Learning Objectives

At the end of this program, participants will be able to:

1. Understand the fire and life safety advantages of CLT for both exposed and non-exposed conditions.
2. Recognize the construction advantages in the speed of build and cost savings.
3. Demonstrate acoustic and building envelope assemblies and discuss their pros and cons.
4. Implement structural detailing appropriate for the application of CLT.
National CLT Milestone

- First 100% CLT Commercial Building in the US
- Whitefish, MT
- 2 stories, 5000 sf
- Structural shell < 5 days

Long Hall, Whitefish MT

- 4 Carpenters
- 2 Stories
- 4 ½ Days
- Timeline Reduced from 26 weeks to 17
- $ (Import) on par CMU
- Weighs 4 Times Less
- 30% Foundation Reduction
- 1 hr rated Stairways & Exterior Walls = CLT
- 143 tons carbon reduction by using wood
Cross Laminated Timber is...

- An engineered solid wood material
- Used as a wall, ceiling, and roof structural element
- Enhances and optimizes the many benefits of wood

**Brief History**

- Initially developed in Switzerland early ‘90’s
- Austria refined to current state in 1996
- Industry started dramatic growth in 2000’s
  - Better production efficiencies
  - Code changes
  - System proven and established
- Currently over 10M cu ft CLT in place
- Project by 2015: 20M – 35M cu ft

**Example Projects**

- "Austria-House" (2006)
  - Turin, Italy
- Building Research Centre
  - Step 2 (2007)
  - Graz, Austria
Example Projects

Multi-storey building (2001)
Vienna / Austria

“Wandritsch-Bridge” (1998)
St. Lorenzen / Austria

Going to New Heights – World’s Tallest Mixed-Use Wood Structure
- 4 Carpenters
- 9 Stories
- 27 Days
- Timeline Reduced from 72 weeks to 49
- 15% less $ than Concrete
- Weighs 4 Times Less
- 70% Foundation Reduction
- 330,000 tons carbon reduction by using wood
  = 210 years of building carbon emissions
- Stairways & Elevator = CLT
- Less than ¾” settlement for all 8 floors

Waugh Thistleton Architects & Techniker Engineers
The Stadthaus 24 Murray Grove, London

Concrete Frame Pedestal Base

Photography by Will Pryce

First Floor - Start timber panel construction of shaft core

Photography by Will Pryce
Second Floor of timber panel construction

Third Floor of timber panel construction

Fourth Floor of timber panel construction

Fifth Floor of timber panel construction
Cross Laminated Timber is...

- Structural
  - High strength to weight ratio
    - Up to 6 times lighter than concrete
- Acoustic
  - Good STC ratings
- Fire
  - Chars and resists fire spread
- Environmental/Carbon
  - Renewable & Sustainable
- Speed of build
  - Large format, accurately pre-manufactured elements
- Thermal Mass
  - Consistent thermal envelope
- Interior Environment
  - Clean, warm, vapor permeable

Design flexibility...

- No underlying structural grid
- Material is structural in all three axis

Prefabication gives...

- Accuracy
- Quick, easy assembly
  - Minimize labor
- Clean fit
- High quality
- Minimum job site waste

Excellent structural performance

- Proven seismic performance
  - E-defense facility in Miki, Japan
  - 7 Story full scale test
    - 14 tests – 10 over .3 g
    - Damage was negligible
- Biaxial cantilevers
- Well known performance characteristics
Optimized renewable product

- Private US forests grow approximately 20,000 ft³/minute
  - Est 1 ft³/ft² CLT Plan
- Finger-jointing and lamination make use of lower value fiber supply
- Carbon sequestration

![Map of Private US forests](http://fia.fs.fed.us/library/brochures/docs/Forest%20Facts%201952-2007%20English%20rev072411.pdf)

Healthy, warm interior

- Air tight but moisture permeable
- Multiple studies link wood and human health
- Visual appeal of wood can reduce stress
- Wood provides warmer reflected tones

![Image of interior](http://example.com/interior_image.jpg)

Conceptual Costing

<table>
<thead>
<tr>
<th>Item</th>
<th>CRMU</th>
<th>CLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original project size: 6,950 sf</td>
<td>$655,000</td>
<td>$616,000</td>
</tr>
<tr>
<td>Insulation</td>
<td>$143,34</td>
<td>$160,000</td>
</tr>
<tr>
<td>Framing</td>
<td>$130,34</td>
<td>$160,000</td>
</tr>
<tr>
<td>Structural Engineering/Code</td>
<td>$7,000</td>
<td>INCLUDED</td>
</tr>
<tr>
<td>Time of closure of Facility</td>
<td>22 weeks</td>
<td>12 weeks</td>
</tr>
<tr>
<td>Lots of Revenue</td>
<td>$40,000</td>
<td>$15,000</td>
</tr>
</tbody>
</table>

