

Structural Mass Timber Design

The Engineer's Role in Optimization



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Course Description

Achieving the highest level of cost efficiency possible with mass timber requires an understanding of both material properties and manufacturer capabilities.

When it comes to laying out a structural grid, the square peg/round hole analogy is pertinent. Trying to force a mass timber solution on a grid laid out for steel or concrete can result in member size inefficiencies and the inability to leverage manufacturer capabilities. Knowing how to best lay out the grid—without sacrificing space functionality—allows the designer to optimize member sizes, but cost efficiency for a mass timber building goes beyond column spacing.

This presentation will examine the structural engineer's role in optimizing a mass timber structural layout by taking a systems vs. product approach. Topics will include known parameters for mass timber design, design challenges, connections, grid spacings, and lessons learned from the structural design of Colorado mass timber projects.

Learning Objectives

1. Discuss how a systems-based approach to mass timber structural layout can result in cost efficiencies and code compliance.
2. Review factors that impact timber member sizing including grid spacing, vibration and fire resistance.
3. Highlight methods of optimizing mass timber grids and connections that result in enhanced erection speed.
4. Explore the role that the structural engineer plays in achieving mass timber structures that are efficient and optimized for manufacturer capabilities, and meet code provisions.

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



RESIDENCE 1



RESIDENCE 1





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)



Glulam Beams & Columns



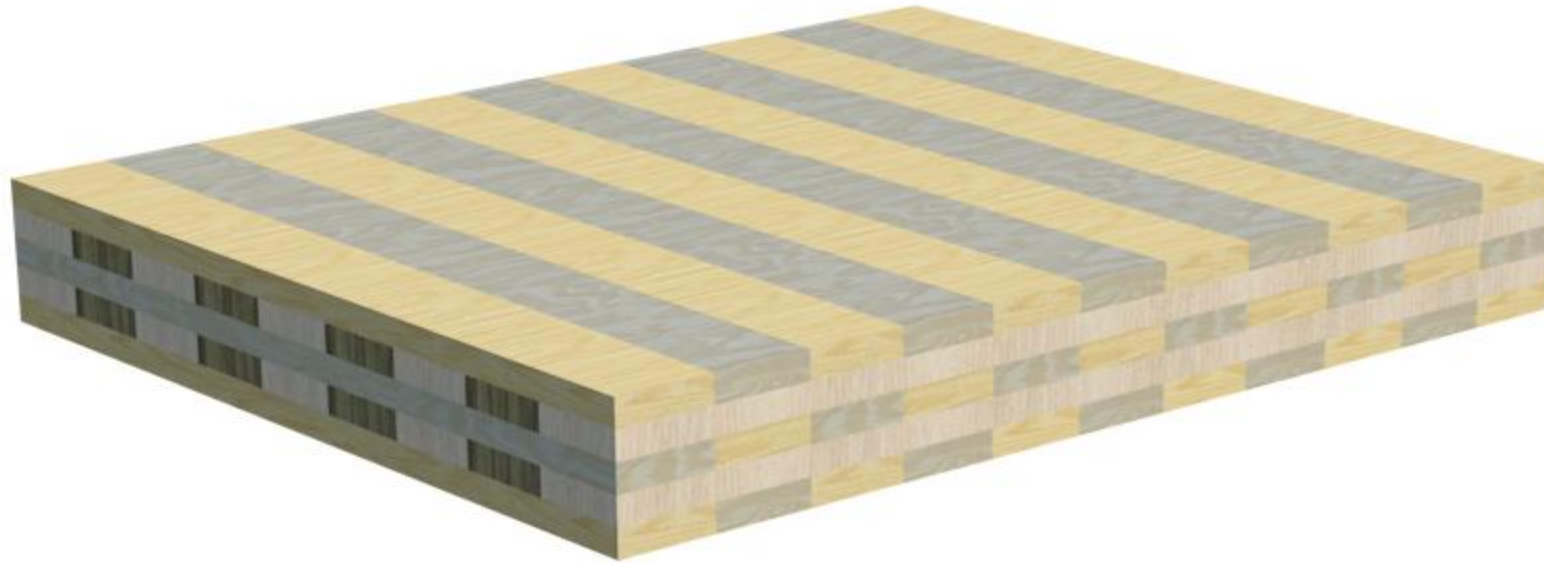
Laminated Veneer Lumber (LVL)
and Mass Plywood Panels (MPP)



Cross Laminated Timber (CLT)



CLT



Cross Laminated Timber

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

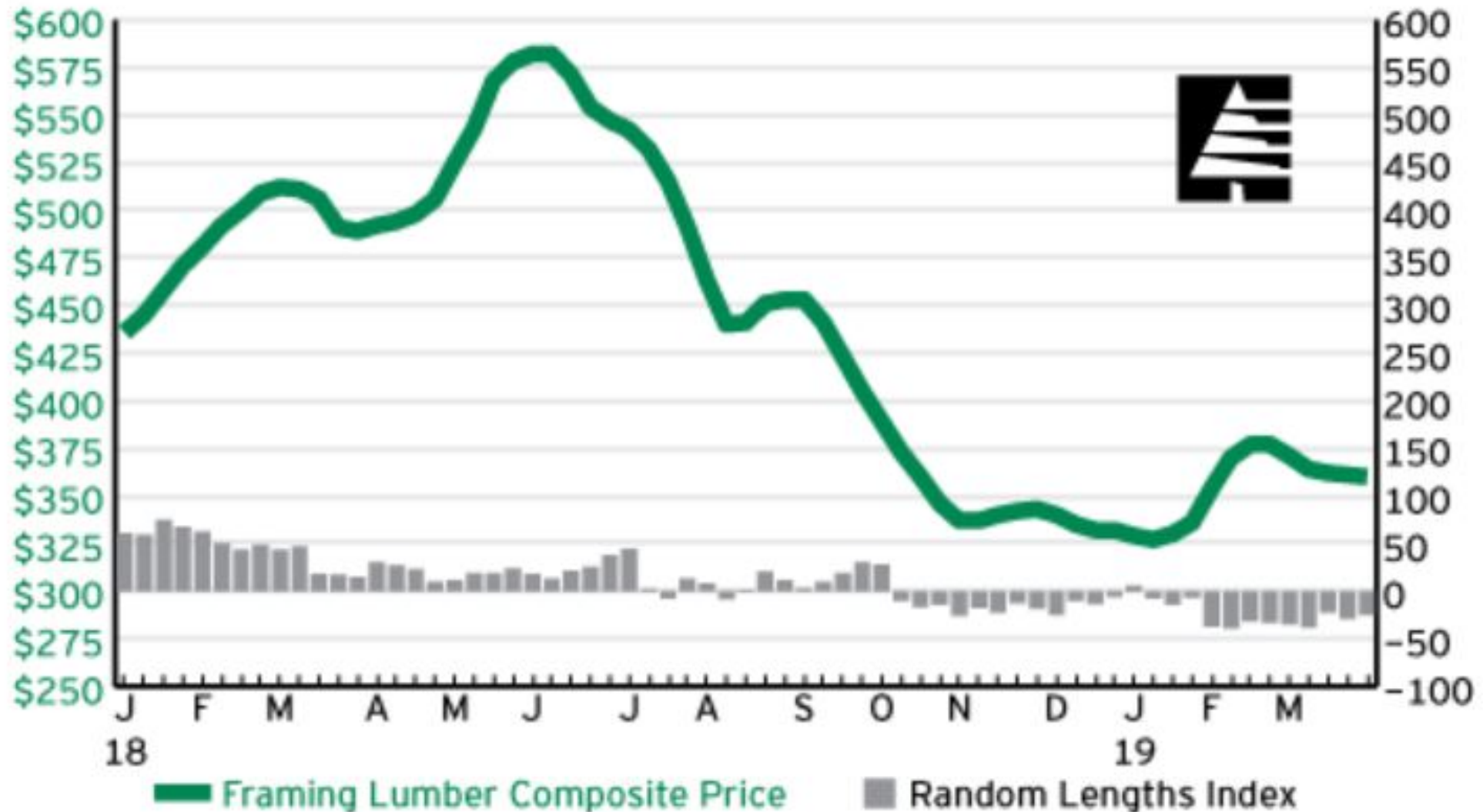


9-ply 7-layer

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

Company	State/Province	Country	Panel size	Typical species
• Structurlam	BC	Canada	10'x40' CLT	SPF / Doug Fir
• Nordic	Quebec	Canada	8'x64' CLT	Black Spruce
• DR Johnson	Oregon	U.S.	10'x24' CLT	Doug Fir
• Smartlam	Montana	U.S.	10.5'x40' CLT	SPF
• Freres Lumber Co	Oregon	U.S.	12'x48'x2' MPP	Doug Fir
• International Beams (w/ KLH)	Alabama Quebec	U.S. Canada	11.5'x52' CLT	Southern Pine
• Katerra	Spokane, WA	U.S.	12'x60' CLT	SPF
• Vaagen Timber	Colville, WA	U.S.	4'x60' CLT	Doug Fir
Coming soon ...				
• Kalesnikoff	Castlegar, BC	Canada		

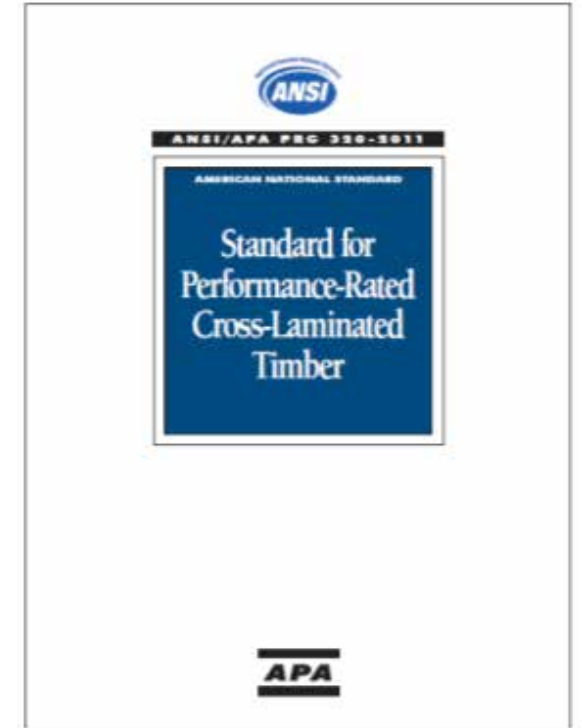
Multiple European Sources (14 +)

Company

- KLH
- AHC/Derix
- Stora Enso
- Hess
- Binderholz
- ...

Country

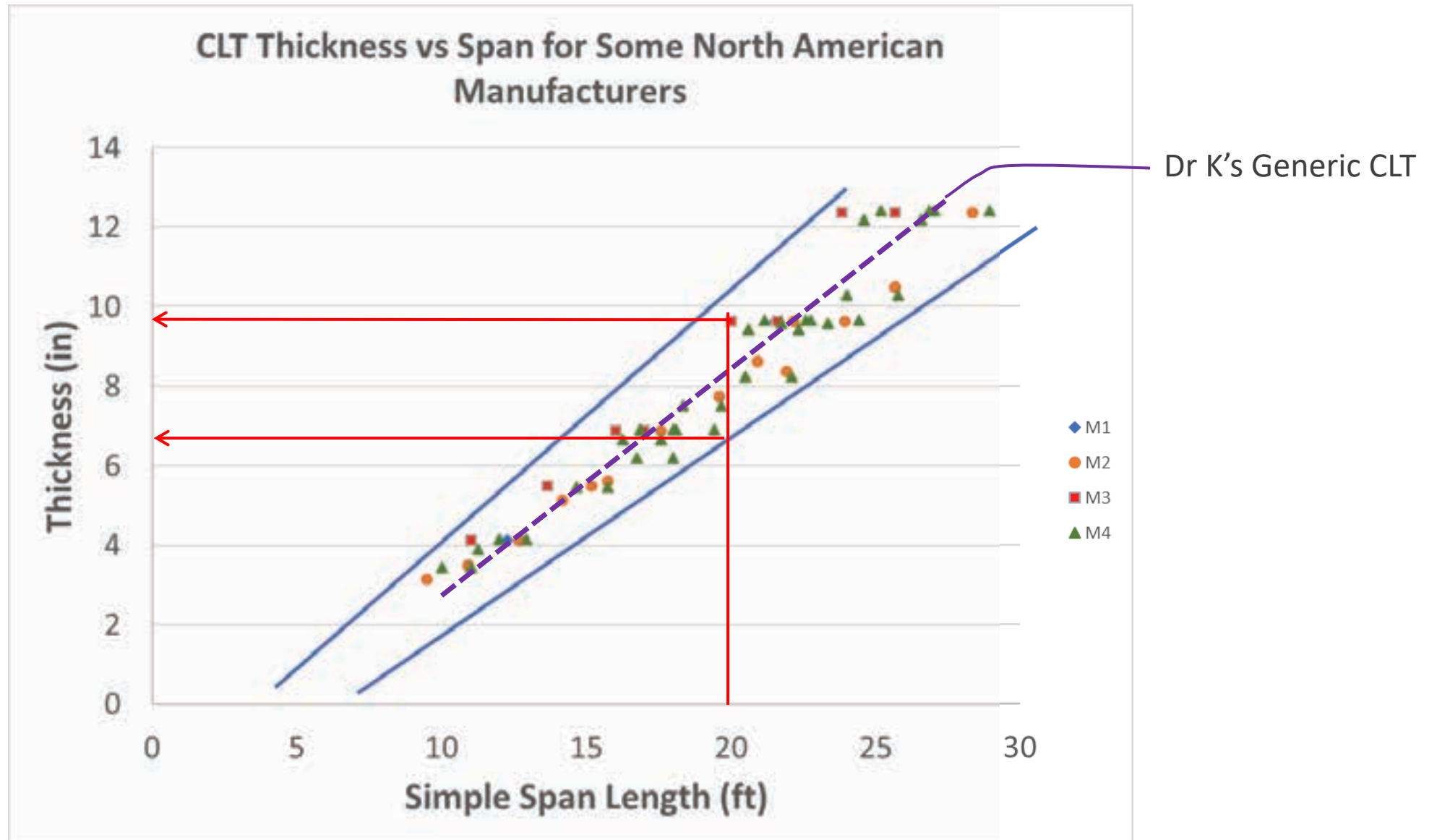
Austria, Switzerland, UK
Germany
Finland and Austria
Germany
Germany





