows a Lot from Heavy Timber Framing

And Borrows a Bit from Pre-Cast & Tilt-Up Concrete

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And Combines Pre-fabrication & Panelization

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And Could Even Utilize Pre-cast Concrete & Steel Systems Too

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Taller Wood Frame Structural Systems

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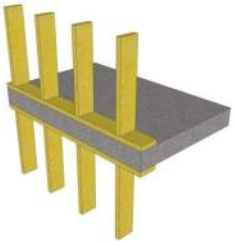
Platform & Balloon Framing



Wood-frame Infill

Mass Timber (CLT) or LVL/LSL/PSL

Post & Beam with Wood/Steel Stud Infill or Curtain wall

Mass/Heavy Timber – Engineered Materials

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- Taller structures require heavier timber & engineered lumber components
  - Cross Laminated Timber (CLT)
  - Glulam
  - Laminated Strand Lumber (LSL)
  - Parallel Strand Lumber (PSL)
  - Laminated Veneer Lumber (LVL)
  - Nail Laminated Lumber (NLL)
- Many tall wood structures will also incorporate steel and concrete – "hybrid systems"

Why Cross Laminated Timber (CLT)?

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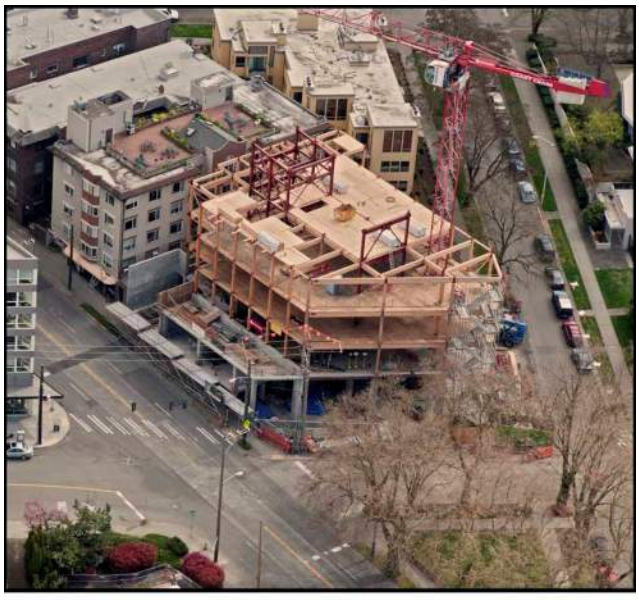
- CLT is a multi-layered engineered wood panel consisting of dimensional lumber that is laminated together in an alternating cross-wise direction
- Typically built up to 3 to 7+ plies thick of ¾" to 1½"lumber
- Glue adhesive most common, though nails or wood dowels may also be used by custom fabricators
- CLT panels can be made up to 13 ft x ~80 ft in dimension, CNC cut with openings, penetrations etc.
- Used for pre-fabricated panel walls, roofs, floors and other components

Wood & Hybrid (Wood, Steel, Concrete) Structures




Hybrid = All Inclusiveness



2012-4.15_2457 Bullitt Center under construction photo: John Stamets

Lots and Lots of Steel Screws & Connectors

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Panelization of Whole Homes with CLT

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Pacific Timberworks

Construction with CLT - Tolerances

- CLT panels are pre-cut to size in factory – often with penetrations, openings, fastener holes pre-cut/drilled
- Panels lift by crane and fit together & connected together
- Requires high degree of attention to detail and minimal tolerances for layout to ensure all pieces fit together - just like traditional timber framing

Not All CLT is the Same

Structural non-finish grade

Custom clear finish interior tongue & groove with wood dowels

High quality interior finish grade

Good vs Bad Use of CLT

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Good – Warm, dry and protected by the building enclosure ☺

