Case Study:
First Commercial Project Opens Doors for CLT in US

Presented by
Darryl Byle, PE,

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

1. Identify the advantages of using cross laminated timber (CLT) for an infill project.

2. Describe building official concerns related to the first use of CLT in a commercial building in Montana and how they were satisfied.

3. Explain how CLT reduced the building’s carbon footprint.

4. Describe how the use of CLT contributed to energy efficiency of the completed building.

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Project Team

• The Long Hall Owner:
  – Andy Hamer
• Designer:
  – Datum Drafting Design/Jason Hatten
• CLT Supplier/Installation:
  – Innovative Timber Systems/SmartWoods
  – Pete McCrone/Pat Clark
    • Raising Crew: Compass Construction
    • 3D SketchUp Modeling: OTB Design Works
• Professional of Record/Project Mgr:
  – DSB Engineering & Consulting, PC (ITS)
Introduction

- Well insulated but...
- Fire resistance
- Inefficient use of footprint and...
- Moisture management
- Interior environment
- Not too healthy – Old wet socks...

Conceptual Design

- Originally 5950 sf
- CMU Perimeter Walls to address fire rating
- Upper level clad with Barn Wood board/batten + accent panels
- Do Jang martial arts studio upstairs
- Retail/business downstairs

Why CLT

- Owner had an affinity for wood and sustainable design
- Datum Drafting invited DSB to present CLT as an alternative to CMU
  1st – What is CLT?
  2nd – Why use it for this project?
  3rd – What challenges do we need to overcome?
What is CLT

- A solid pre-fabricated, monolithic engineered wood material used to construct the entire building envelope including floors, walls, and roofs.

Why CLT

- **Why CLT?**
  - Structural
  - Acoustic
  - Fire
  - Environmental/Carbon
  - Speed of build
  - Thermal Mass
  - Interior Environment
Why CLT

- **Structural**
  - Dimensional stability
  - High stiffness
    - in-plane
    - out-of-plane
  - Biaxial loading
    - Bidirectional cantilever
  - Increased splitting resistance
  - NEW ways to design
  - NEW solutions

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Structural

- **Out of Plane Loading**
  - Load distributed
  - Dissipates quickly
  - Panel/corbel/beam assy acts as moment frame

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Structural

- Conducted at E-Defense in Japan
  - Building weight 270t (120t + 150t)
  - Wall panel thickness
    - 140 mm floors 1 and 2
    - 125 mm floors 3 and 4
    - 85 mm top 3 floors
    - All floor panels 142 mm
  - Wall panels length 2.5 m
  - Two 3-axial records used
    - Kashiwazaki Kariwa Quake
      - X (0.3g) Y (0.68g) Z (0.4g)
    - Kobe JMA Quake
      - X (0.6g) Y (0.82g) Z (0.34g)
  - Total of 14 tests
    - 10 tests were \( \geq 0.3g \)

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Why CLT

- **Acoustic**
  - Solid panels effective against airborne sound
  - Flanking paths limited
    - Simple sealing around perimeter
    - Minimal penetrations
  - CLT alone = 39 STC
    - One element vs 3-5

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Why CLT

- [http://www.youtube.com/watch?v=T08KRyVhyeo](http://www.youtube.com/watch?v=T08KRyVhyeo)

- The building showed very good seismic behavior under all severe earthquake motions
  - Max top displacement of 287 mm (X) and 175 mm (Y)
  - Max storey drifts approx 2.4% (X) and 1.6% (Y)
  - The damage after all tests was negligible
Why CLT

- **Fire**
  - Similar to heavy timber
  - Charring well established
  - Existing standards
    - NDS
    - IBC
  - Single side exposure
    - Load distribution via diaphragmatic action
  - Elaborate later…

Why CLT

- **Environment/Carbon**
  - Completely renewable
    - 148 cubic meters of wood for this building would grow in NA in 26 seconds
  - Carbon Store
    - 104 metric tons
  - Avoid Greenhouse Gas generated from concrete and steel production
    - 59 metric tons
  - Total estimated Carbon benefit:
    - 143 metric tons CO₂

(Post-project statistics from WoodWorks Case Study: CLT Milestone in Montana)

Why CLT

- **Speed of build**
  - Pre-cut panels
  - Controlled construction environment
  - CNC accuracy
  - Site costs reduced
    - Fewer people
    - Less time
  - Structure available sooner = cash flow

(Sneak peek…)

Speed of Build
Why CLT

- **Thermal**
  - Thermal mass
    - Thermal buffering
    - Inside thermal envelope
    - Vs CMU exterior
  - Provides additional insulation value
  - Allows nearly uniform thermal blanket
  - Tight envelope
    - All joints caulked & taped
    - Fire caulk on rated walls
    - CNC joints tight