Total Costs: CRMU $712,000 vs. CLT $671,000

<table>
<thead>
<tr>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic scope</td>
</tr>
<tr>
<td>Reduce CLT G/LB shipping to 55,000</td>
</tr>
<tr>
<td>Updated Savings</td>
</tr>
</tbody>
</table>

![Cost Comparison Table](http://example.com/cost_table.jpg)
Conceptual Costing

### Sawbuck Do Jang, Whitefish - Cost Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>CMU</th>
<th>CLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original project size: 6,950 ft</td>
<td>665,000.00</td>
<td>616,000.00</td>
</tr>
<tr>
<td>Initial Cost (Whole Scheme):</td>
<td>7,000.00</td>
<td>INCLUDED</td>
</tr>
<tr>
<td>Structural Engineering/Code</td>
<td>$ 665,000.00</td>
<td>$ 616,000.00</td>
</tr>
<tr>
<td>Time of closure of Facility</td>
<td>20 weeks</td>
<td>17 weeks</td>
</tr>
<tr>
<td>Loss of Revenue</td>
<td>40,000.00</td>
<td>15,000.00</td>
</tr>
<tr>
<td>Total</td>
<td>$ 712,000.00</td>
<td>$ 671,000.00</td>
</tr>
</tbody>
</table>

**Savings**

- Domestic source: Reduce CLT/GB shipping to $5,000
- Updated Savings: $ 76,000.00
- Savings: $ 41,000.00 (6.11%) over CMU

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**Approx 10 week build time savings**

**Projected Savings greater than 6% over CMU**

**Projected Savings closer to 12% over CMU with domestic source**
CLT Costing “Rules of Thumb”

- Full CLT construction (walls, floors, roof)
  - Square foot floor area ≈ cubic foot of CLT
- Cubic foot of CLT ≈ $20-$23 + delivery
- Installed cost ≈ $30-$35
- Schedule 15-20 minutes/panel
  - Regardless of size
- (OBVIOUSLY VERY CRUDE BALLPARK)

Lay-up and Production

- Finger-jointed, planed lamellas laid tightly side-by-side in layers
- Non-VOC glue applied between layers
- Placed in large format press – up to 100 psi for gap free bond
- Surface finish:
  - Industrial
  - Visual

CLT Manufaturer’s ANSI Standard

- ANSI/APA
  - PRG 320-2011
    - Standard for Performance-Rated Cross-Laminated Timber
    - Start: Mar 11, 2010
    - 35 Committee Members
    - Release: Dec 22, 2011
CLT ANSI Standard

- ANSI/APA PRG 320-2011
  - Key Areas...

CLT Composition

- Lengths: to 50 feet
- Widths: to 12 feet
- Thicknesses: 2 ½” to 12” +
- Layers: 3 to 9 +
- Lamella: 5/8” to 2”
- Wood: Pine, DF/L, Spruce
- Density: 30-35 lb/ft³

CLT Performance Criteria

- Moisture content: 12% +/- 2%
- Dimensional stability:
  - In panel plane:
    - 0.01% per % change in moisture content
  - Across thickness:
    - 0.20% per % change in moisture content
- Airtight – no measurable leakage

ANSI Std Dimensional Tolerances
CLT Fire Resistance

- Objectives of Fire Resistance
  - Safe evacuation of occupants
  - Contain fire and smoke in compartment of origin
  - Prevent spread of fire from compartment
  - Fire fighters safety
  - Property protection
  - Structural integrity

- Insulation Failure
  - Temperature rise of 140 °C average or 180 °C at any point on unexposed side
  - Ext time of 0.5 mm at 1 hr = 30 °C (86 °F)

- Integrity Failure
  - Passage of flame or gases hot enough to ignite cotton pads
  - Char rates well known
    - 1.5 in/hr
    - 2+ layers remain

- Structural Failure
  - Inability to sustain the applied load at some point during the test
    - 1 vert layer = > 5k bearing
    - Freespan load = < 1475 plf
    - Surrounding structure transfers load

- Protection of metal connection devices

CLT vs Heavy Timber

- Heavy Timber Design for Fire Resistance
  - Multi-sided charring
  - Single axis loading – multiple discreet structural elements
  - Cannot redistribute load

- CLT Design for Fire Resistance
  - Single-sided charring
  - Multi-axis loading – single monolithic structural element
  - Can redistribute load

Graph from Experimental Analysis of Cross-laminated Timber Panels in Fire, Andrea Frangi, Mario Fontana, Enich Hugi, Robert Jaoulion, Fire Safety Journal (2009)

CLT STRUCTURAL
General CLT Design Principal

- Align grain of major strength axis parallel to primary panel load
  - Wall gravity loads = vertical grain layers
  - Beam design = span with major axis
- Ignore layers/grain perpendicular to primary panel load

CLT under stress...