CLT PRESS

CLT COST DEPENDS ON THE TOTAL VOLUME OF WOOD



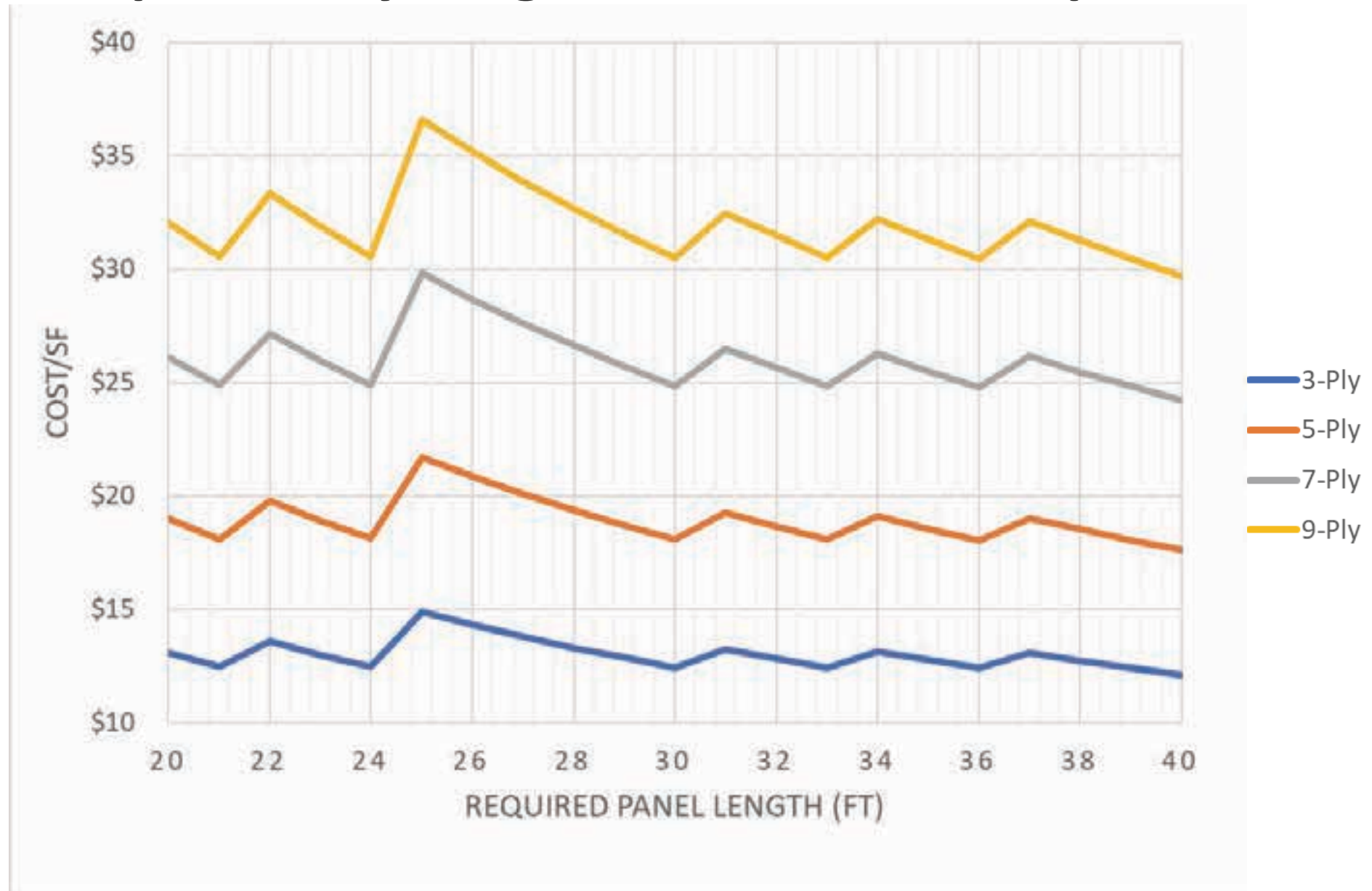
Unit cost of CLT panels by length and number of plies

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



CSU PAVILION



CSU PAVILION



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



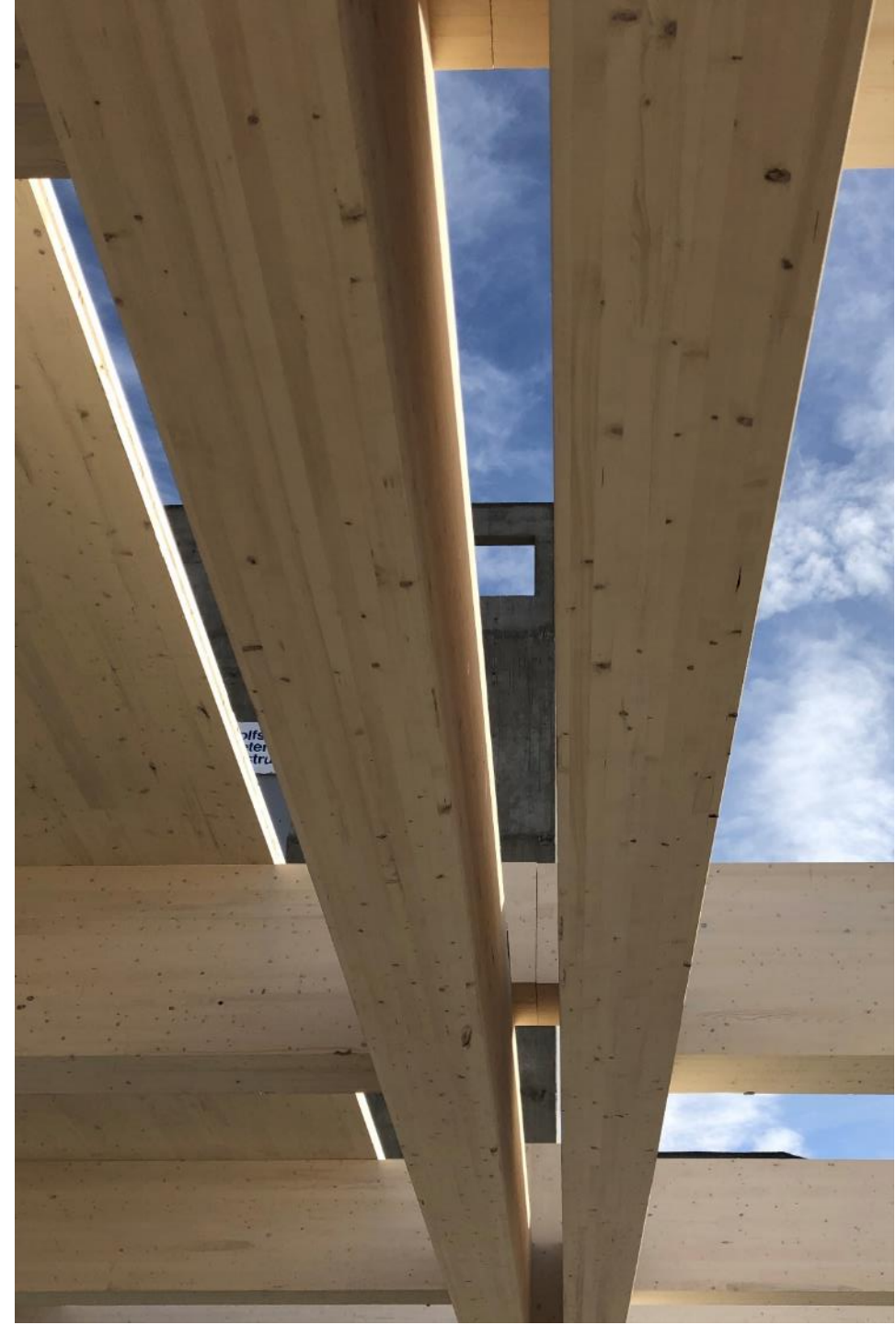
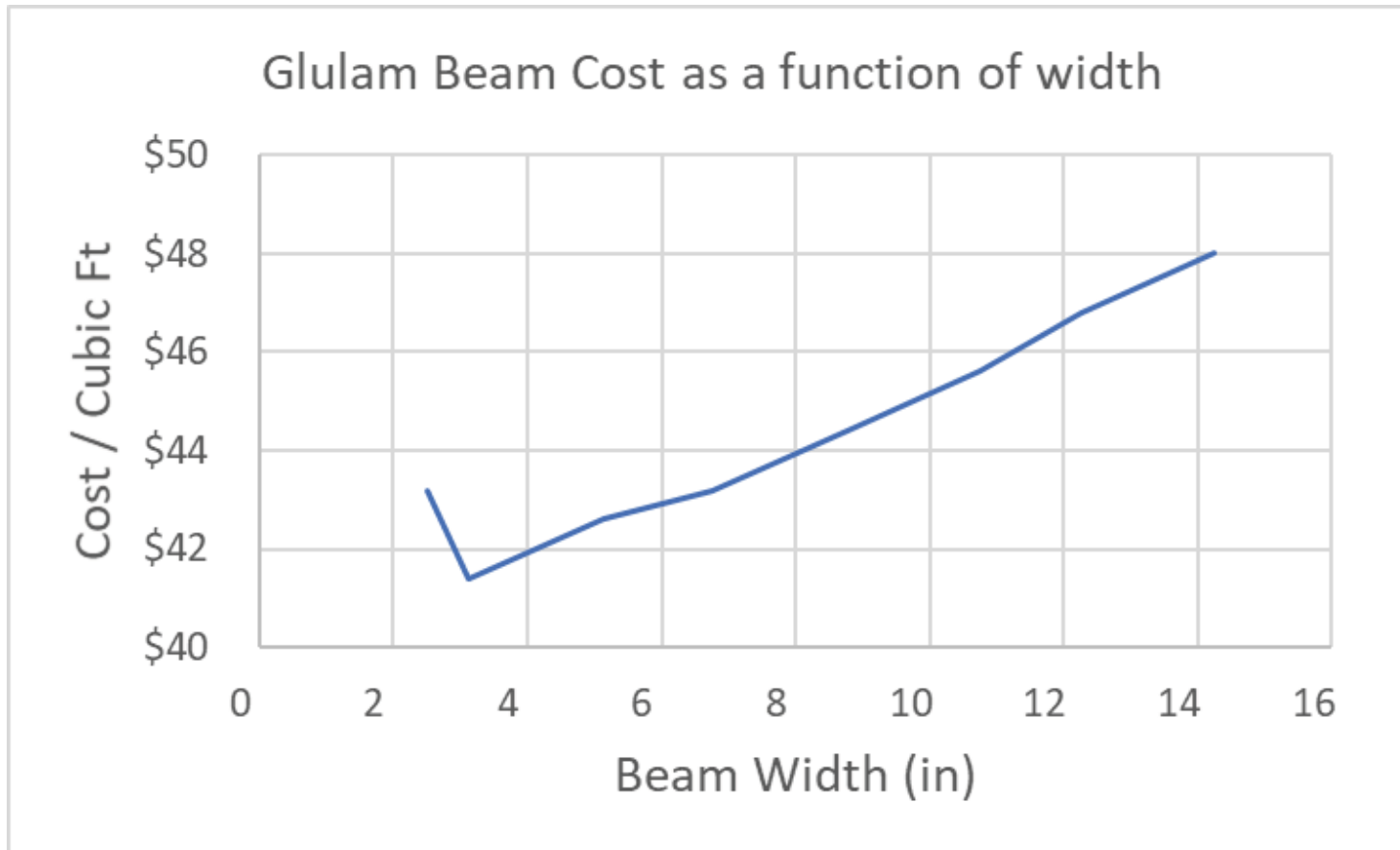
Photo: unalam