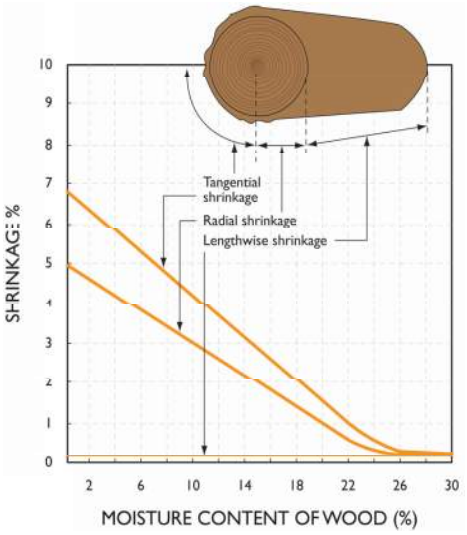
Bad – exposed to weathering ☹

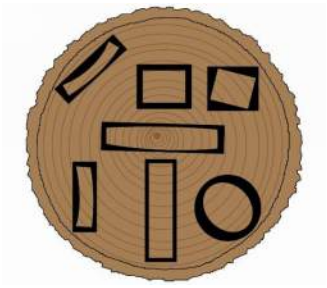
Building Enclosure Design Considerations for Mid- to High-Rise Wood Buildings

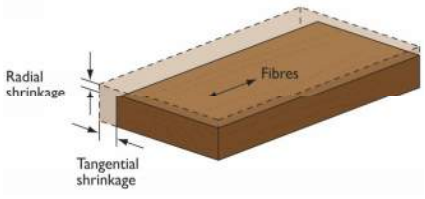
Building Enclosure Design Fundamentals

- Primary function of the **Building Enclosure**: Separate the exterior & interior environments
  - Protect wood during construction & in-service for life
  - Serves functional and aesthetic & purpose
  - Controls heat, air, and moisture transfer along with noise and fire
  - Designed to accommodate building movement, structural loads, initial & seasonal wood movement
- Key passive design element for an energy efficient & sustainable building

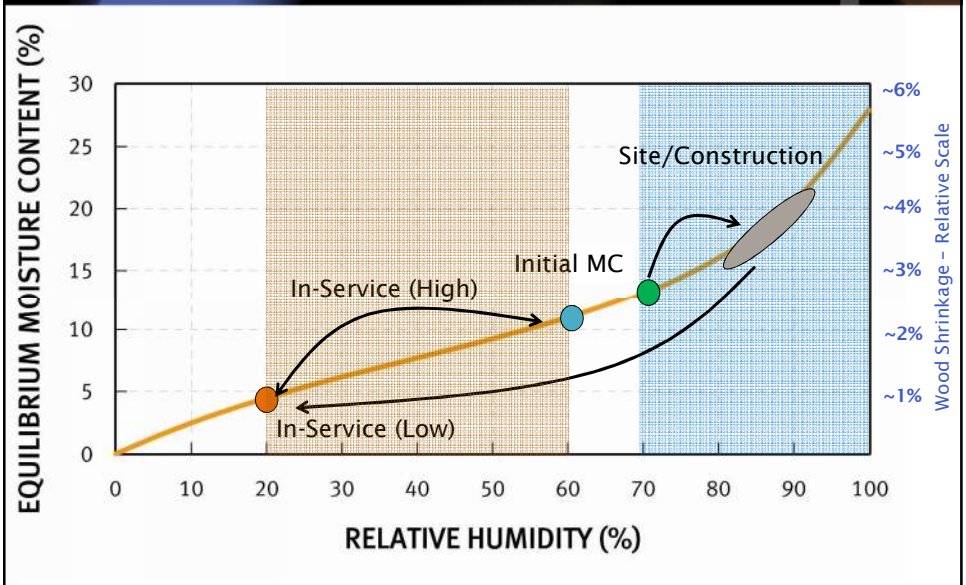
Consider the Behaviour of Wood in Construction