CLT Effective Moment of Inertia
CLT Effective Moment of Inertia

- Increasing number of layers:
  - 3 Layers
  - 7 Layers

- Decreasing $I_{eff}$:
  - 57%
  - 28%
### CLT Effective Moment of Inertia

**Calculation value \( I_{\text{eff}} \)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Lay-up</th>
<th>( I_{\text{eff}} ) (dependent on span between supports of single span)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,00 m</td>
<td>2,00 m</td>
<td>3,00 m</td>
</tr>
<tr>
<td>0.80 m</td>
<td>2,00 m</td>
<td>3,00 m</td>
</tr>
<tr>
<td>0.90 m</td>
<td>2,00 m</td>
<td>3,00 m</td>
</tr>
<tr>
<td>1.00 m</td>
<td>2,00 m</td>
<td>3,00 m</td>
</tr>
</tbody>
</table>

**Increasing span width**

- \( 1,00 \text{ m} \) to \( 8,00 \text{ m} \)
  - **53/45 = 17%**
  - **96/78 = 23%**
  - **96/53 = 81%**
<table>
<thead>
<tr>
<th>Panel Thickness</th>
<th>3.07 in</th>
<th>3.86 in</th>
<th>4.65 in</th>
<th>5.28 in</th>
<th>5.51 in</th>
<th>5.75 in</th>
<th>6.30 in</th>
<th>6.81 in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Span L/480 Uniform Load</td>
<td>78.35 DL</td>
<td>99.35 DL</td>
<td>118.35 DL</td>
<td>134.85 DL</td>
<td>146.55 DL</td>
<td>160.55 DL</td>
<td>173.55 DL</td>
<td></td>
</tr>
</tbody>
</table>

**CLT Design Chart**

- **Panel Thickness**: 3.07 in
- **Single Span L/480 Uniform Load**: 78.35 DL
- **Width between supports L**: 60 ft
- **Uniform Load (psf)**: 50 psf

9.5’/3.07” = 3.1
For quick estimate
Thickness (inches) \times 3 = \text{Maximum span (feet)}
Connectors in CLT

Minimum distances between connecting means in the lateral surfaces

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>Minimum Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screws</td>
<td>( b_1 ) ( b_2 ) ( b_3 ) ( b_4 ) ( b_5 ) ( b_6 )</td>
</tr>
<tr>
<td>Nails</td>
<td>( (3+3 \text{ cm}) ) ( 3 ) ( 3 ) ( 3 ) ( 3 ) ( 3 ) ( 3 )</td>
</tr>
<tr>
<td>Dowel pins</td>
<td>( 3 ) ( 3 ) ( 3 ) ( 3 ) ( 3 ) ( 3 )</td>
</tr>
<tr>
<td>Bolts</td>
<td>( 3 ) ( 3 ) ( 3 ) ( 3 ) ( 3 ) ( 3 )</td>
</tr>
</tbody>
</table>

Minimum thickness of adhesive layer in mm

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>Minimum Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screws</td>
<td>3 mm</td>
</tr>
<tr>
<td>Dowel pins</td>
<td>3 mm</td>
</tr>
<tr>
<td>Bolts</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

 Minimum anchoring depth of jointing means in narrow surfaces in mm

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>Minimum Anchoring Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screws</td>
<td>3 mm</td>
</tr>
<tr>
<td>Dowel pins</td>
<td>3 mm</td>
</tr>
<tr>
<td>Bolts</td>
<td>3 mm</td>
</tr>
</tbody>
</table>
Foundation

Foundation Connection
- Foundation to CLT Connection
  - Anchor bolt offset from panel connection
  - Flex connection

Section View Connections
Section View Connections

Questions?

This concludes The American Institute of Architects Continuing Education Systems Course.

DARRYL S BYLE, PE
darryl@crosslamsolutions.com
www.crosslamsolutions.com
406-261-4654