EFFICIENT STRUCTURAL DESIGNS FOR MASS TIMBER BUILDINGS: THE ENGINEER’S ROLE IN OPTIMIZATION

Presented By:

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Senior Technical Director
WoodWorks

Greg Kingsley, PhD, PE
President & CEO
KL&A Engineers & Builders

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

- Exposed Timber (where & how much)
- Acoustics
- Concealed Spaces
- Connections
- Penetrations
- Grids & Spans
- Construction Type
- Fire-Resistance Ratings
- Member Sizes
- MEP Layout

The Answer is...They All Need to Be Weighed (Plus Others)
KEY EARLY DESIGN DECISIONS

Grids & Spans

- Consider Efficient Layouts
- Repetition & Scale
- Cost and Volume of Timber
- Manufacturer Panel Sizing
KEY EARLY DESIGN DECISIONS

Grids & Spans

- Consider Efficient Layouts
- Repetition & Scale
- Manufacturer Panel Sizing
- Transportation
# Key Early Design Decisions

## Construction Type

<table>
<thead>
<tr>
<th>Occupancies</th>
<th>Allowable Building Height above Grade Plane, Feet (IBC Table 504.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B, R</td>
<td>270 180 85 85 85 70 60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occupancies</th>
<th>Allowable Number of Stories above Grade Plane (IBC Table 505.4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2, A-3, A-4</td>
<td>18 12 6 4 4 3 3 2</td>
</tr>
<tr>
<td>B</td>
<td>18 12 9 6 6 4 4 3</td>
</tr>
<tr>
<td>R-2</td>
<td>18 12 8 5 5 5 4 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occupancies</th>
<th>Allowable Area Factor (At) for SM, Feet² (IBC Table 506.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2, A-3, A-4</td>
<td>135,000 90,000 56,250 45,000 42,000 28,500 34,500 18,000</td>
</tr>
<tr>
<td>B</td>
<td>324,000 216,000 135,000 108,000 85,500 57,000 54,000 27,000</td>
</tr>
<tr>
<td>R-2</td>
<td>184,500 123,000 76,875 61,500 72,000 48,000 36,000 21,000</td>
</tr>
</tbody>
</table>
**KEY EARLY DESIGN DECISIONS**

**Fire-Resistance Ratings**
- Driven Primarily By Construction Type
- Rated Structure or Not?
- Rating achieved through timber alone or non-com protection required?

**TABLE 601**

<table>
<thead>
<tr>
<th>BUILDING ELEMENT</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
<th>TYPE IV</th>
<th>TYPE V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Primary structural frame (see Section 202)</td>
<td>3&lt;sup&gt;a, b&lt;/sup&gt;</td>
<td>2&lt;sup&gt;a, b, c&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b, c&lt;/sup&gt;</td>
<td>0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b, c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bearing walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior&lt;sup&gt;a, c&lt;/sup&gt;</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Interior</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Nonbearing walls and partitions Exterior</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonbearing walls and partitions Interior&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Floor construction and associated secondary structural members (see Section 202)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Roof construction and associated secondary structural members (see Section 202)</td>
<td>1&lt;sup&gt;1/2&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b,c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

See Table 705.5
KEY EARLY DESIGN DECISIONS

Fire-Resistance Ratings

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

<table>
<thead>
<tr>
<th>Panel</th>
<th>Example Floor Span Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-ply CLT (4-1/8&quot; thick)</td>
<td>Up to 12 ft</td>
</tr>
<tr>
<td>5-ply CLT (6-7/8&quot; thick)</td>
<td>14 to 17 ft</td>
</tr>
<tr>
<td>7-ply CLT (9-5/8&quot;)</td>
<td>17 to 21 ft</td>
</tr>
<tr>
<td>2x4 NLT</td>
<td>Up to 12 ft</td>
</tr>
<tr>
<td>2x6 NLT</td>
<td>10 to 17 ft</td>
</tr>
<tr>
<td>2x8 NLT</td>
<td>14 to 21 ft</td>
</tr>
<tr>
<td>5&quot; MPP</td>
<td>10 to 15 ft</td>
</tr>
</tbody>
</table>
KEY EARLY DESIGN DECISIONS

