Structural Mass Timber Design

The Engineer’s Role in Optimization

Presented by Greg Kingsley, PhD, PE
The Engineer’s Role in Economy: OUTLINE

1. **The challenge**: Are we using mass timber effectively?
   A. Case Study 1: A simple house

2. **Mass timber panels** and what they cost.
   B. Case Study 2: A sustainability showpiece

3. **Mass timber beams and columns** and what they cost.
   C. Bay studies
   D. Case Study 3: Boulder office

4. **Mass timber connections** and what they cost
   E. Case Study 4: Denver office

5. **Steel beams and columns** and what they cost
   F. Case Study 5: Steel/timber hybrid office
   G. Case Studies 6 and 7: Starting with timber
THE CHALLENGE

Are we using mass timber effectively?
Case Study 1 - Wyoming

In which we get our introduction to mass timber
RESIDENCE 1

Carney Logan Burke Architects
MASS TIMBER PANELS

What are they?
What does a structural engineer need to consider?
Some Mass Timber Panel Options

- Nail Laminated Timber (NLT)
- Glue Laminated Timber (GLT)
- Laminated Veneer Lumber (LVL) and Mass Plywood Panels (MPP)
- Cross Laminated Timber (CLT)

Images Source: Structurecraft
Common CLT Layups

3-ply 3-layer (3.43” - 4.14”)

5-ply 5-layer (5.47” - 6.90”)

7-ply 7-layer (7.52” - 9.66”)

9-ply 9-layer (9.57” - 12.42”)

7-ply 5-layer

9-ply 7-layer
Now we are going to talk about cost ... scary!

Someone has to go first
WHAT DOES CROSS LAMINATED TIMBER COST?
CLT COST DEPENDS ON THE PRICE OF LUMBER
CLT COST DEPENDS ON THE MANUFACTURER

Certified North American producers of structural CLT

<table>
<thead>
<tr>
<th>Company</th>
<th>State/Province</th>
<th>Country</th>
<th>Panel size</th>
<th>Typical species</th>
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</thead>
<tbody>
<tr>
<td>Structurlam</td>
<td>BC</td>
<td>Canada</td>
<td>10’ x 40’ CLT</td>
<td>SPF / Doug Fir</td>
</tr>
<tr>
<td>Nordic</td>
<td>Quebec</td>
<td>Canada</td>
<td>8’ x 64’ CLT</td>
<td>Black Spruce</td>
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<tr>
<td>DR Johnson</td>
<td>Oregon</td>
<td>U.S.</td>
<td>10’ x 24’ CLT</td>
<td>Doug Fir</td>
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<tr>
<td>Smartlam</td>
<td>Montana</td>
<td>U.S.</td>
<td>10.5’ x 40’ CLT</td>
<td>SPF</td>
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<tr>
<td>Freress Lumber Co</td>
<td>Oregon</td>
<td>U.S.</td>
<td>12’ x 48’ MPP</td>
<td>Doug Fir</td>
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<tr>
<td>International Beams</td>
<td>Alabama</td>
<td>U.S.</td>
<td>11.5’ x 52’ CLT</td>
<td>Southern Pine</td>
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<tr>
<td>(w/ KLH)</td>
<td>Quebec</td>
<td>Canada</td>
<td></td>
<td></td>
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<tr>
<td>Katerra</td>
<td>Spokane, WA</td>
<td>U.S.</td>
<td>12’ x 60’ CLT</td>
<td>SPF</td>
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<tr>
<td>Vaagen Timber</td>
<td>Colville, WA</td>
<td>U.S.</td>
<td>4’ x 60’ CLT</td>
<td>Doug Fir</td>
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</table>

Coming soon … January 2020?
- Kalesnikoff               | Castlegar, BC  | Canada  | 11.5’ x 60’ CLT | SPF / Doug Fir           |
<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>• KLH</td>
<td>Austria, Switzerland, UK</td>
</tr>
<tr>
<td>• AHC/Derix</td>
<td>Germany</td>
</tr>
<tr>
<td>• Stora Enso</td>
<td>Finland and Austria</td>
</tr>
<tr>
<td>• Hess</td>
<td>Germany</td>
</tr>
<tr>
<td>• Binderholz</td>
<td>Germany</td>
</tr>
<tr>
<td>• ...</td>
<td>?</td>
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</table>
CLT COST DEPENDS ON THE TOTAL VOLUME OF WOOD
Unit cost of CLT panels by length and number of plies