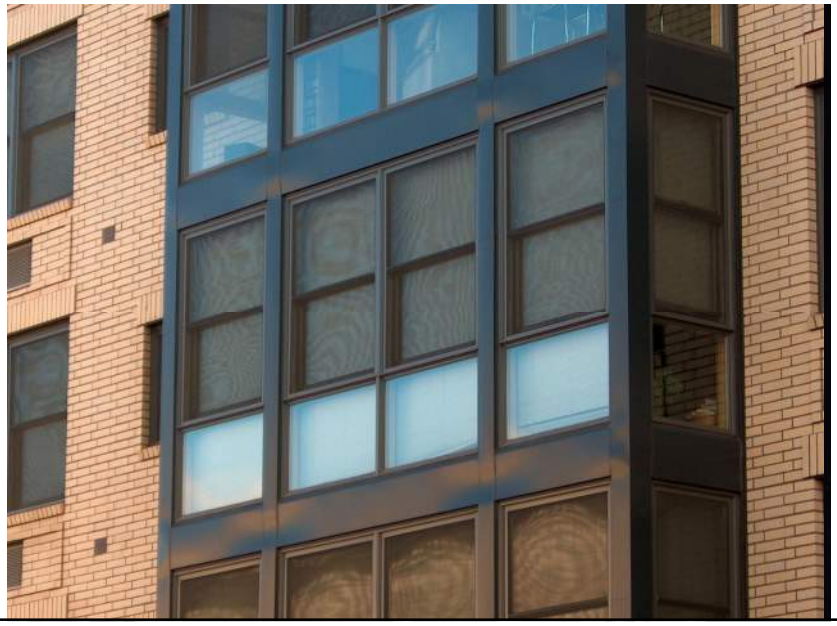


Wood Moisture, Relative Humidity & Movement

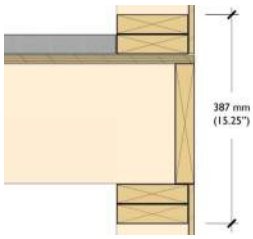


Wood shrinkage is 0.20% to 0.25% in dimension per 1% change in MC

Wood Shrinkage Lessons Learned from Mid-rises

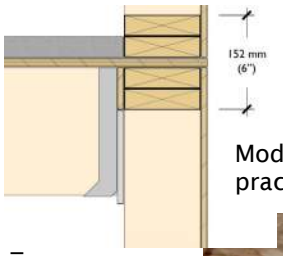


Reducing Wood Shrinkage in Midrise Buildings



Traditional platform framing = maximum shrinkage potential

Use of engineered lumber floor joists & headers



Modified platform framing practices – hung joists

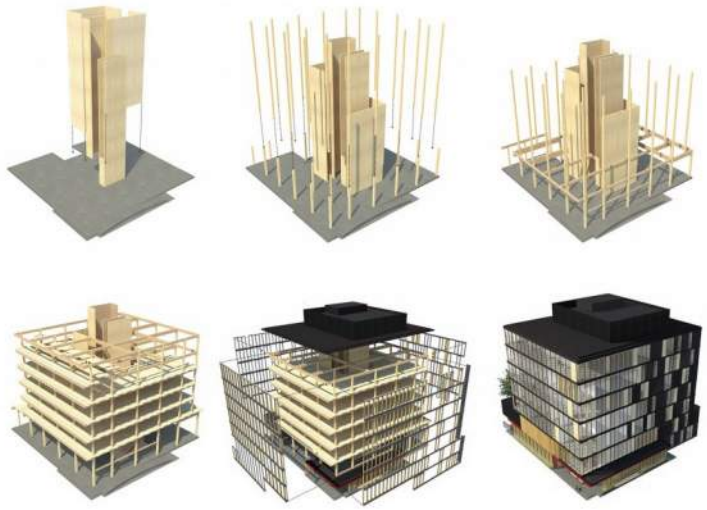
Unique Movement Considerations for Tall Wood

- Mass timber buildings typically utilize continuous columns & shear wall panels
  - Removes radial & tangential wood grain from the shrinkage path so only minimal longitudinal grain shrinkage & compression/creep
  - Hopefully wood components are also dry – after being manufactured at 12-14% MC
- Mass timber shrinkage concerns primarily surround thickness changes radial/tangential wood within glulam beams, CLT and NLL panels
- Not so much the entire building shrinking but the differential movement between assemblies & floors
- Be very careful with NLL roof/floor panels – lots of wood to swell when wetted & hard to dry out

Wood Movement at the Wood Innovation & Design Centre (WIDC) - Measured

Photo: Ema Peters

Wood Movement at WIDC - Measured



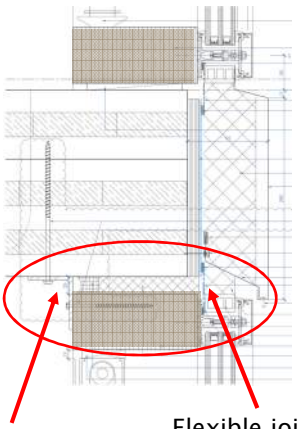
Design & Architectural Renders: Michael Green Architecture (MGA)