GLULAM BEAM PRESS

Dr K's Glulam Beam Cost

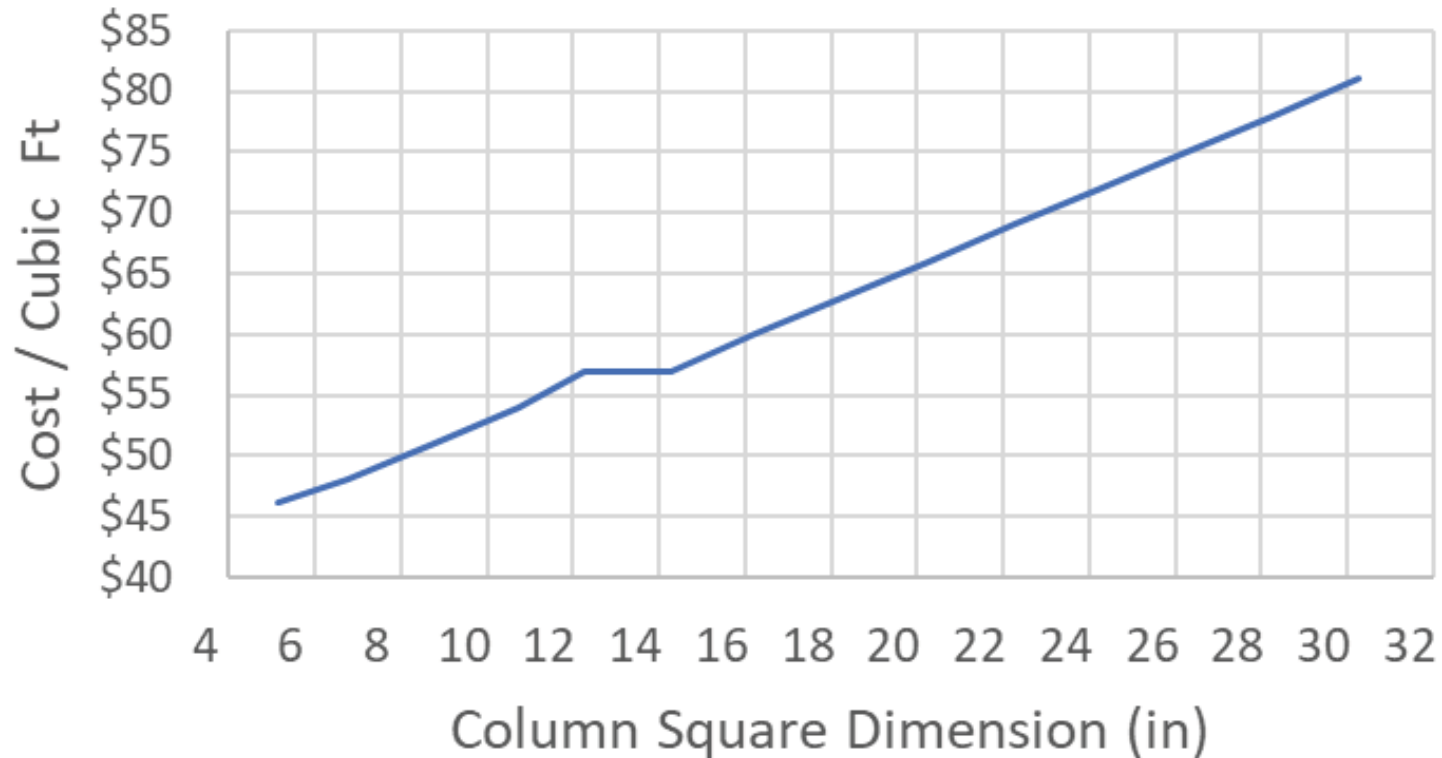
Unit cost per cubic ft is a function of beam width



Dr K's Glulam Column Cost

Unit cost per cubic ft is a function of column width

Glulam Column Cost as a function of 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

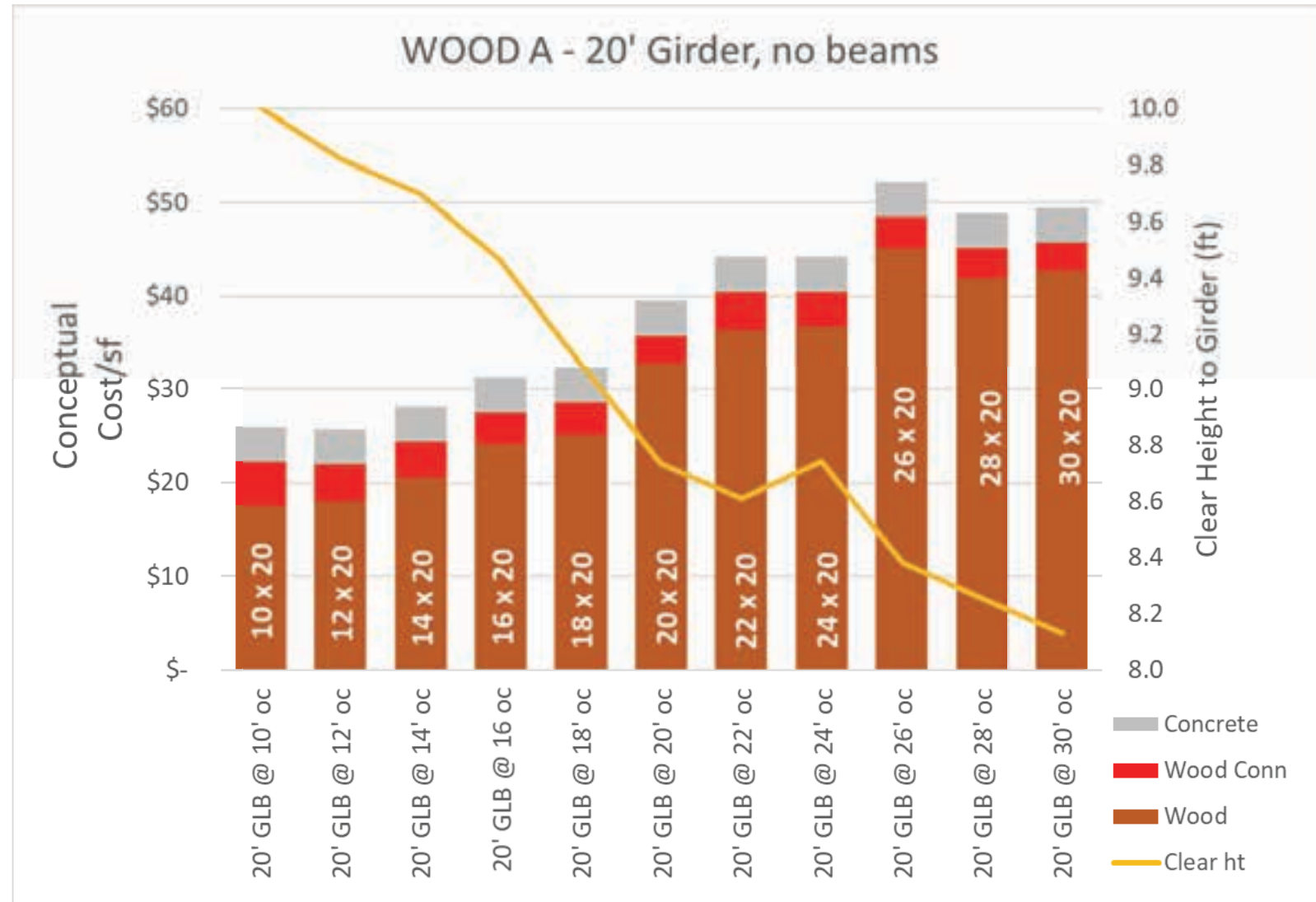
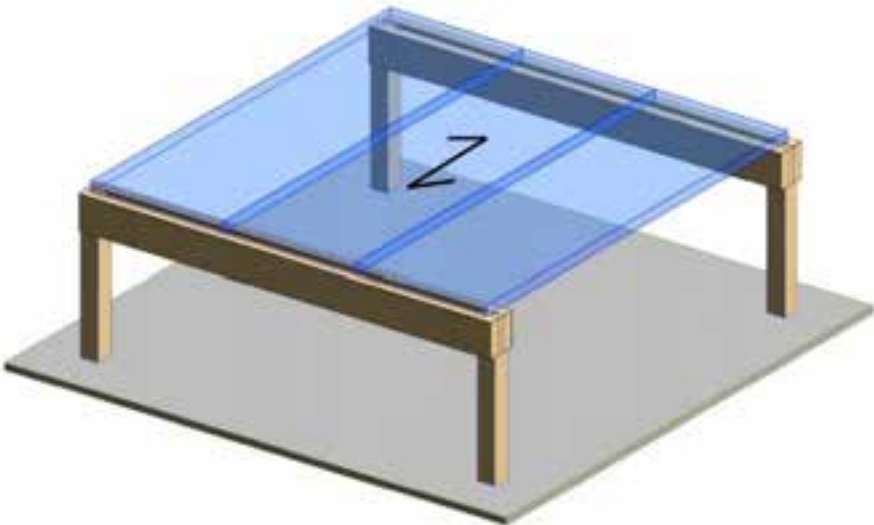
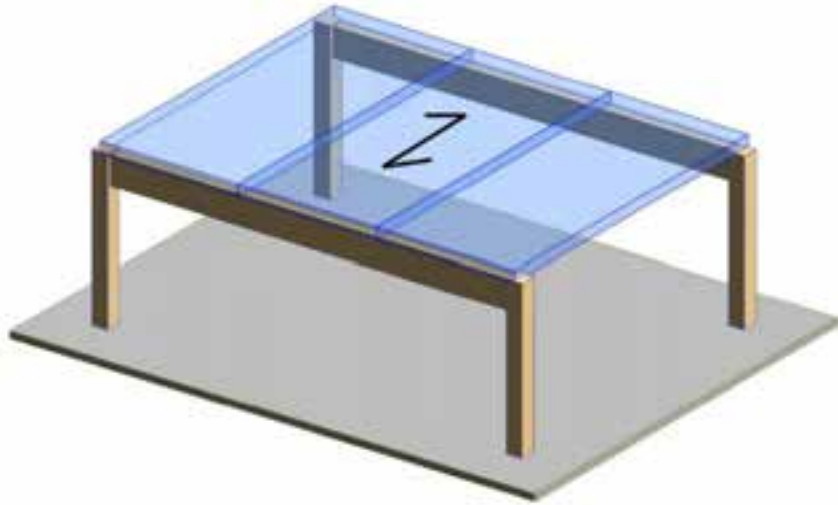
“Conceptual Costs” do not include