Conceptual cost of Dr K’s Generic CLT is intended to include:
  • CLT
  • Shop fab
  • Sanding
  • Delivered
  • Screws

but does not include:
  • Finishes
THE GRID WILL AFFECT CLT FAB AND ERECT COST

Manufacturer constraints will affect design choices:

- Strength
- Stiffness
- Vibration
- Material species
- Material grade
- Layup
- Panel dimensions (erection speed)
Case Study 2 - Colorado
CSU Pavilion

In which we make an environmental statement
CSU PAVILION

• 2-stories
• Type V construction
• 7-ply CLT floors
• 7-ply CLT roofs
• Structurlam
• Completed 2014
CSU PAVILION
WHAT DOES GLUE-LAMINATED TIMBER COST?
Built up sections: available from some manufacturers for wide beams, large columns. Widths of 24”+ available

GLT
Glue Laminated Timber

Photo: unalam
Dr K’s Glulam Beam Cost

Unit cost per cubic ft is a function of beam width
Dr K’s Glulam Column Cost

Unit cost per cubic ft is a function of column width
WHAT DOES CONCRETE COST?
Concrete

• Cost based on unit price per cubic yard

• Topping only in this study
Bay Studies
Estimating the “Conceptual Cost” of a structural bay

- CLT Cost
- Wood Beams and Girders
- Wood Columns
- Wood connections
  - Beams, Girders, Columns
- Steel Beams and Girders
- Steel Columns
- Concrete

Conceptual cost estimates that follow are appropriate only for illustrating the relative difference between similar systems.

They are not accurate enough to compare steel vs concrete vs mass timber systems.
Estimating the “Conceptual Cost” of a structural bay

“Conceptual Costs” do not include

• Lateral systems
• General conditions
• General requirements
• Construction time
• Shipping
• Protection
• Finishes etc. etc.

Conceptual cost estimates that follow are appropriate only for illustrating the relative difference between similar systems.

They are not accurate enough to compare steel vs concrete vs mass timber systems.
20 ft timber bents, no beams, CLT of varying span
Square Grid w/ secondary beams, 3-ply CLT of varying span
Square bay, CLT with 2 equal (varying) spans
Case Study 3 - Colorado Boulder Loading Dock

In which we push the grid to its limit
BOULDER LOADING DOCK
• Type IV, Sprinklered Construction
• 2-story
• 2012 IBC
• 7-ply 5-layer CLT Floors
• 5-ply CLT roof
• 3-ply CLT shear walls
• Stora Enso and Ligna Terra
• 25 x 30 Grid
Typical Connections

WALL SECTION AT BEARING WALL

CLT TO INTERIOR BEAM CONNECTION

CLT WALL PANEL
- PROVIDE CONTINUOUS MOISTURE PROTECTION FOR CONCRETE PLACED AGAINST CLT
- CONN ANGLE RE: CLT ENGINEER
- CONCRETE TOPPING RE: PLAN

FURRING AND METAL PANEL RE: ARCH

RIGID INSULATION RE: ARCH

CLT PANEL
- SCREWS RE: CLT SUPPLIER 12" OC MAX

T/SLAB RE: PLAN

GRID

CONCRETE TOPPING RE: PLAN

CLT PANEL
- SCREWS RE: CLT SUPPLIER 12" OC MAX
- GLULAM BEAM RE: PLAN NOTCH TO RECEIVE CLT PANEL

1 1/2"
BOULDER LOADING DOCK

- 25 x 30 Grid
- 7-ply 5-layer CLT Floors
- 5-ply CLT roof
- 3-ply CLT shear walls

OZ Architecture
Quinlan
KL&A
30 ft timber bents, no beams, CLT of varying span
BOULDER LOADING DOCK

Simple connections
WHAT MASS TIMBER CONNECTIONS COST?
WOOD CONNECTIONS ARE A DESIGN/COST DRIVER

“Wood structures are just connections held together by members”
Mass timber design connections

Panel to beam connections

Photo Credit: myticon
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
Case Study 4 - Colorado
Platte Fifteen

In which we get serious about economy
PLATTE FIFTEEN

Office / Retail
Type III-B Construction
1 floor concrete below grade
1 floor concrete above grade
3 floors + roof in mass timber
Concrete cores

30’ x 30’ grid
PLATTE 15
Office / Retail
Type III-B Construction
30’ x 30’ grid
PLATTE 15
Office / Retail
Type III-B Construction
30’ x 30’ grid
Early Pricing showed mass timber came at a premium.

