Structural Mass Timber Design

The Engineer’s Role in Optimization

Presented by Greg Kingsley, PhD, PE

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board.
The Engineer’s Role in Economy: OUTLINE

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

   B. Case Study 2: A sustainability showpiece

   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
CLT

Cross Laminated Timber

Images and Slide Courtesy of Fast and Epp
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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<tbody>
<tr>
<td>Structurlam</td>
<td>BC</td>
<td>Canada</td>
<td>10’ x 40’ CLT</td>
<td>SPF / Doug Fir</td>
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<tr>
<td>Nordic</td>
<td>Quebec</td>
<td>Canada</td>
<td>8’ x 64’ CLT</td>
<td>Black Spruce</td>
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<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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<td>Smartlam</td>
<td>Montana</td>
<td>U.S.</td>
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<td>SPF</td>
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<td>Freres Lumber Co</td>
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<td>U.S.</td>
<td>12’ x 48’ MPP</td>
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<td>International Beams (w/ KLH)</td>
<td>Quebec</td>
<td>Canada</td>
<td>11.5’ x 52’ CLT</td>
<td>Southern Pine</td>
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<td>Katerra</td>
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<td>12’ x 60’ CLT</td>
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<td>Vaagen Timber</td>
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<td>4’ x 60’ CLT</td>
<td>Doug Fir</td>
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Coming soon ... January 2020?

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<td>11.5’ x 60’ CLT</td>
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### Multiple European Sources (14 +)

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<td>Austria, Switzerland, UK</td>
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<tr>
<td>AHC/Derix</td>
<td>Germany</td>
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<tr>
<td>Stora Enso</td>
<td>Finland and Austria</td>
</tr>
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<td>Hess</td>
<td>Germany</td>
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<tr>
<td>Binderholz</td>
<td>Germany</td>
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CLT COST DEPENDS ON THE TOTAL VOLUME OF WOOD

Dr K’s Generic CLT
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
GLULAM BEAM PRESS
Dr K’s Glulam Beam Cost

Unit cost per cubic ft is a function of beam width

![Graph showing cost per cubic foot as a function of beam width](image)
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
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
BOULDER LOADING DOCK

- 25 x 30 Grid
- 7-ply 5-layer CLT Floors
- 5-ply CLT roof
- 3-ply CLT shear walls
30 ft timber bents, no beams, CLT of varying span
BOULDER LOADING DOCK
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

<table>
<thead>
<tr>
<th>Project Options - Price Comparison</th>
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<tbody>
<tr>
<td>Base = Drilled Piers and CLT</td>
</tr>
<tr>
<td>Option #2 = &quot;Bathtub&quot; and CLT</td>
</tr>
<tr>
<td>Option #3 = Drilled Piers and Structural Steel</td>
</tr>
<tr>
<td>Option #4 = &quot;Bathtub&quot; and Structural Steel</td>
</tr>
</tbody>
</table>

$10,000,000 $12,000,000 $28,000,000 $28,000,000 $28,000,000 $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>CLT PRODUCER #1</th>
<th>CLT PRODUCER #2</th>
<th>CLT PRODUCER #3</th>
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<tr>
<td><strong>Material Aesthetics</strong></td>
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<tr>
<td>Owner preference for lighter color</td>
<td>SPF</td>
<td>Spruce</td>
<td>European Spruce</td>
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<td>Advantage:</td>
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<td>100</td>
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<tr>
<td><strong>Servicing Zero Lot Line</strong></td>
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<td>Can delivery be sequenced or &quot;hot loaded&quot;</td>
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<td>Yes</td>
<td>Container</td>
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<td>Advantage:</td>
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<td><strong>Replacement Flexibility</strong></td>
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<td>Distance from project</td>
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<td>Advantage:</td>
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<td><strong>Local Crew for Installation</strong></td>
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<td>Installed by Colorado Crews</td>
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<td>Advantage:</td>
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<td><strong>Total Importance:</strong></td>
<td>120</td>
<td>170</td>
<td>120</td>
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<td><strong>Total Cost:</strong></td>
<td>$4.6M</td>
<td>$4.7M</td>
<td>$4.7M</td>
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The table above compares three CLT producers based on various factors. Each factor is rated on a scale of 0 to 100, with 100 being the highest advantage. The total importance and cost are calculated based on these ratings.
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
WOOD STUDY E - 3-Ply CLT Timber Grid

Conceptual Cost/sf

Clear Height to Girder (ft)

- Concrete
- Wood Connections
- Wood
- Clear Ht
20x30 Double girder, no beams, 7-ply CLT

30x30 Single girder and beams w/ 3-ply CLT
Platte Fifteen Bay Study

Conceptual Comparison of Platte15 Structural Systems

- **Conceptual Cost $/SF**
  - $40 to $5
  - $10 to $15
  - $20 to $25
  - $25 to $30
  - $30 to $35
  - $35 to $40

- **Clear Height to Girder (ft)**
  - 8.0 to 8.5
  - 9.0 to 9.5
  - 10.0 to 10.5
  - 11.0

- **Materials**
  - Concrete
  - Steel
  - Connections
  - Wood
  - Concrete

- **Examples**
  - 20 x 30
  - 30 x 30
  - 30 x 30
  - 30 x 30
  - 30 x 30
  - 30 x 40
  - 30 x 30
  - 30 x 30
  - 30 x 30
  - 30 x 40

- **Legend**
  - Grey: Concrete
  - Blue: Steel
  - Red: Connections
  - Orange: Wood
  - Yellow: Clear Ht
PLATTE 15
50+ ft panels span five 10 ft bays
STEEL / TIMBER HYBRIDS

Surround Architecture

Collegiate Peaks Bank - RiNo

Surround Architecture
WHAT DOES STEEL COST?
Steel Mill Base Price
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>Size Description</th>
<th>Price per piece</th>
<th>Price per ton</th>
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</thead>
<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>
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<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 vs Wood 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
Open office – 30 x 30 steel grid with 3-ply CLT

HYBRID E - 3-Ply CLT on Steel Grid

Conceptual Cost/sf

Sub-optimal CLT length

Lowest price

Selected

Clear Height to Girder (ft)

Concrete
Steel
Wood
Typical Connections

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

CLT EDGE AT CFS WALL - SECOND FLOOR

TYPICAL CLT PANEL TO BEAM
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
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
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
Square bay, CLT with 2 equal (varying) spans
Some important topics that affect cost but not addressed here ...

Fire Rated Construction
 MEP Coordination
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<th>BUILDING ELEMENT</th>
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<th>Type III</th>
<th>Type IV</th>
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</table>
Tall Wood requires design for fire rated assemblies
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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