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

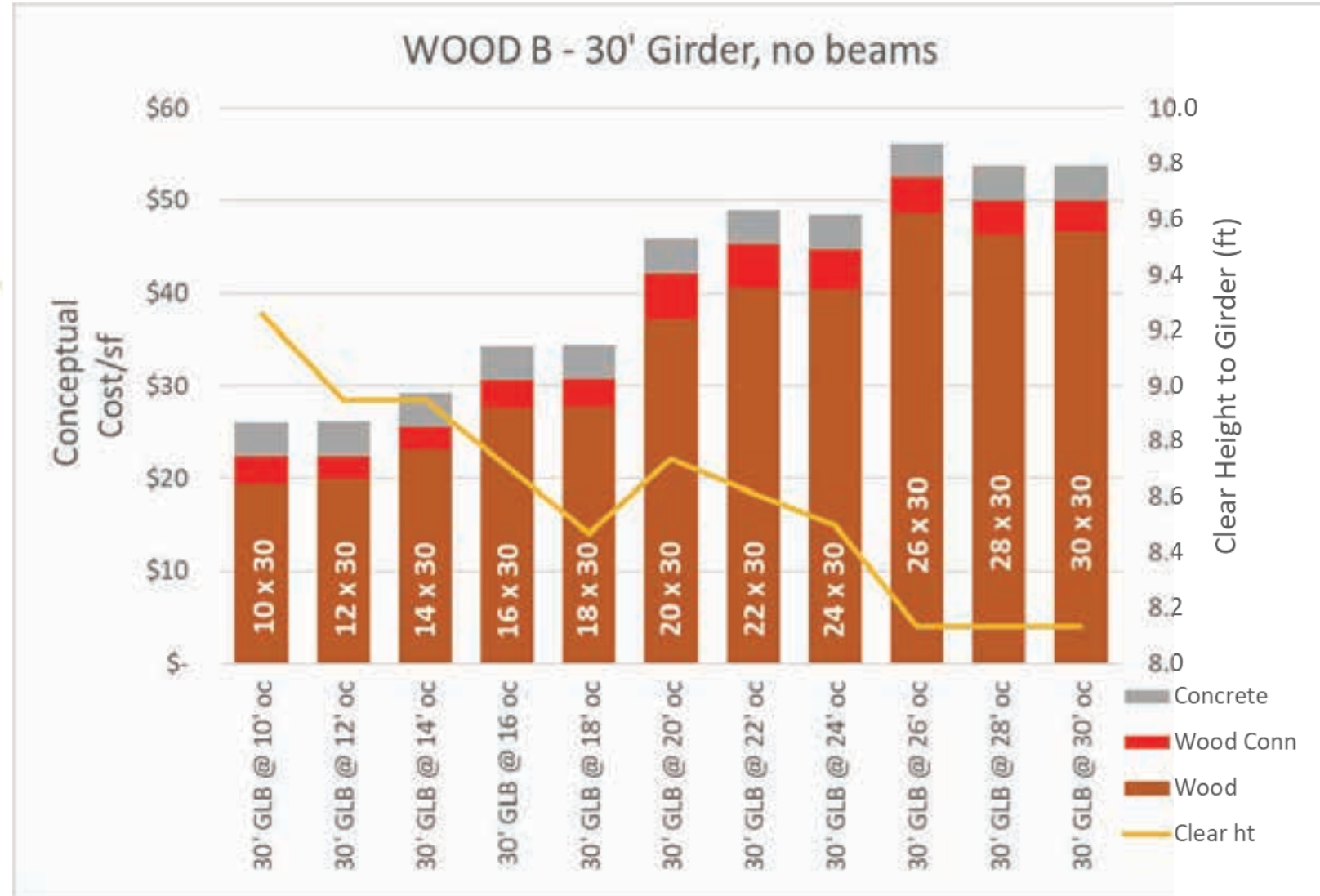
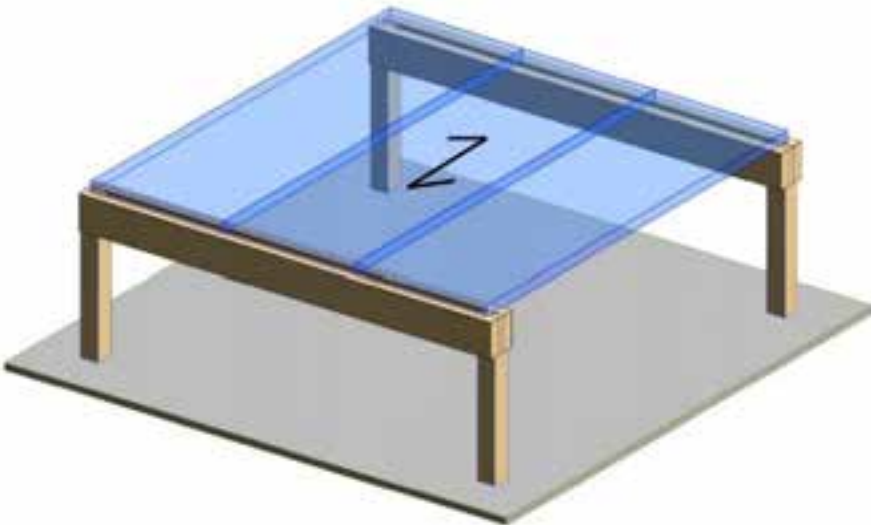
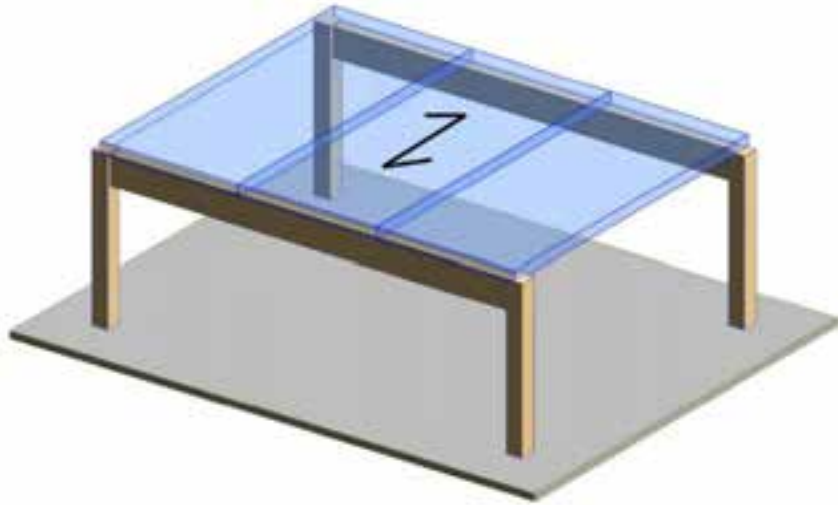
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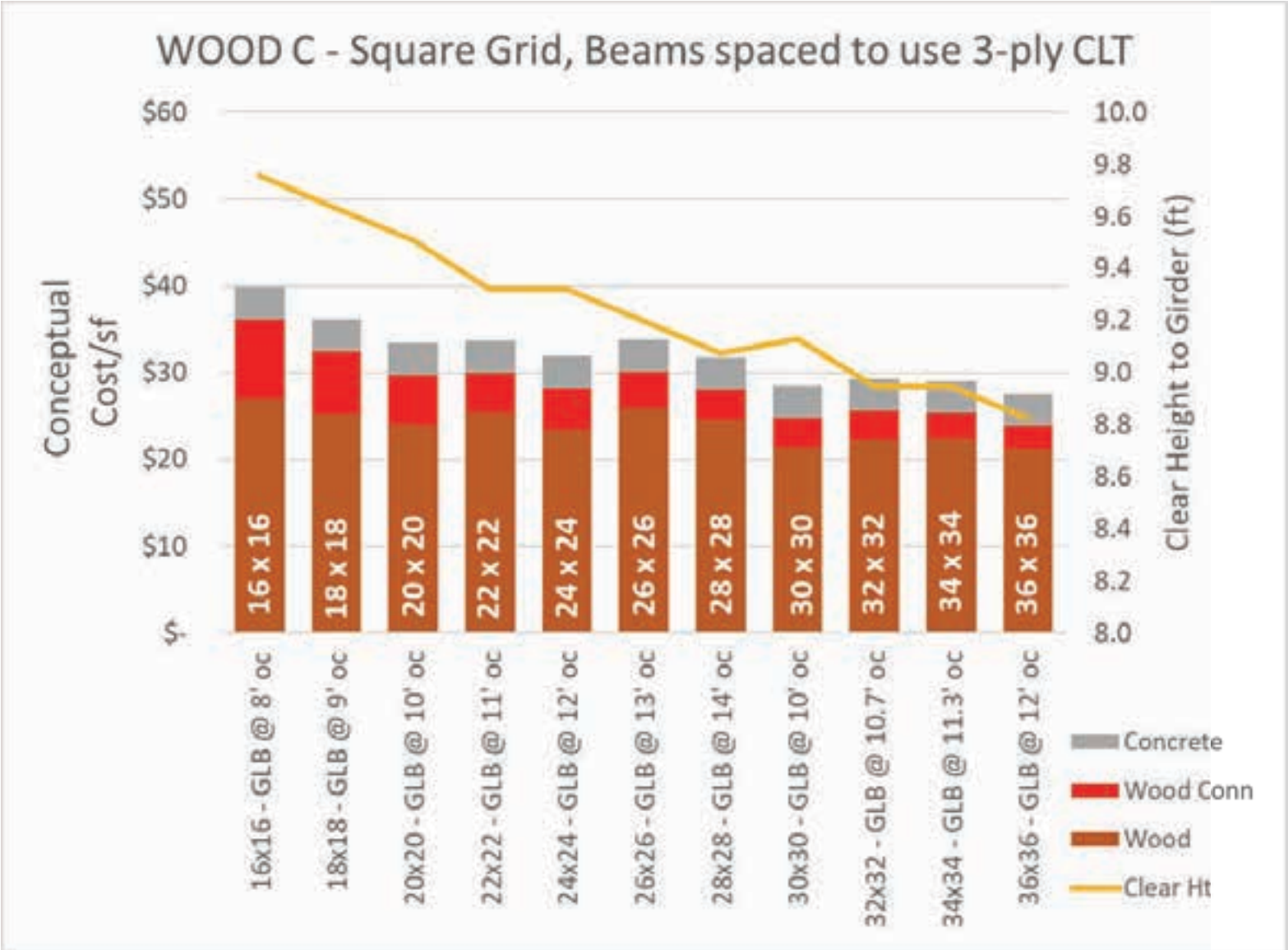
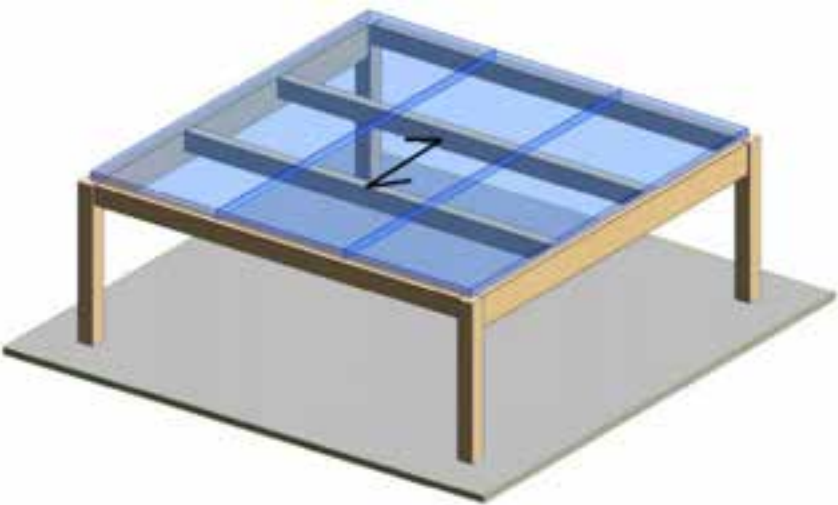
20 ft timber bents, no beams, CLT of varying span