Project Options - Price Comparison

- **Base = Drilled Piers and CLT**
  - $10,000,000
  - $30,000,000

- **Option #2 = “Bathtub” and CLT**
  - $12,000,000
  - $30,000,000

- **Option #3 = Drilled Piers and Structural Steel**
  - $10,000,000
  - $28,000,000

- **Option #4 = “Bathtub” and Structural Steel**
  - $12,000,000
  - $28,000,000

Slide courtesy of Adolfson & Peterson Construction
Critical cost control decisions for mass timber are made here
Selecting a CLT / Glulam Manufacturer for Platte 15

- GC used Choosing by Advantages (CBA)
  - Wood species (like paint colors!)
  - Manufactures’ unique efficiencies
  - Strength of coordination team
  - Project history
  - North American vs. Overseas
  - Facility visit

Slide courtesy of Adolfson & Peterson Construction
## Choosing By Advantages (CBA)

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>ALTERNATIVES</th>
<th>CLT PRODUCER #1</th>
<th>CLT PRODUCER #2</th>
<th>CLT PRODUCER #3</th>
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<tbody>
<tr>
<td><strong>Material Aesthetics</strong></td>
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<tr>
<td>Owner preference for lighter color</td>
<td>SPF</td>
<td>0</td>
<td>85</td>
<td>100</td>
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<tr>
<td>Advantage:</td>
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<tr>
<td><strong>Servicing Zero Lot Line</strong></td>
<td></td>
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<tr>
<td>Can delivery be sequenced or &quot;hot loaded&quot;</td>
<td>Yes</td>
<td>Yes</td>
<td>Container</td>
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<td>Advantage:</td>
<td></td>
<td>60</td>
<td>60</td>
<td>0</td>
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<td><strong>Replacement Flexibility</strong></td>
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<tr>
<td>Distance from project</td>
<td>1300 miles</td>
<td>2100 miles</td>
<td>5400 miles</td>
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<td>Advantage:</td>
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<td>40</td>
<td>25</td>
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<tr>
<td><strong>Local Crew for Installation</strong></td>
<td>Installed by Colorado Crews</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<td>Advantage:</td>
<td></td>
<td>20</td>
<td>0</td>
<td>20</td>
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<tr>
<td><strong>Total Importance:</strong></td>
<td>120</td>
<td>170</td>
<td>120</td>
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<tr>
<td><strong>Total Cost:</strong></td>
<td>$4.6M</td>
<td>$4.7M</td>
<td>$4.7M</td>
<td>$4.7M</td>
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Slide courtesy of Adolfson & Peterson Construction
Getting trades comfortable

Mass timber may be new to many of the subcontractors.

Comfort with the system will affect the cost.
Wood Bay Study: 15x15 up to 30x30
20x30 Double girder, no beams, 7-ply CLT

30x30 Single girder and beams w/ 3-ply CLT
PLATTE 15

50+ ft panels span five 10 ft bays

OZ Architecture  Adolfson & Peterson Construction

KL&A & Nordic
STEEL / TIMBER HYBRIDS

Collegiate Peaks Bank - RiNo
WHAT DOES STEEL COST?
Steel Pricing

Material Cost +
Detailing and Fabrication Cost +
Erection Cost

Total Cost

Approximately 2/3 of cost is labor and handling, not material
So …

Fewer larger pieces are usually more economical than many small pieces

<table>
<thead>
<tr>
<th>Section Size</th>
<th>Price per Piece</th>
<th>Price per Ton</th>
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<tbody>
<tr>
<td>W10x26 spanning 20 ft</td>
<td>$1,161 / pc</td>
<td>$4,255 / ton</td>
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<tr>
<td>W16x40 spanning 30 ft</td>
<td>$1,705 / pc</td>
<td>$2,707 / ton</td>
</tr>
<tr>
<td>W24x84 spanning 50 ft</td>
<td>$3,906 / pc</td>
<td>$1,771 / ton</td>
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</tbody>
</table>
Steel bent with CLT of varying spans between
Steel frame with beams @ 10 ft o.c., CLT spans 10 ft
Hybrid Bay Study: 15x15 up to 30x30
Open office – 30 x 30 steel grid with 3-ply CLT

HYBRID E - 3-Ply CLT on Steel Grid

Clear Height to Girder (ft)
Hybrid vs Wood Grid

HYBRID E - 3-Ply CLT on Steel Grid

WOOD STUDY E - 3-Ply CLT Timber Grid
Case Study 5 - Colorado Boulder Office

In which we explore hybrid solutions
Boulder Office

- Type III-B Construction
- 2-Stories
- Hybrid steel frame with CLT floors
- 30 x 30 grid