- **Interior Environment**
  - Food grade glues
  - Unsung benefit of CLT
    - Structure self-regulates its moisture
      - Gortex type of function
      - No moisture trapped in cavities
      - Hygro-thermal balance
  - **WUFI**
    - Wärme und Feuchte instationär (Transient Heat and Moisture)
    - Building Envelope Thermal & Moisture Analysis
Why CLT

• So the owner is interested…
• 1st question:
  • What does it cost?
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: 5950 sf</td>
<td>$665,000.00</td>
<td>$616,000.00</td>
</tr>
<tr>
<td>2009 ICC BVD 6 ccc: IIB=$143.24, RIA=$130.34</td>
<td>$40,000.00</td>
<td>$40,000.00</td>
</tr>
<tr>
<td>MT Adj = .84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IIB = $715,000; RIA = $651,500</td>
<td>$7,000.00</td>
<td>INCLUDED</td>
</tr>
<tr>
<td>Initial Cost (Whole Scheme)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipping CLT &amp; GLB from Austria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural Engineering/Code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time of closure of Facility</td>
<td>22 weeks</td>
<td>12 weeks</td>
</tr>
<tr>
<td>Minimum (No allowance made for weather)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss of Revenue</td>
<td>$40,000.00</td>
<td>$16,000.00</td>
</tr>
<tr>
<td>Assumed $2,500 per week</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>$712,000.00</td>
<td>$671,000.00</td>
</tr>
</tbody>
</table>

Savings

$41,000.00  6.11%

Domestic source
Reduce CLT/GLB shipping to $5,000

Updated Savings

$76,000.00  11.95%

Conceptual Parameters

- Shipping dimensional constraints
  - 39’ x 7’4”
- Maximize interior space
  - Minimize wall thickness
  - Minimize cross-walls downstairs
- Maximize interior exposure of CLT
  - No sheet rock or fire protection
- Wants interior exposed beams
- Exterior appearance fixed by ARC approval
  - No wall penetrations
  - Non-combustible wall cladding/insulation
- Liquidated damages will be assessed for delays/missed milestones

Code Considerations

Game is on if... the Building Official will ‘buy in’...

OR

104.11 Alternative materials, design and methods of construction and equipment.

- Chapter 7 Fire-Resistance-Rated Construction
- Chapter 8 Interior Finishes
- Chapter 14 Exterior Walls
- Chapter 15 Roof Assemblies and Rooftop Structures
- Chapter 16 Structural Design
- Section 2304.11 Protection Against Decay and Termites
Code Considerations

• 104.11 Alternative materials, design and methods of construction and equipment.
  – The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.
  – Translation…

New technology requires “buy-in” from the regulatory community
– “Buy-in” = acceptable to the “Authority Having Jurisdiction” (AHJ).
– Provide sufficient information to the AHJ for them to find CLT
  – …is a satisfactory solution
  – …complies with the intent of the building code
  – …is at least equivalent to code prescribed solutions in
    • Quality
    • Strength
    • Effectiveness
    • Fire-resistance
    • Durability
    • Safety

Section 602 Construction Classification
– Type V Construction
  • Limited area
  • Direct implementation
– Type IV Construction
  • Based on post & beam construction
  • Doesn’t account for panelized benefits
    – Single side fire access
    – Monolithic structural stability
  • Element sizing based on 3 exposed sides
  • CLT exposed on one side

Chapter 7 Fire-Resistance-Rated Construction
– Insulation Failure
  • Temperature rise of 140 °C average or 180 °C at any point on unexposed side.
  – Est temp of 88 mm at 1 hr = 30 °C (86 °F)
– Integrity Failure
  • Passage of flame or gases hot enough to ignite cotton pads.
    – 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

Graph from Experimental Analysis of Cross-laminated Timber Panels in Fire, Andrea Frangi, Mario Fontana, Erich Hugi, Rober Jubstlin, Fire Safety Journal (2009)
Code Considerations

- Wood performs well ‘under fire’ 😊
  - Well known characteristics
    - Large wood members
      - Burn slowly
      - Form char layer
        - Isolates/insulates remaining fiber
    - Non-charred wood
      - Retains strength
      - Dimensional stability
- No concealed spaces
- NDS Part 16
  - Fire Design of Wood Members