Wood Movement at WIDC - Measured

- Overall building height ~96 ft – continuous glulam columns/CLT core walls with glulam beams/CLT floor panels
  - Glulam columns 6 tall floors – total ~ ½" (0.04%) longitudinal shrinkage/compression
  - CLT core walls 6 tall floors – total ~ ¾" (0.06%) longitudinal shrinkage/compression
  - 5 ply CLT floor panels (6.5") ~3/16" shrinkage in thicknness (3%)

Initial wood moisture content of 14% dried down to a low of ~ 4%

WIDC: Curtainwall & Wall Panel Movement Joints

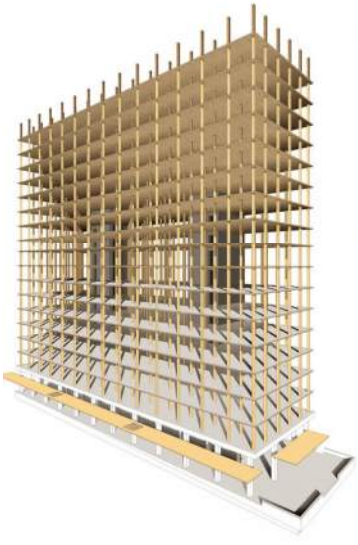


Slip structural connection

Flexible joint material at head & jamb

WIDC: Curtainwall & Wall Panel Movement Joints

18 Storey Wood Shrinkage? To the Minimum



Material Trends for Wood-frame Building Enclosures

Air Barrier System Trends for Mid-rise & Taller Wood Buildings

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- → Taller wood buildings = increased and prolonged exposure to weather, wind and rain
- → More robust Air Barrier and WRBs needed to accommodate higher wind pressures, increase wetting & longer exposure
- → Rigid, self-adhered, or liquid membrane approaches preferred over mechanically attached sheets to accommodate loads
- → Shift to "exterior air barrier" approaches at sheathing plane
- → Vapor permeable membranes growing in popularity – especially for wood-frame
- → Range of cladding supports & penetrations to seal

Exterior Air Barrier Systems for Taller Wood Buildings

Vapor permeable ***self-adhered*** *membranes over exterior sheathing*

Taped/sealed rigid wood or gypsum sheathing

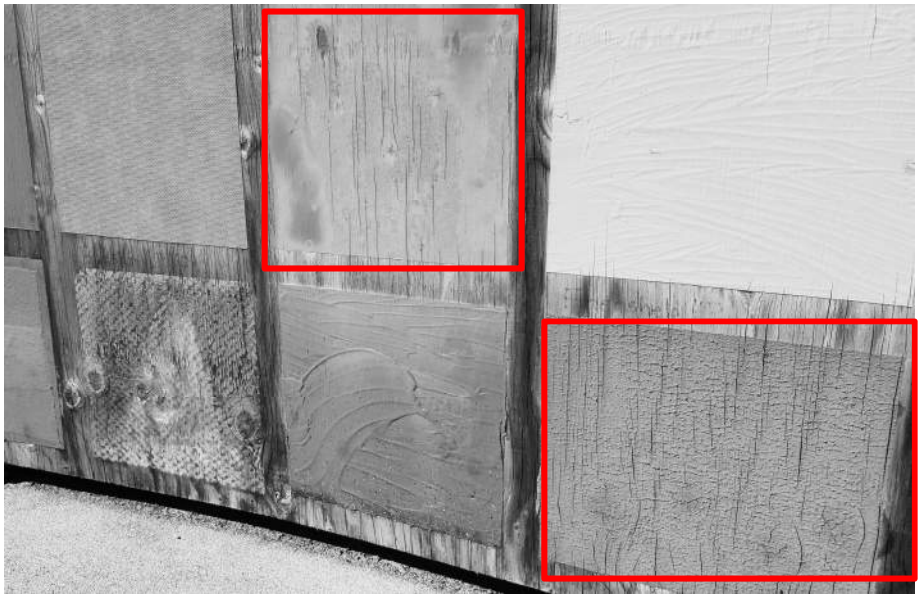
Liquid/fluid applied membranes over exterior sheathing

Liquid/Fluid Applied Air Barrier Systems

→ Liquid/Fluid applied membranes (roller, brush or spray) applied to sheathing with joint/gap fillers and reinforcing

Liquid Membrane Considerations for CLT, NLL and Other Wood Panels

Liquid Membrane Selection & Wood Movement?