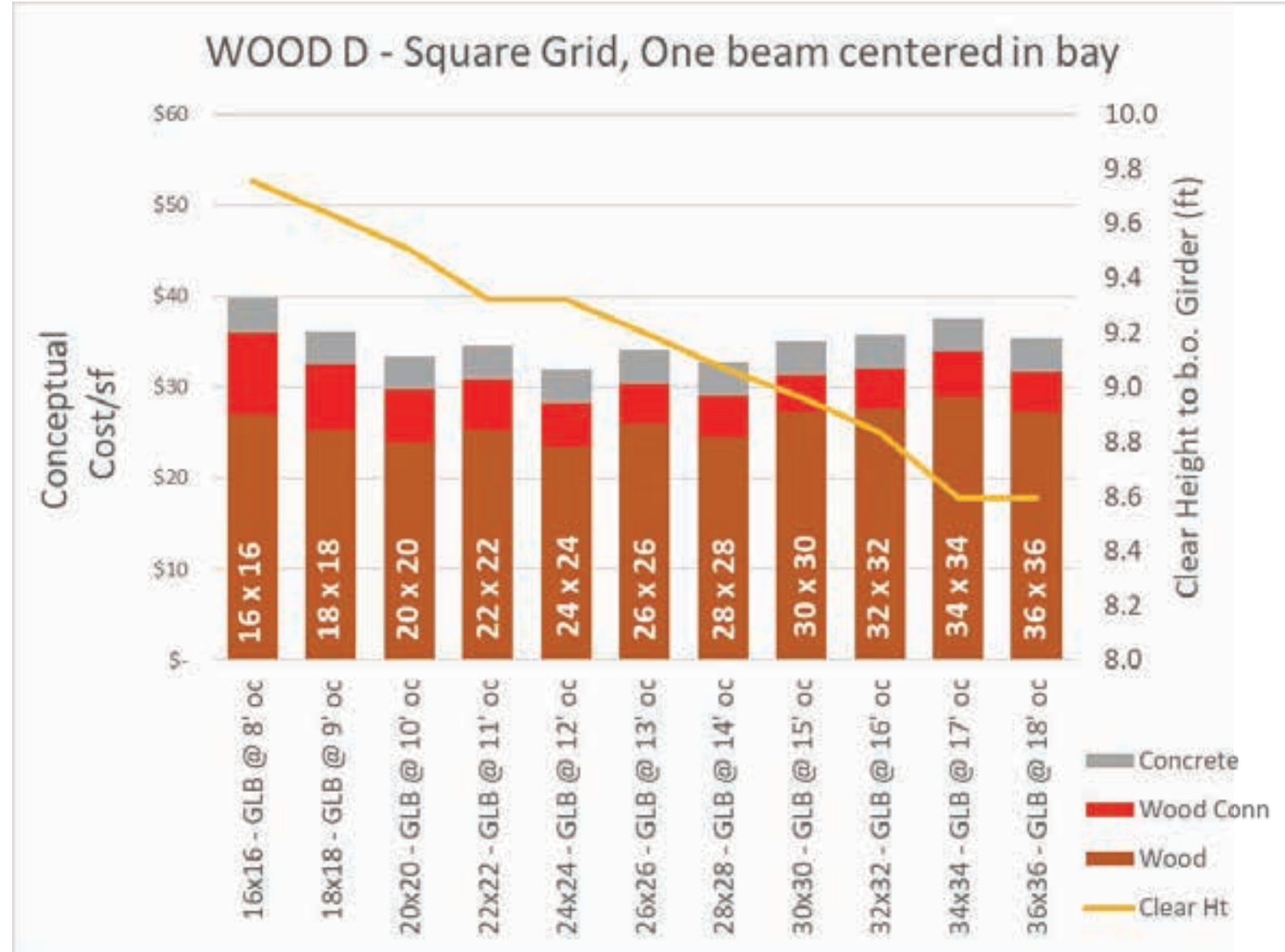
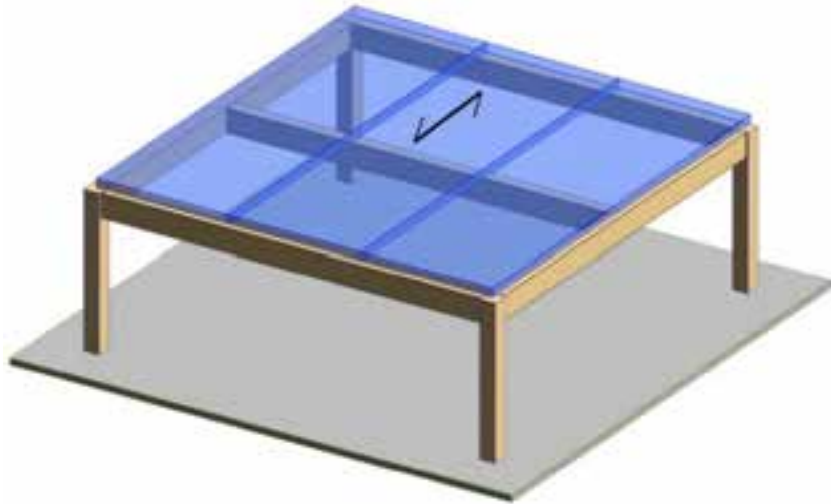
30 ft timber bents, no beams, CLT of varying span