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

Heavy Timber Design for Fire Resistance

- Multi-sided charring
- Single axis loading
- Cannot redistribute load

CLT Design for Fire Resistance

- Single-sided charring
- Multi-axis loading
- Can redistribute load

Chapter 8 Interior Finishes

- TABLE 803.9 – INTERIOR WALL AND CEILING FINISH REQUIREMENTS BY OCCUPANCY
  - Sprinklered Rooms and enclosed spaces in A, B, E, F, H, M, R, S = C
  - 803.1.1 Interior wall and ceiling finish materials
    - Class A:
      - Flame spread index 0-25
      - Smoke-developed index 0-450.
    - Class B:
      - Flame spread index 26-75
      - Smoke-developed index 0-450.
    - Class C:
      - Flame spread index 76-200
      - Smoke-developed index 0-450.
      - Spruce and Douglas fir
        - Flame-spread index of 60-100.
        - No wood product exceeds smoke-developed index of 450

Class A:
- Flame spread index 0-25
- Smoke-developed index 0-450.

Class B:
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Spruce and Douglas fir
- Flame-spread index of 60-100.
- No wood product exceeds smoke-developed index of 450
Code Considerations

• Chapter 14 Exterior Walls &
• Chapter 15 Roof Assemblies and Rooftop Structures
  – Moisture management
    • Flashing
    • No moisture accumulation
      – Convective sweeping of in-wall condensation
      – Roof venting
  – Wall cladding structural issues

The Long and short of it…
the Building Official **will** ‘buy in’…

– Wall cladding structural issues
Transition to CLT

- Tight lot constraints
  - Maximize preassembly
  - Wall cladding configuration
  - Fastener installation
- Soils report
  - Light footprint a benefit
    - Wall 1/3 the weight = 9” less footing

Panel Configuration

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

Panel Configuration

- Lateral Loading
  - Distributes thru panel
  - Tongue and groove distributes load to base

Transition to CLT

- Sub Coordination
  - Concrete
    - Flat +/- 1/8”
    - Square +/- ¼”
  - Drill in Anchor bolts – rebar placement can’t interfere

- Sub Coordination
  - Plumbing/Mechanical
    - No floor/ceiling cavity
    - Aesthetic routing or chase
    - Roof and plumbing drains
    - Rooftop Mini-split units

www.OTBDesignworks.com
Panel Configuration

- Vertical vs Horizontal (7’4” max width)
- Logistics

Panel Configuration

- Fun design features of CLT
  - Cantilevered floors
  - Live walls
  - Shear
  - In-plane bending

Panel Configuration

- Shop Drawings ... 130+
Shipping

- 4 containers
- Logistically organize each panel
- Consolidate highest needs in 1st container for RUSH
- 1st container comes in 2nd – 2 weeks late 😃
  - Long story…
  - US Production should alleviate this…

Preassembly

- Panels assembled and loaded in reverse order
- Custom strong-back for stability and load distribution
- A-frame on flatbed to site

Raising

- Sill plate in place
- Sheathing covering finished concrete
- Walls braced off floor mounted ledger boards
- Trailers in front and back - Crane moves
- Classic timing for street repair…

Raising

- Glulams rest in pockets – top plate provides lateral
- CLT beams rest on CLT walls – screw through walls
- Curved beams connect part way down wall
  - Concealed connector
**Raising**

- Adjustments are easy with the right tools
- CNC’d panels go together tightly with nice clean joints
- (Unlike precast concrete 😊)

**Sealing**

- Fire Caulk at all north & south ext wall joints
- Vapor permeable tapes on all joints
- Polymer foam tapes (sound)

**Insulation**

- Solid blanket – minimal thermal shorts
- Quick, non-combustible, moisture neutral
- Easy to place in tight space

**Cladding**

- Metal Hat channel N/S
- Wood battens E/W
- Diagonal load bearing screws
Montana Dept of Env Quality conducted an on-site educational training test
  - Visual inspection
  - Blower door analysis
  - Infrared camera scan
    - Relative coloration
Blower Door Test

- Test Day Conditions:
  - External temp: 35 degrees F
  - Internal temp: 65 degrees F
  - Partly Cloudy

- Air changes/hour at 50 Pascal (ACH 50)
  - Lower floor: 1.65 ACH 50
  - Upper floor: 1.41 ACH 50
    - Max acceptable is 4 ACH 50
    - < 10% tested buildings are tighter than 2 ACH 50

- US Army Corp. of Engineers blower door test
  - Lower floor: .122 CFM/sq ft (at -75 PA)
  - Upper floor: .126 CFM/sq ft (at -75 PA)
  - Upper floor: .175 CFM/sq ft (at +75 PA)
    - Max allowed: .25 CFM/sq ft (ASTM E-779)

Questions?

This concludes The American Institute of Architects Continuing Education Systems Course

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