Member Sizes

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

0 HR FRR: Consider 3-ply Panel

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

Albina Yard, Portland, OR
20x20 Grid, 1 purlin per bay
3-ply CLT
Image: Lever Architecture
KEY EARLY DESIGN DECISIONS

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

0 HR FRR: Consider 3-ply Panel
- Efficient Spans of 10-12 ft
- Grids of 20x20 (1 purlin) to 30x30 (2 purlins) may be efficient

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

Member Sizes

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

1 or 2 HR FRR: Likely 5-ply Panel
- Efficient spans of 14-17 ft
- Grids of 15x30 (no purlins) to 30x30 (1 purlin) may be efficient

First Tech Credit Union, Hillsboro, OR
12x32 Grid, One-Way Beams
5-ply (5.5”) CLT
Image: Swinerton
KEY EARLY DESIGN DECISIONS

Member Sizes
• Impact of FRR on Sizing
• Impact of Sizing on Efficient Spans
• Consider connections – can drive member sizing

1 or 2 HR FRR: Likely 5-ply Panel
• Efficient spans of 14-17 ft
• Grids of 15x30 (no purlins) to 30x30 (1 purlin) may be efficient

Clay Creative, Portland, OR
30x30 Grid, 1 purlin per bay
2x6 NLT
Image: Mackenzie
KEY EARLY DESIGN DECISIONS

MEP Integration: Smaller Bay at Central Core, Branches in Exterior Bays

Credit: Blaine Brownell
Credit: WoodWorks
KEY EARLY DESIGN DECISIONS

MEP Integration: Dropped Below MT Framing

Credit: Alex Schreyer
Credit: WoodWorks
KEY EARLY DESIGN DECISIONS

MEP Integration: Penetrations Through MT Framing
KEY EARLY DESIGN DECISIONS

MEP Integration: Under Slab, Through Chases
KEY EARLY DESIGN DECISIONS

MEP Integration: In RAF Above MT Panels

Credit: BOKA Powell
Efficient Structural Designs for Mass Timber Buildings: The Engineer’s Role in Optimization

By Ricky McLain and Greg Kingsley

Part 2: Grid Cost Studies on Colorado Mass Timber Projects
MASS TIMBER COST DEPENDS ON THE PRICE OF LUMBER
Conceptual cost of CLT is intended to include:

- CLT
- Shop fab
- Sanding
- Delivered
- Screws

but does not include:

- Finishes

CLT COST DEPENDS ON VOLUME AND EFFICIENCY
GLULAM BEAM AND COLUMN COST

Glulam Beam and Column Cost as a function of width

Cost / Cubic Ft

Column

Beam

Beam Width or Column Width (in)
Connection Cost – Different Connection “Classes”
Connection Cost based on “Connection Class”

Cost for each class is based on …

- Connection material
- Screws and bolts
- Beam end fabrication
- Girder fabrication
- Field Installation

Cost increases with …

- Connection “Class”
  - Simple screws
  - Complex hidden custom connector
- Reaction carried
20 ft timber bents, no beams, CLT of varying span
BOULDER LOADING DOCK

- 25 x 30 Grid
- 7-ply 5-layer CLT Floors
Square bay, CLT with 2 equal (varying) spans
PLATTE FIFTEEN

- 30 x 30 Grid
- 3-ply CLT Floors
<table>
<thead>
<tr>
<th></th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
<th>30'</th>
</tr>
</thead>
<tbody>
<tr>
<td>15'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20'</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>25'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Wood Bay Study: 15x15 up to 30x30
Hybrid Steel and Wood vs Wood

HYBRID E - 3-Ply CLT on Steel Grid

WOOD STUDY E - 3-Ply CLT Timber Grid
Some conclusions

• **Timber is not the same as steel**
  - When establish grid, remember:
    - Timber: Wood volume is key  Cost usually goes up with span
    - Steel: Number of pieces is key  Cost usually goes down with span

• **Collaboration and coordination is critical**
  - Engage all stakeholders early!
  - Architects, engineers, contractors, fabricators, erectors all have a part to play in optimizing systems

• **After grids are set, don’t forget other factors**
  - Connection cost
  - Constructability
  - Interface with other materials
THANK YOU

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