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

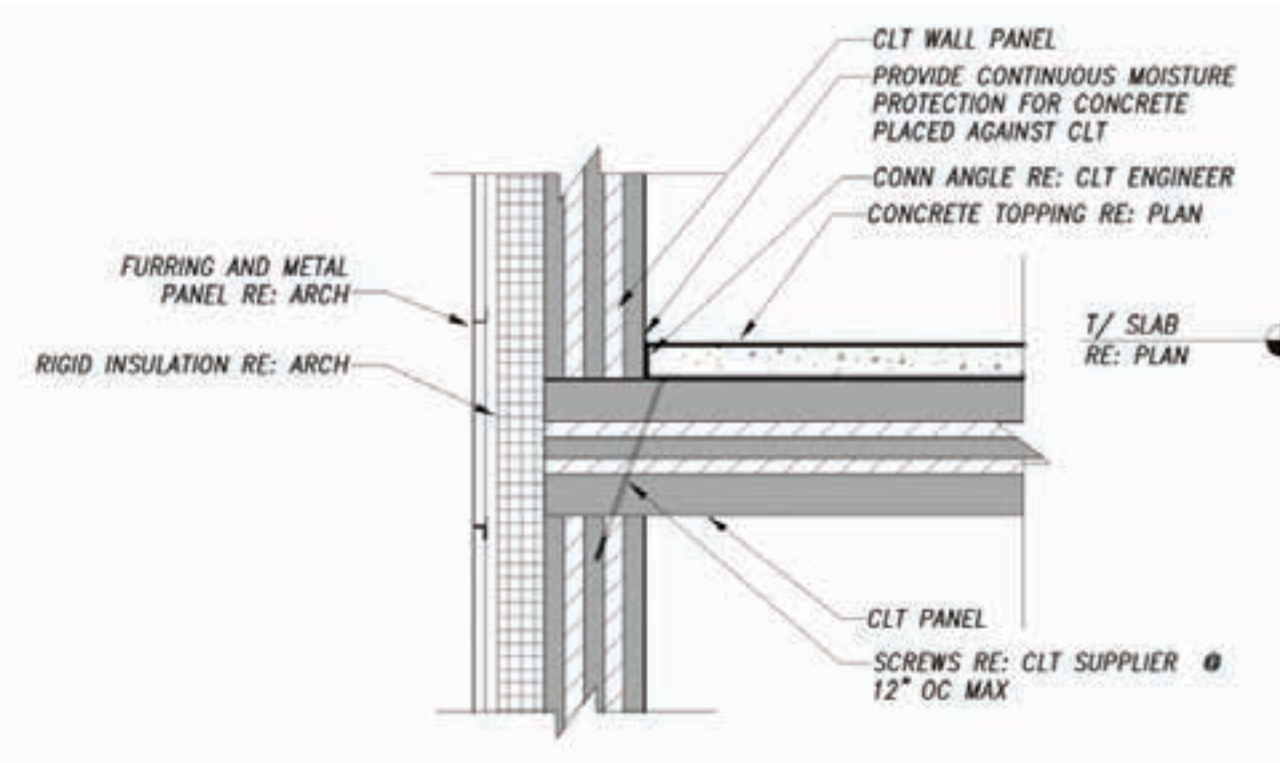
BOULDER LOADING DOCK



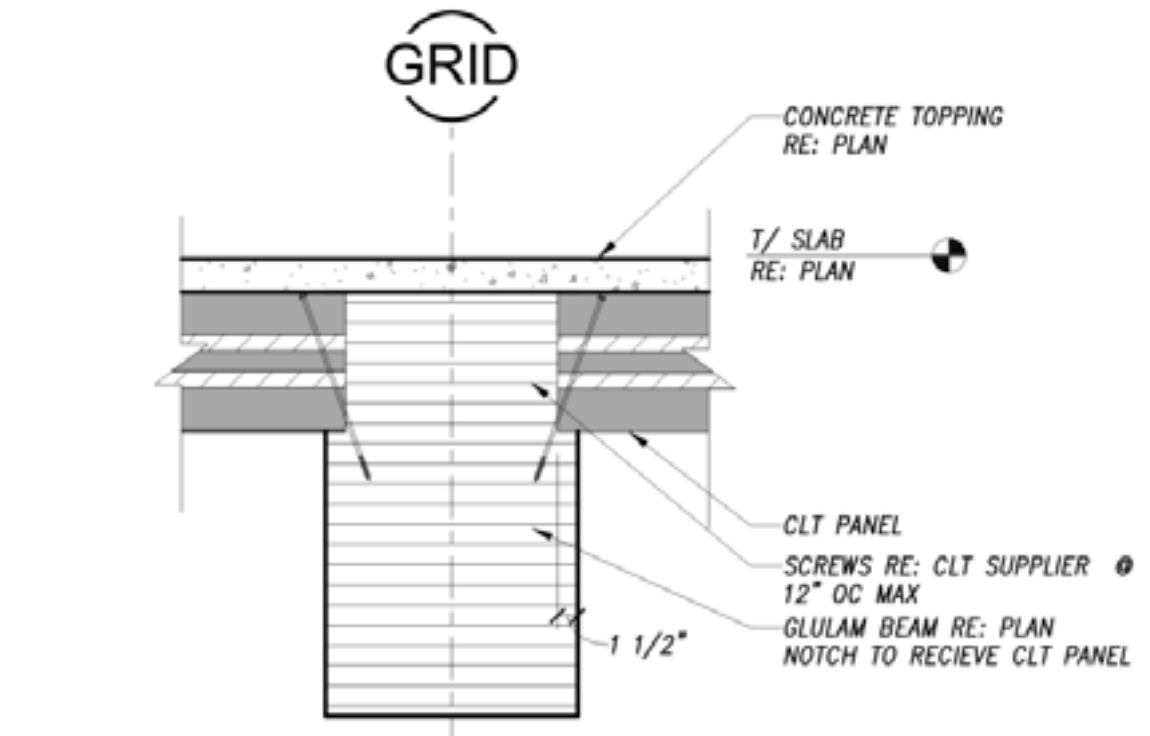
BOULDER LOADING DOCK



Typical Connections



WALL SECTION AT BEARING WALL



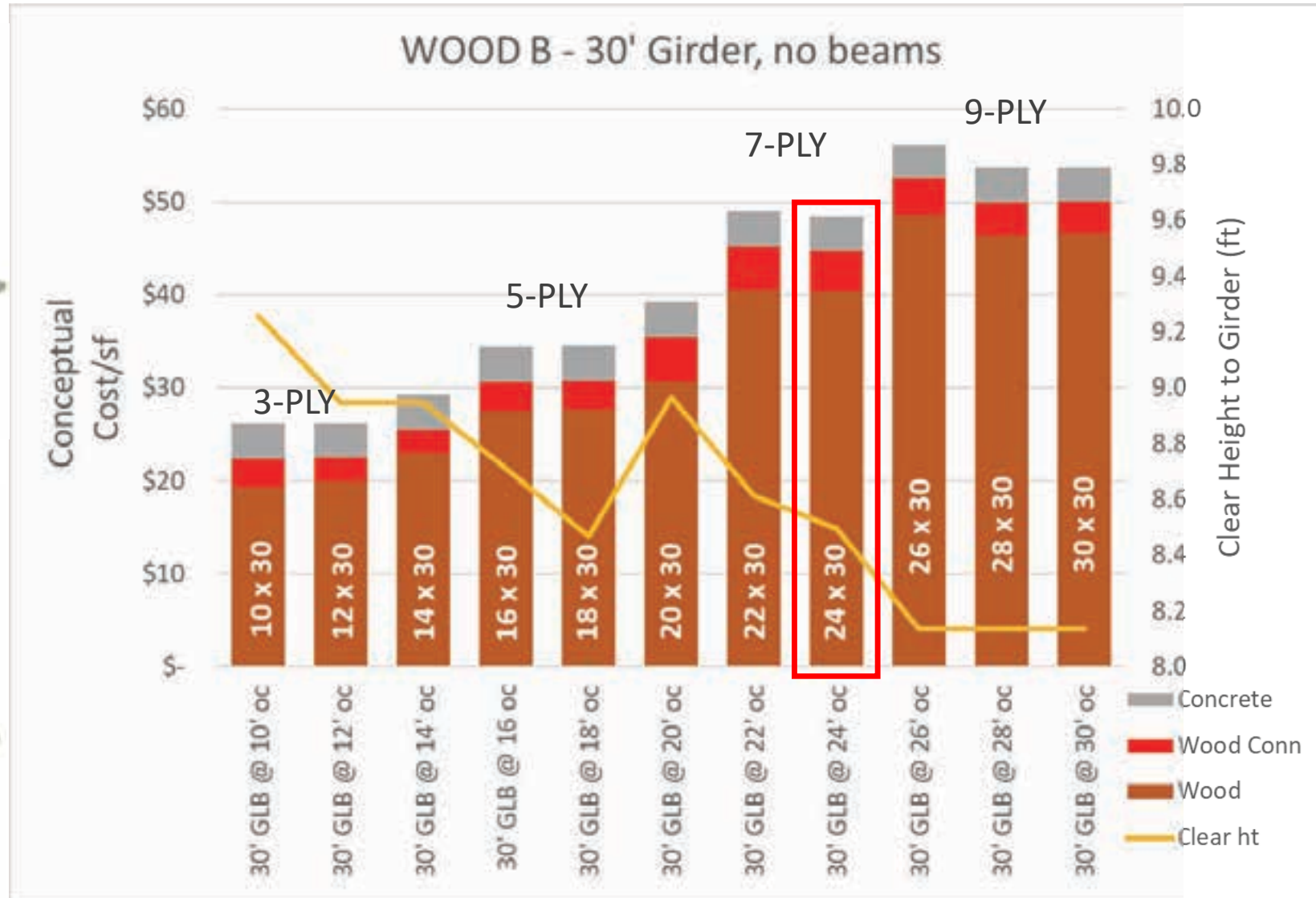
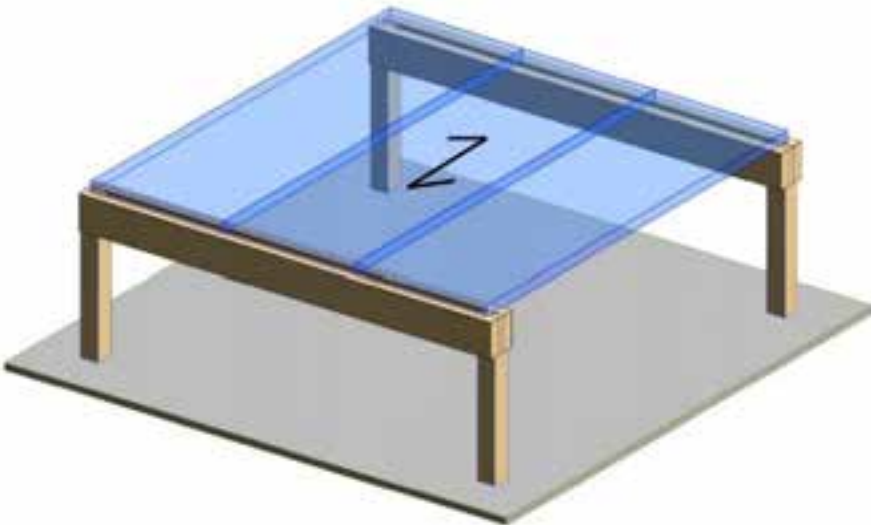
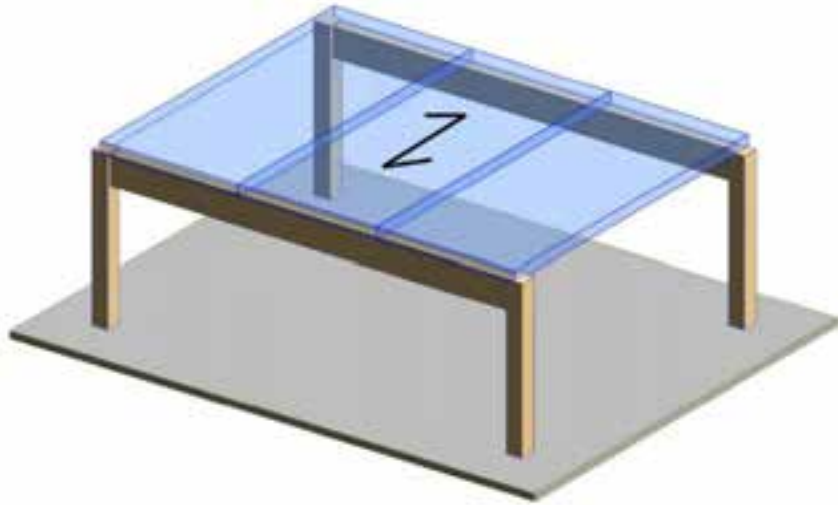
CLT TO INTERIOR BEAM CONNECTION

BOULDER LOADING DOCK

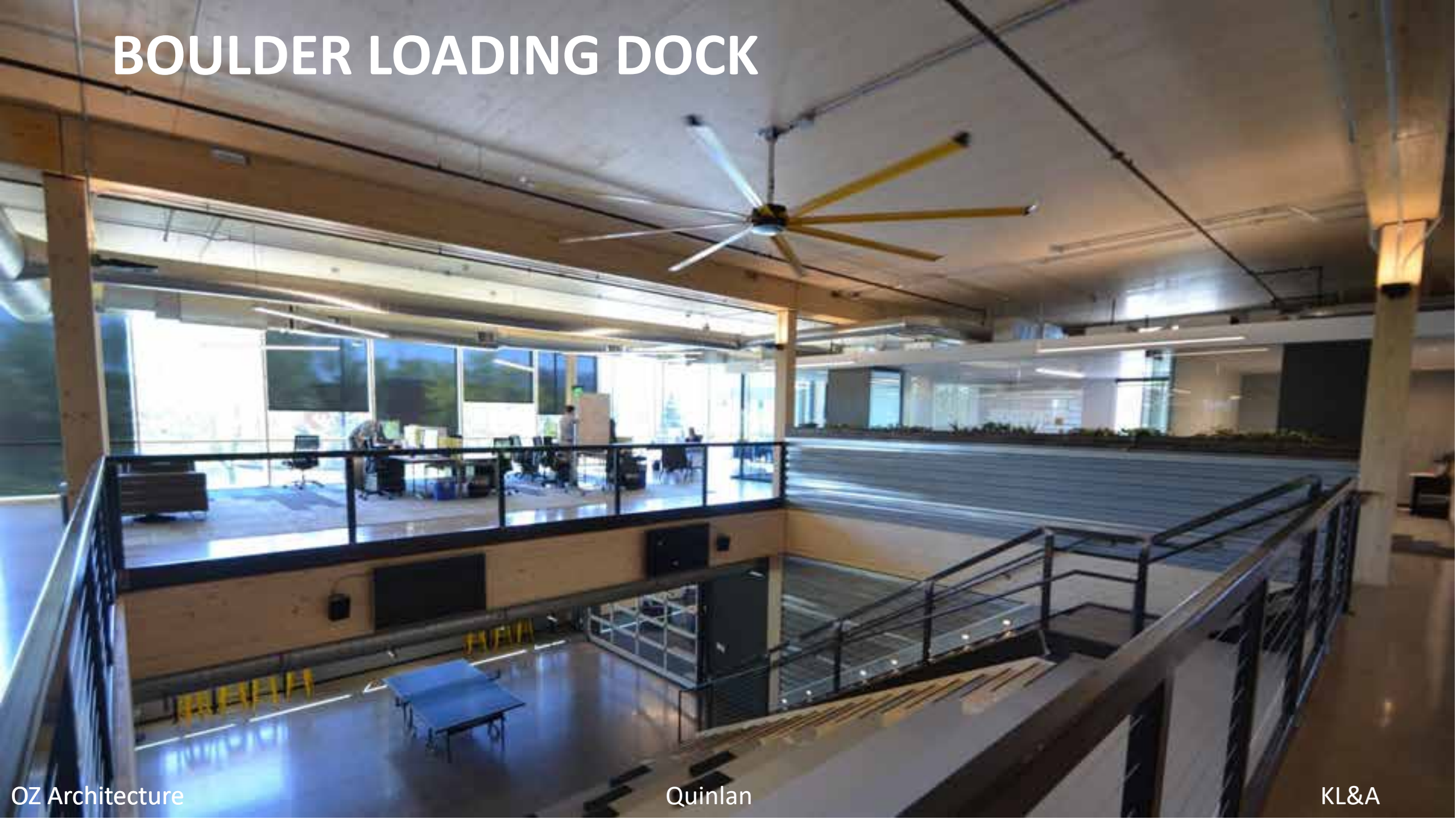
- 25 x 30 Grid
- 7-ply 5-layer CLT Floors
- 5-ply CLT roof
- 3-ply CLT shear walls



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

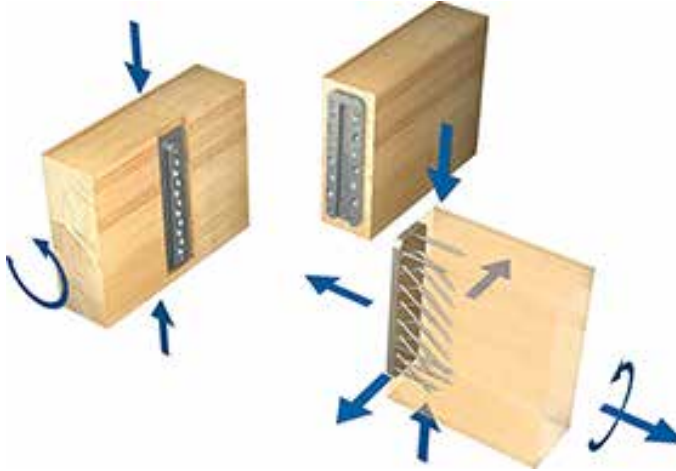


Photo Credit: myticon



Panel to beam connections

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”
 - Reaction carried
 - Simple screws
 - Complex hidden custom connector