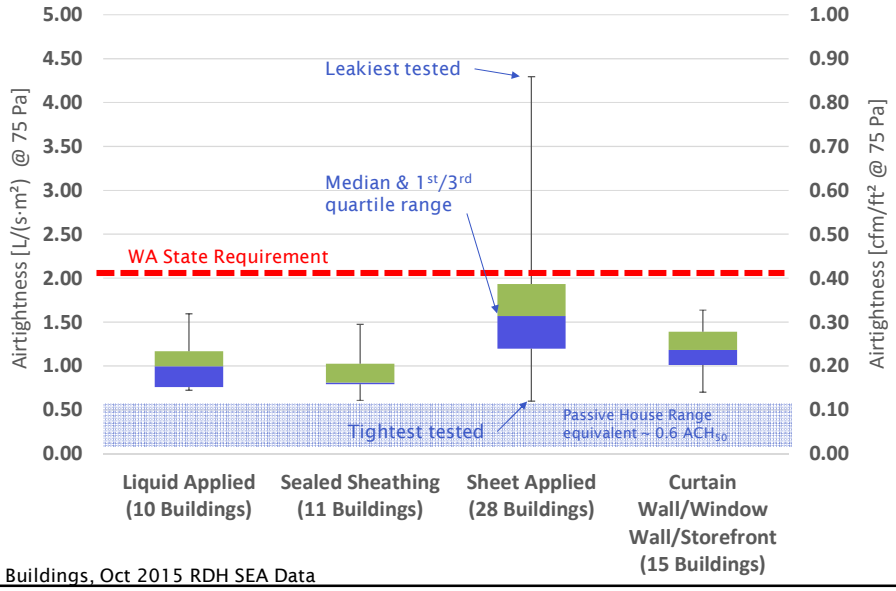
Material Selection for Taller Wood Buildings

→ Watch use of vapor impermeable materials over wood that is wet or could get wet
  - → Self adhered membranes
  - → Foam plastic insulations

→ Vapor diffusion **wetting & drying** ability for assemblies & details should always be assessed – ensure balance

Measured Performance of Different Air Barrier Systems & Details in Washington State

How Well Is the Industry Doing – WA State



54 Buildings, Oct 2015 RDH SEA Data

Orchard Passive House Airtightness

Sealed Sheathing Air Barrier –
0.13 ACH @50 Pa
~0.014 cfm/ft² @75 Pa

Building Enclosure Assemblies & Detailing Considerations for Taller Wood Buildings

Building Enclosures for Mass Timber

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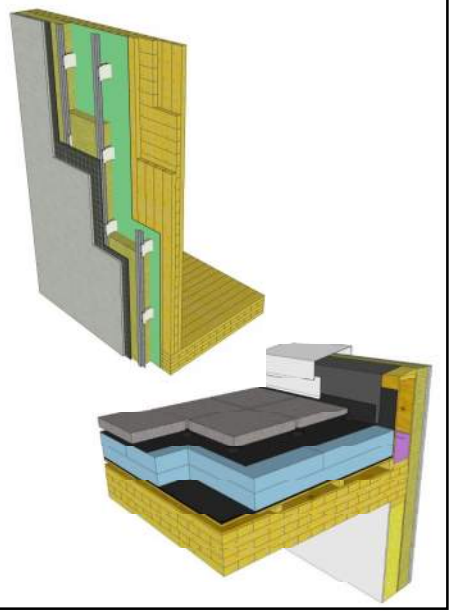
- **Key Considerations:**
  - Design to always keep heavy timber components warm and dry
  - Design assembly with the ability to dry out if it was built wet or gets wet in-service
  - Wood itself provides nominally ~R-1/inch so still need 2-4 inches of insulation to meet codes
    - All insulation should be placed on exterior of heavy timber panels along with continuous air barrier/water resistive barrier
  - Heavy timber assemblies are fairly simple & efficient compared to other systems