OZ Architecture

KL&A
Open office – 30 x 30 steel grid with 3-ply CLT

HYBRID E - 3-Ply CLT on Steel Grid

Lowest price

Selected

Conceptual Cost/sf

Clear Height to Girder (ft)

Sub-optimal CLT length
Typical Connections

- Type III-B Construction
- Hybrid steel frame with CLT floors
- 30 x 30 grid

CLT EDGE AT CFS WALL - SECOND FLOOR

3/4" = 1'-0"
Case Study 6 - Colorado
Denver RiNo Office

In which we raise the floor
DENVER RiNo OFFICE

- Grid: 20 ft x 20 ft Typical
- Type III-B, fully sprinklered
- 3-stories above grade
- 93,000 sf
- Roof: 3-ply CLT
- Floor 3: 3-ply CLT
- Floor 2: 7-ply CLT
  (High ceiling retail space below)
- Floor 1: Concrete
  (Parking below)
Square bay, CLT with 2 equal (varying) spans

WOOD D2 - Square Grid, One beam centered in bay

Connection Cost Savings

Conceptual Cost/sf

Clear Height to Girder (ft)

Concrete
Wood Conn
Wood
Clear Ht
DENVER RiNo OFFICE

- Grid: 20 ft x 20 ft
- Type III-B, fully sprinklered
- 3-stories above grade
- 93,000 sf
- 3-ply CLT roof
- 3-ply CLT floor 3
- 7-ply CLT floor 2
- Concrete floor 1
Case Study 7 - Colorado Denver University Pioneer Career Achievement Center (DU PCAC)

In which we search for the sweet spot
Denver University – BCCA
Burwell Center for Career Achievement

- Grid 24 ft x 24 ft
- 3-ply Doug Fir CLT floors
- 5-ply Doug Fir CLT shear walls
- Doug Fir glulam beams
- Doug Fir glulam columns

Early design images
Denver University – BCCA
Burwell Center for Career Achievement

- Grid 24 ft x 24 ft
- 3-ply Doug Fir CLT floors
- 5-ply Doug Fir CLT shear walls
- Doug Fir glulam beams
- Doug Fir glulam columns
Denver University – BCCA
Burwell Center for Career Achievement

- Grid 24 ft x 24 ft
- 3-ply Doug Fir CLT floors
- 5-ply Doug Fir CLT shear walls
- Doug Fir glulam beams
- Doug Fir glulam columns
• Grid 24 ft x 24 ft
• 3-ply Doug Fir CLT floors
• 5-ply Doug Fir CLT shear walls
• Doug Fir glulam beams
• Doug Fir glulam columns
Square bay, CLT with 2 equal (varying) spans
Some important topics that affect cost but not addressed here ...

Fire Rated Construction
MEP Coordination
# Proposed IBC Table 601
## Fire Resistant Rated Construction

<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>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
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<tr>
<td>Primary structural frame</td>
<td>3 2</td>
<td>1 0</td>
<td>1 0</td>
<td>3 2 2</td>
<td>HT 1 0</td>
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<tr>
<td>Bearing walls</td>
<td>Exterior</td>
<td>3 2</td>
<td>1 0</td>
<td>2 2</td>
<td>3 2 2 2</td>
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<tr>
<td></td>
<td>Interior</td>
<td>3 2</td>
<td>1 0</td>
<td>1 0</td>
<td>3 2 2 1/HT</td>
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<tr>
<td>Nonbearing walls</td>
<td>Exterior</td>
<td>See Table 602</td>
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<tr>
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<td>Interior</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0</td>
<td>0 0 0</td>
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<tr>
<td>Floor</td>
<td>2 2</td>
<td>1 0</td>
<td>1 0</td>
<td>2 2 2</td>
<td>HT 1 0</td>
</tr>
<tr>
<td>Roof</td>
<td>1.5 1</td>
<td>1 0</td>
<td>1 0</td>
<td>1.5 1 1</td>
<td>HT 1 0</td>
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</tbody>
</table>
Tall Wood requires design for fire rated assemblies
Loading Dock - MEP
Platte Fifteen - MEP
Some conclusions

• Don’t hammer square pegs into round holes
  • 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 fabricators 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
This concludes The American Institute of Architects Continuing Education Systems Course

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