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



OZ Architecture

Adolfson & Peterson Construction

KL&A & Nordic

PLATTE 15

Office / Retail

Type III-B Construction

30' x 30' grid

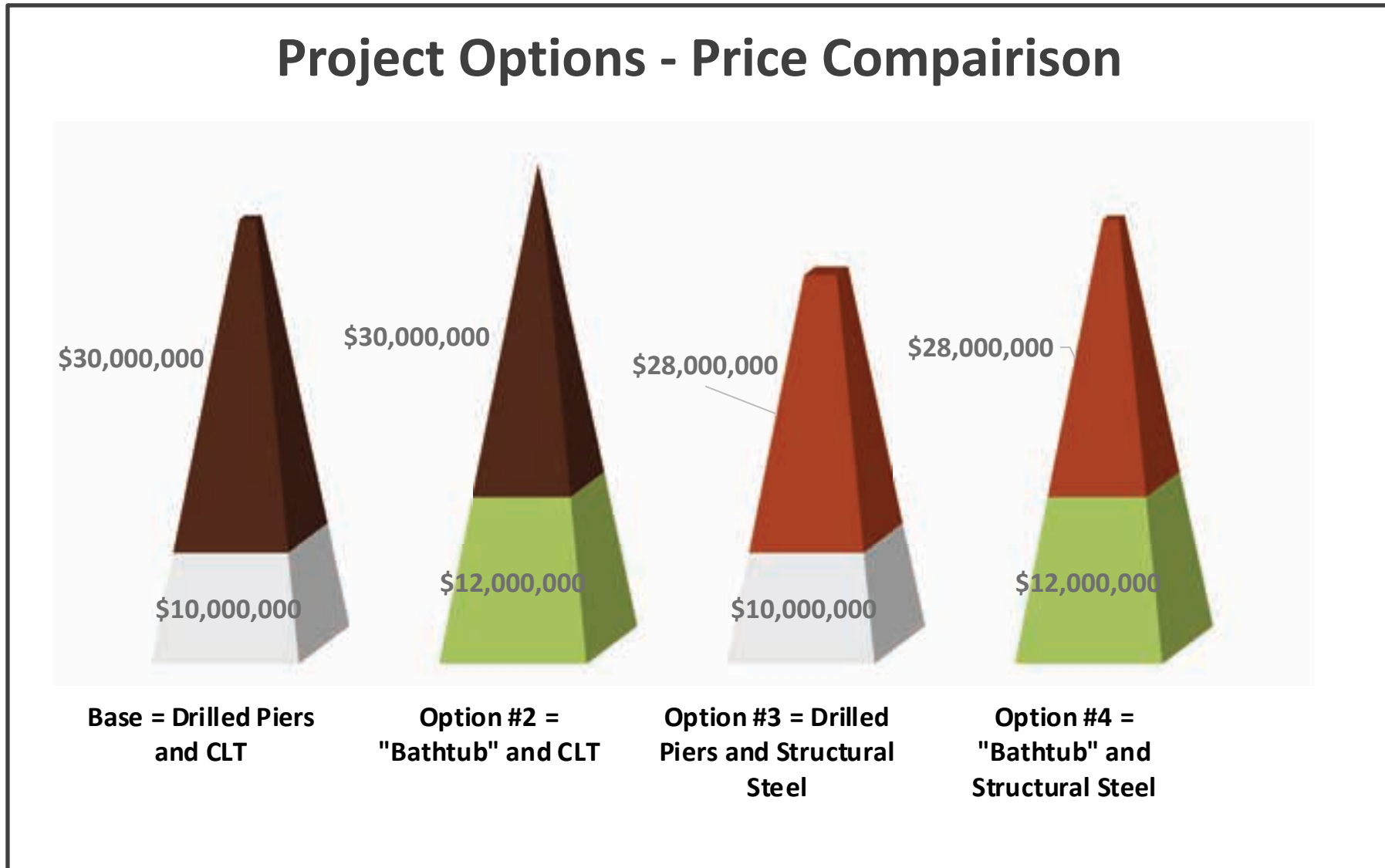


OZ Architecture

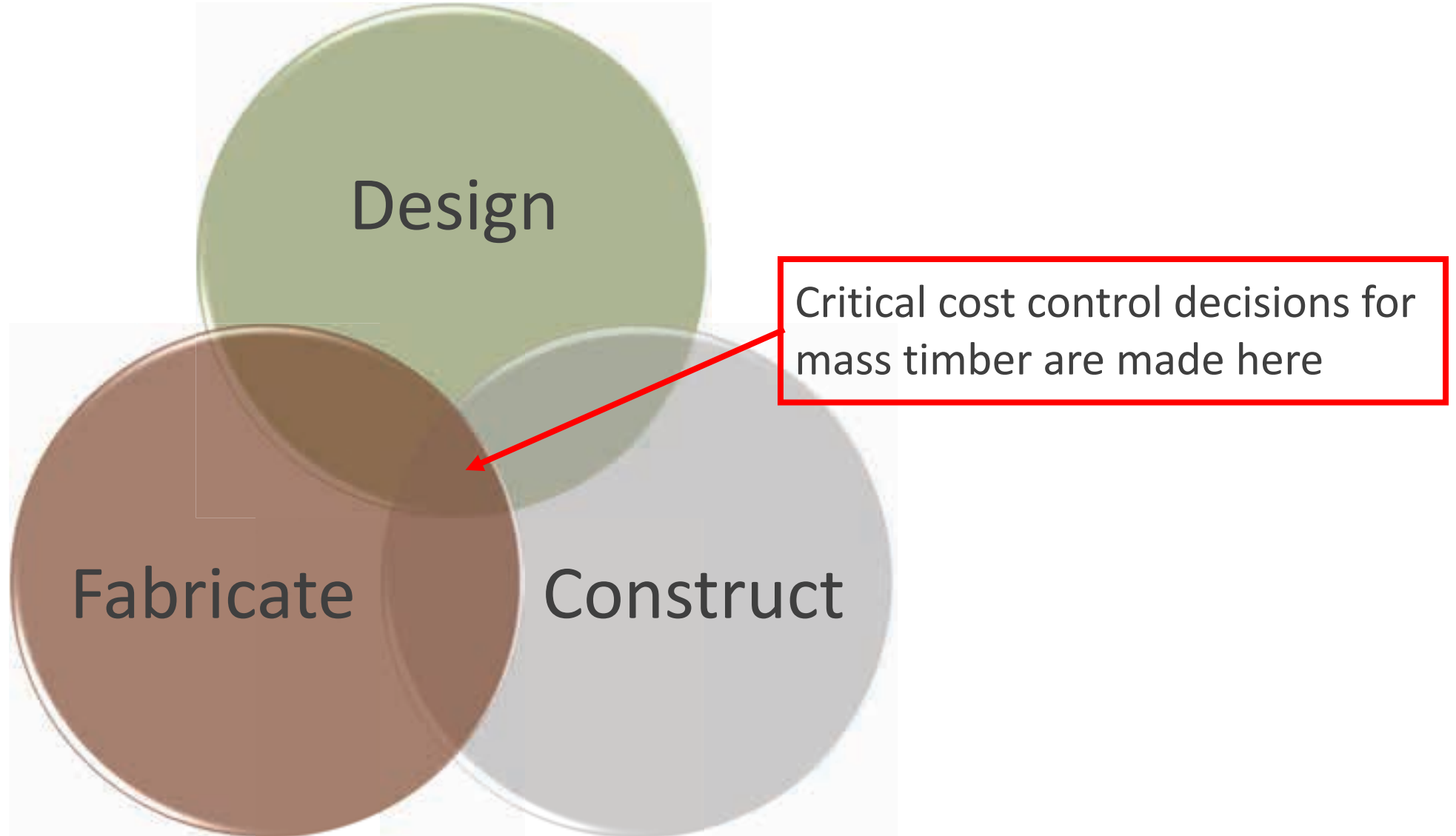
Adolfson & Peterson Construction

KL&A & Nordic

Early Pricing showed mass timber came at a premium



Platte Fifteen – Cost Control



Selecting a CLT / Glulam Manufacturer for Platte 15

- Choosing by advantage works best
- Wood species are like paint colors
- Listen closely to manufactures individual efficiencies
- Strength of coordination team
- Project history
- North American vs. Overseas
- Visit the facility



Getting trades comfortable

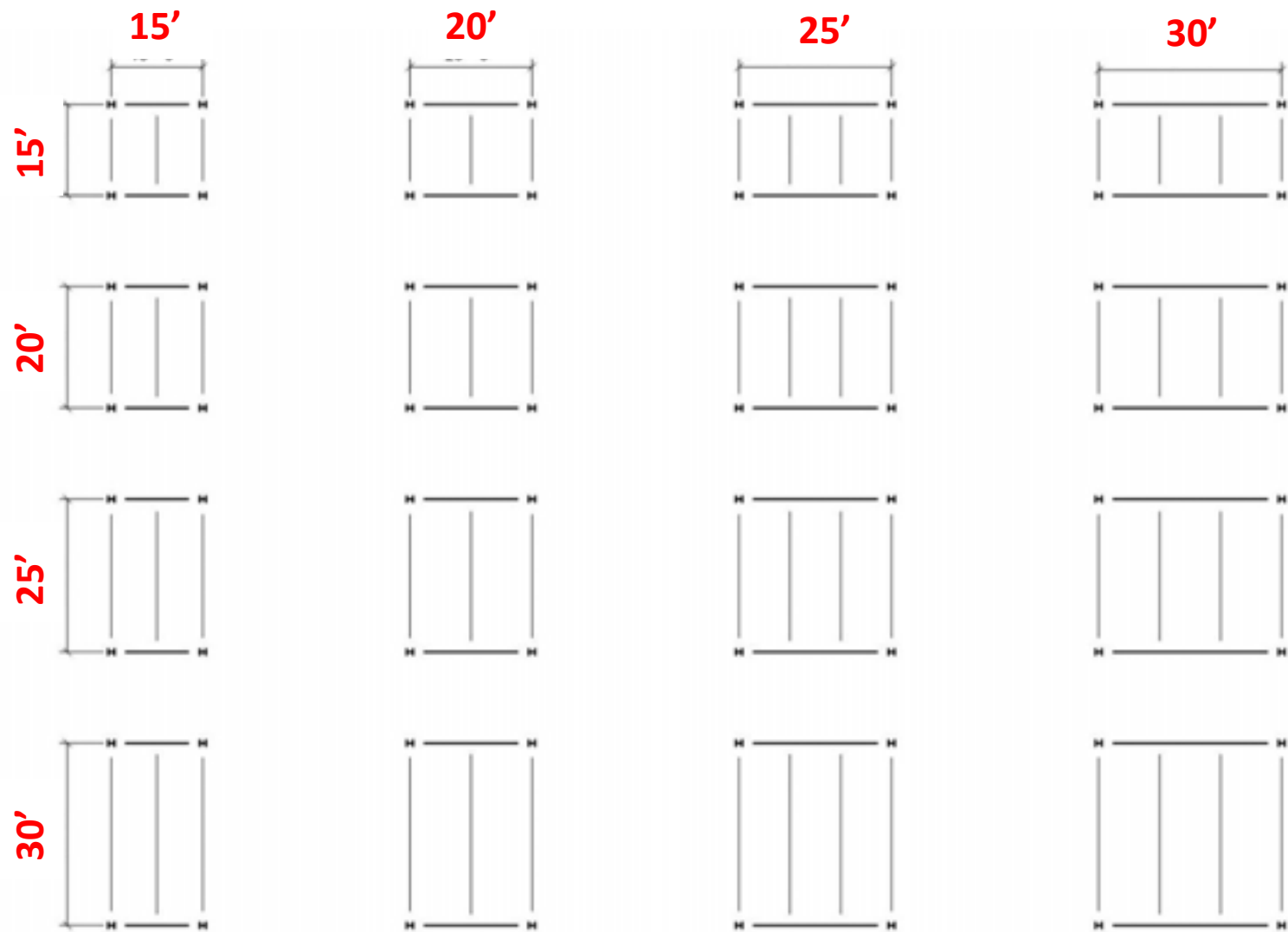


Mass timber may be new to many of the subcontractors. Getting them familiar will affect the cost.

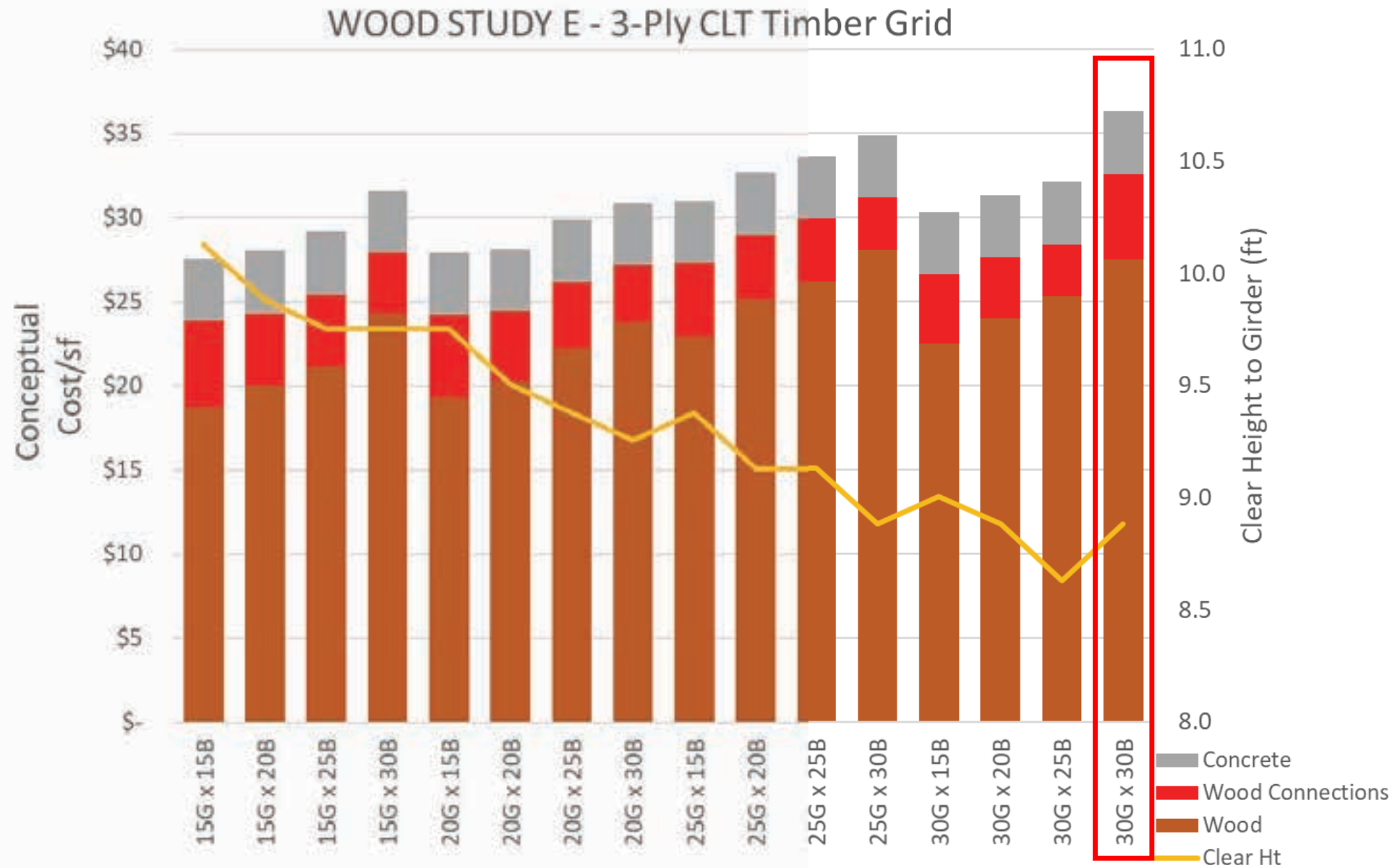
Choosing By Advantages (CBA)