Wall Design for Taller Wood Buildings

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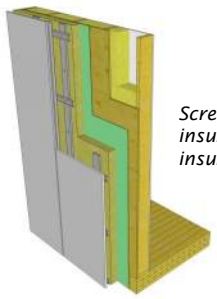
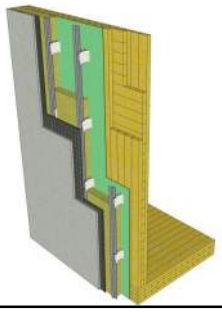
- **Key Considerations:** Durability, Airtightness & Thermal Efficiency
- **Strategies:**
  - Exterior or split-insulated wood walls
  - Thermally efficient cladding attachments through exterior insulation
  - Non-combustible & moisture tolerant cavity insulation
  - Non-combustible rainscreen claddings



Screws through insulation over split insulated wall



Various clip & rail systems through exterior insulation

Wood Framing in Taller Wood Buildings

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- Taller stick frame & heavy timber panel buildings = less room for stud frame insulation
  - Challenges to meeting prescriptive R-value requirements without exterior insulation in walls

Mid-rise Wood Framing Factors & Where to Place Insulation

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Getting to Higher R-values with Walls

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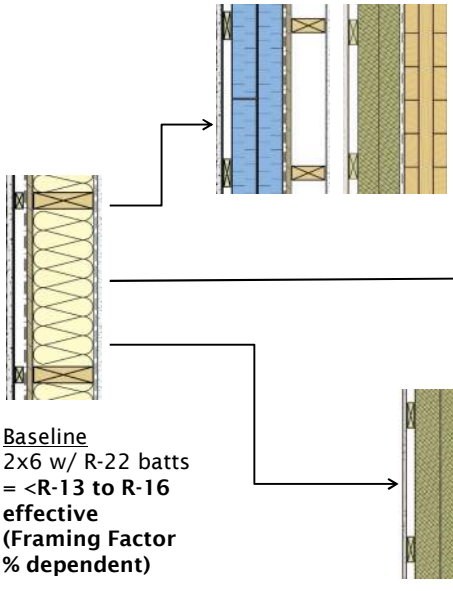

Exterior Insulation:
<R-15 to R-40+ effective
- Constraints: cladding attachment, wall thickness
- Good durability

Deep or Double Stud:
R-20 to R-40+ effective
- Constraints wall thickness
- Fair durability, sensitive to air/vapour

Split Insulation:
R-20 to R-40+ effective
- Constraints: cladding attachment
- Good durability with proper design

Baseline
2x6 w/ R-22 batts
= **<R-13 to R-16 effective**
(Framing Factor % dependent)

Cladding Attachment through Exterior Insulation

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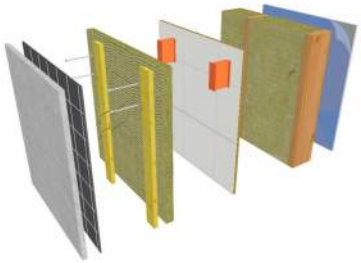
Thermally Efficient Clip & Rail Systems



Thermally Efficient Masonry Ties & Supports

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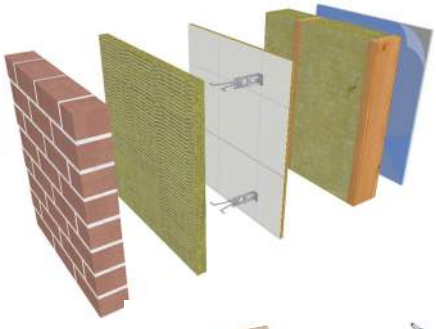

Masonry Systems Guide

Cladding Attachment through Exterior Insulation

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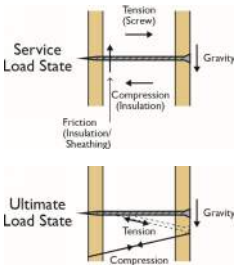
Screws through Exterior Insulation & Vertical Strapping



Case Study: Passive House Prefabrication

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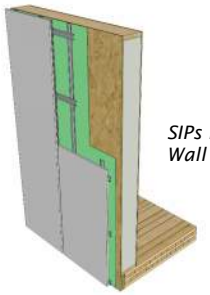
- R-40 pre-fabricated wood-frame walls, 6" Rigid Mineral wool over 2x6 framed & insulated wall
- Metal cladding with long screws through insulation & rainscreen strapping

Case Study: Passive House Prefabrication

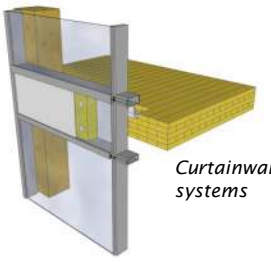
Wall Designs for Taller Wood Buildings

→ **Strategies (continued)**

- → Robust air-tight, water resistant & breathable wall membrane (AB/WRB)
- → Membrane compatibility with glazing, roofing, and other assembly materials
- → Simple integration with glazing systems & other penetrations
- → Watch details at interfaces with mass timber structure (movement, gaps)

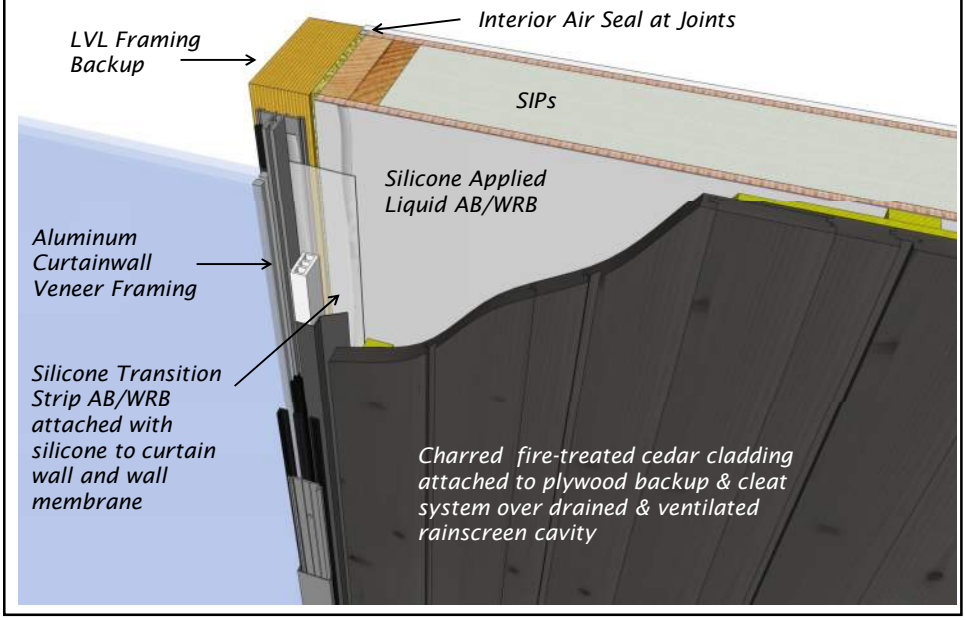


SIPs Pre-fabricated Wall Panels



Curtainwall systems

Case Study: WIDC Infill Walls – SIPs & Curtainwall



Case Study: WIDC AB/WRB Membrane

Case Study: WIDC Cladding Panels

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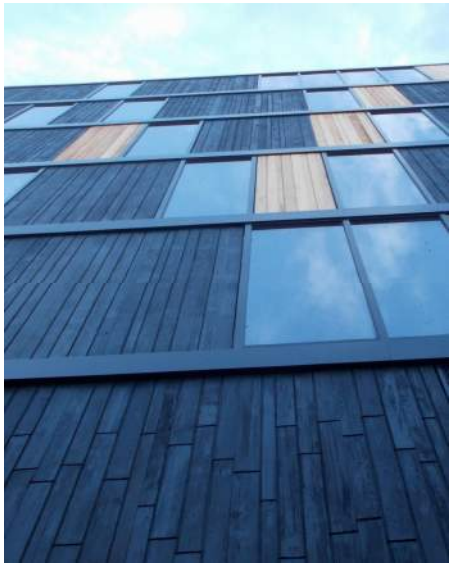

John Boys, Nicola Log-works

Mass Timber Roofs…. And Many Lessons Learned

Roof Design for Larger Wood Buildings

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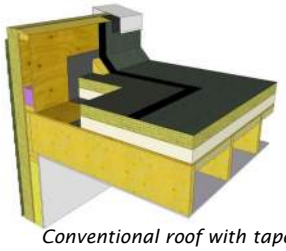
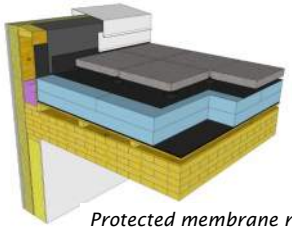
- **Key Considerations:** Keep dry, allow to dry, robustness of assemblies, sloping strategy
- **Strategies:**
  - Protect wood roof from getting wet during construction
  - Design assembly with redundancy for in-service drying
  - Slope structure where possible
  - Insulation always on top in conventional or protected membrane assemblies – avoid insulating below
  - Question the need for heavy timber panels when other systems may suffice



Conventional roof with tapered insulation over wood joists



Protected membrane roof over vented & tapered structure over CLT

Keep Wood Dry

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- Several taller & larger wood building projects in Pacific Northwest have had issues & delays during construction as a result of wet roofs & fungal contamination
- Hence guidance for protection during construction, temporary roofs, immediate roofing, scheduling, built-in redundancy for drying

Keep Wood Dry & Use Appropriate Materials

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Key Lessons: Don't use paper faced insulation in contact w/ damp wood & drying through more than one layer of plywood can be too slow

Care with Temporary Roofs

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Key Lessons: Be very careful with selection of temporary roof membranes on flat roofs – impermeable peel & stick can be a double edged sword

Protect Roofs from Rain – But Not Too Late

Key Lessons: Do not treat wood floors & roofs like concrete - do not let nail-laminated lumber get wet (it will swell a lot) & do not assume it will dry out fast enough on its own…

Monitoring & Drying

Key Lessons: Drying of heavier timber wood roofs is possible during construction in wet climates but does take time and money

Case Study – WIDC Roof Assembly

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Case Study – WIDC Roof Assembly

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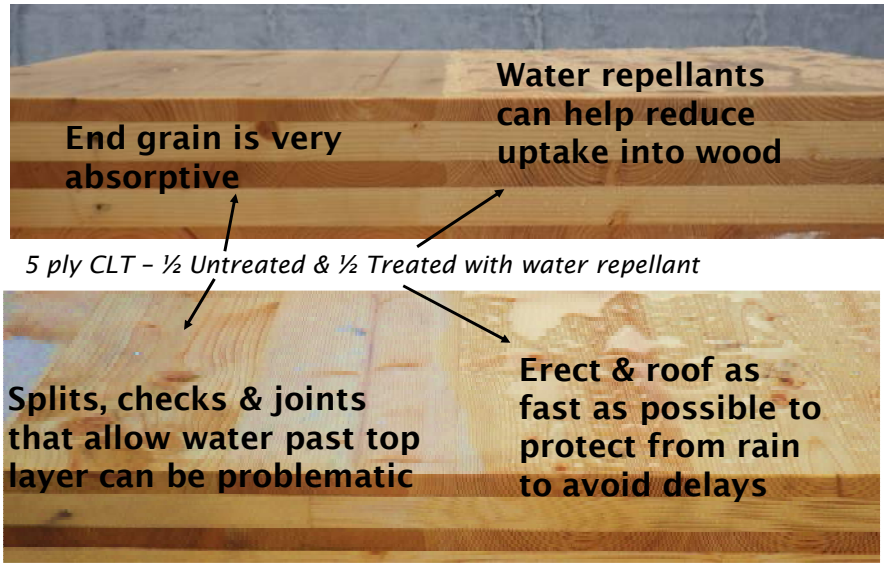
Protection of CLT & NLL Panels During Construction

→ Pre-applied torch applied roofing membranes applied to horizontal panels in factory

→ Laps torched onsite immediately after installation

Protection of Wood During Construction - Finland

Protection of CLT from Construction Wetting



Summary – Onward & Upward with Wood

- Growing industry interest in the design & construction of both larger and taller mass timber buildings
- Design of building enclosures for redundancy & drying – vapor open drying, air-tight and thermally efficient
- Need to protect mass timber elements like CLT & NLL from wetting during construction – does not behave like plywood or solid lumber
  - Protect with the right membranes at the right time
  - Design for redundancy where possible
  - Growing use of pre-fabricated elements


Discussion + Questions
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