FACTORS	ALTERNATIVES					
	CLT PRODUCER #1		CLT PRODUCER #2		CLT PRODUCER #3	
Material Aesthetics						
Owner preference for lighter color	<u>SPF</u>		Spruce		European Spruce	
<i>Advantage:</i>		0		85		100
Servicing Zero Lot Line						
Can delivery be sequenced or "hot loaded"	Yes		Yes		<u>Container</u>	
<i>Advantage:</i>		60		60		0
Replacement Flexibility						
Distance from project	1300 miles		2100 miles		<u>5400 miles</u>	
<i>Advantage:</i>		40		25		0
Local Crew for Installation						
Installed by Colorado Crews	Yes		<u>No</u>		Yes	
<i>Advantage:</i>		20		0		20
Total Importance:	120		170		120	
Total Cost:	\$4.6M		\$4.7M		\$4.7M	

Wood Bay Study: 15x15 up to 30x30



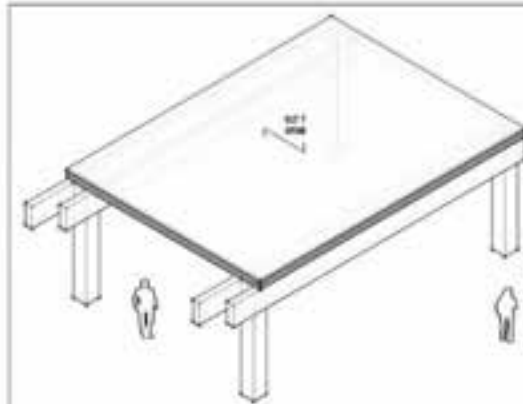
Wood Bay Study



20x30 Double girder, no beams, 7-ply CLT

STRUCTURAL OPTION A

Baseline per 100% SD Set



SUMMARY

Primary Material(s):	CLT, GLULAM, CONCRETE
Structural Grid:	20' X 30'
Clear Height at Floor:	11'-10 3/4"
Clear Height at Girders:	9'-7 3/4"
Floor Assembly:	L7S-2 CLT / 10.25" + Sound mat + 3" Concrete
Columns:	18" X 18" (Glulam)
Girders:	Continuous Paired S.75" X 27"
Beams:	N/A
Possible Construction Type:	Type IV

Pros:

- No beams, only girders
- Mechanical can run parallel to structure
- Possible efficiency in installation with 60" girder dimension

Cons:

- A-typical office grid
- Type IV construction prohibits concealed spaces
- 60" girders are likely sourced in North America
- Approximate wood volume - .38 FT³/FT²

Visual References:



KL&A, Inc.
Structural Engineering and Builders

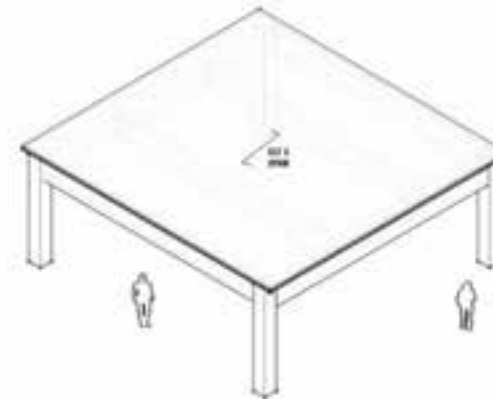


WILHELMUS
URBAN DESIGN
BUTTERICK DESIGN

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

STRUCTURAL OPTION B

30X30 Single Span, Single Girder CLT3



SUMMARY

Primary Material(s):	CLT, GLULAM, CONCRETE
Structural Grid:	30' X 30'
Clear Height at Floor:	12'-5"
Clear Height at Girders:	9'-10-5/8"
Floor Assembly:	CLT 3 / 3.90" + Sound mat + 3" Concrete
Columns:	18" X 18" (Glulam)
Girders:	12.25" X 33"
Beams:	12.25 X 27" at 10' O.C.
Possible Construction Type:	Type IV

Pros:

- Larger structural grid
- Reduced cost for single girder
- Option to notch girder into floor to reduce exposed dimension
- Approximate wood volume - .34 FT³/FT²
- Potential for long CLT panels minimum of 30' up to a maximum of 60'

Cons:

- Additional cost to notch girder into floor to align with bottom of beam
- Introduction of beams, so can't tuck systems tight to floor
- Type IV construction prohibits concealed spaces
- Increased quantity of pieces
- Possible acoustical implications should be reviewed

Visual References:

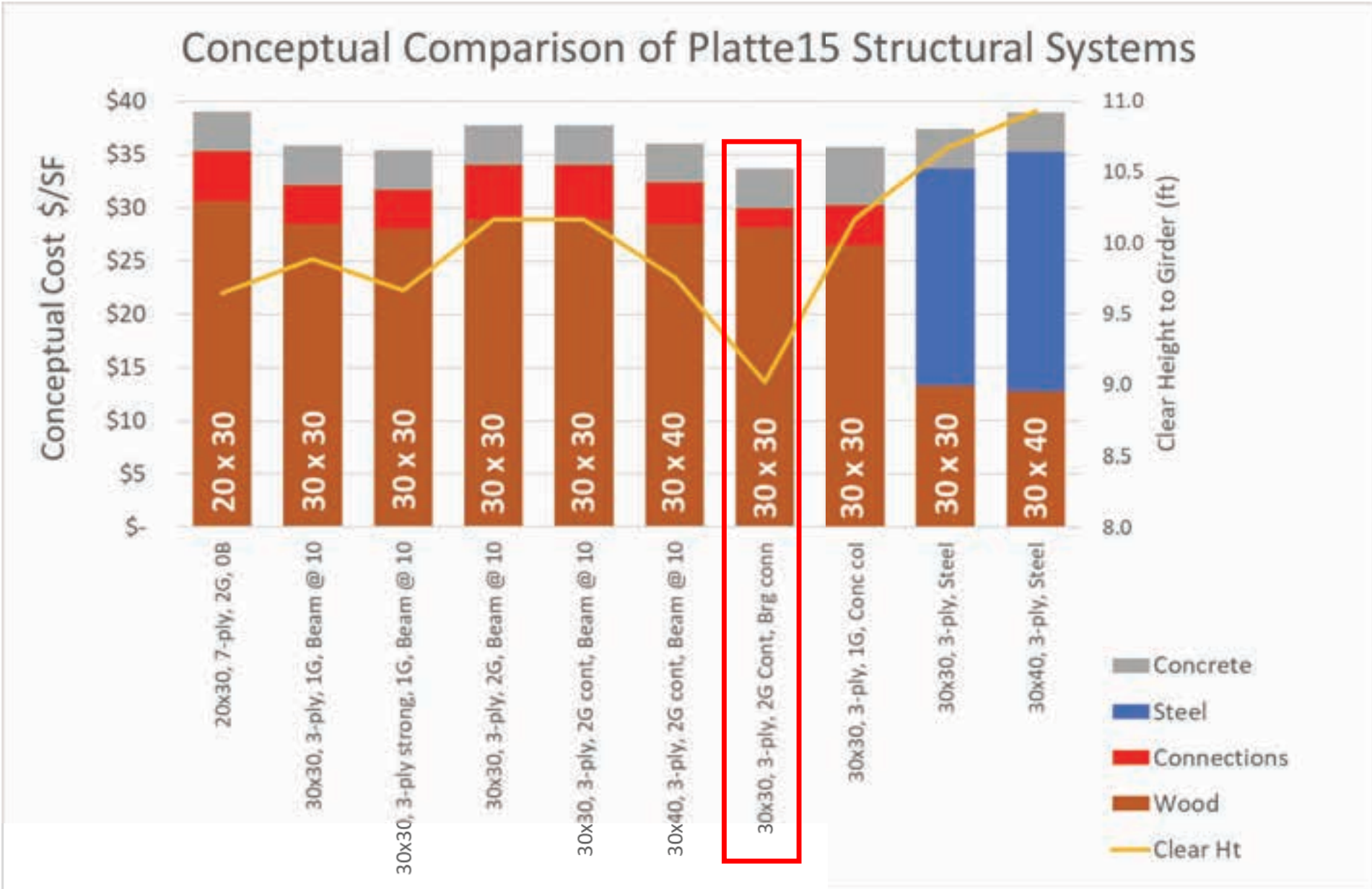


KL&A, Inc.
Structural Engineering and Builders



WILHELMUS
URBAN DESIGN
BUTTERICK DESIGN

Platte Fifteen Bay Study



PLATTE 15



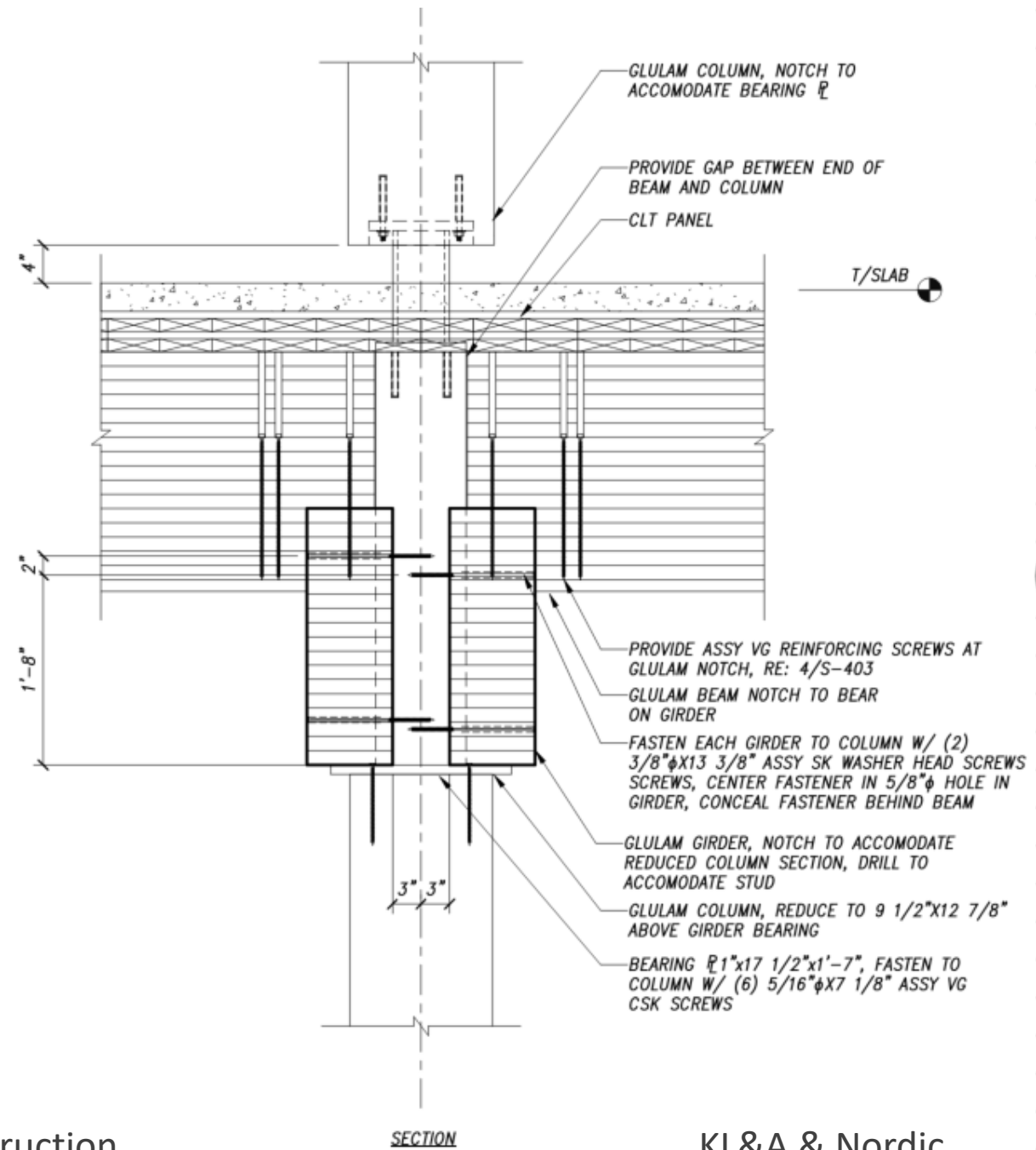
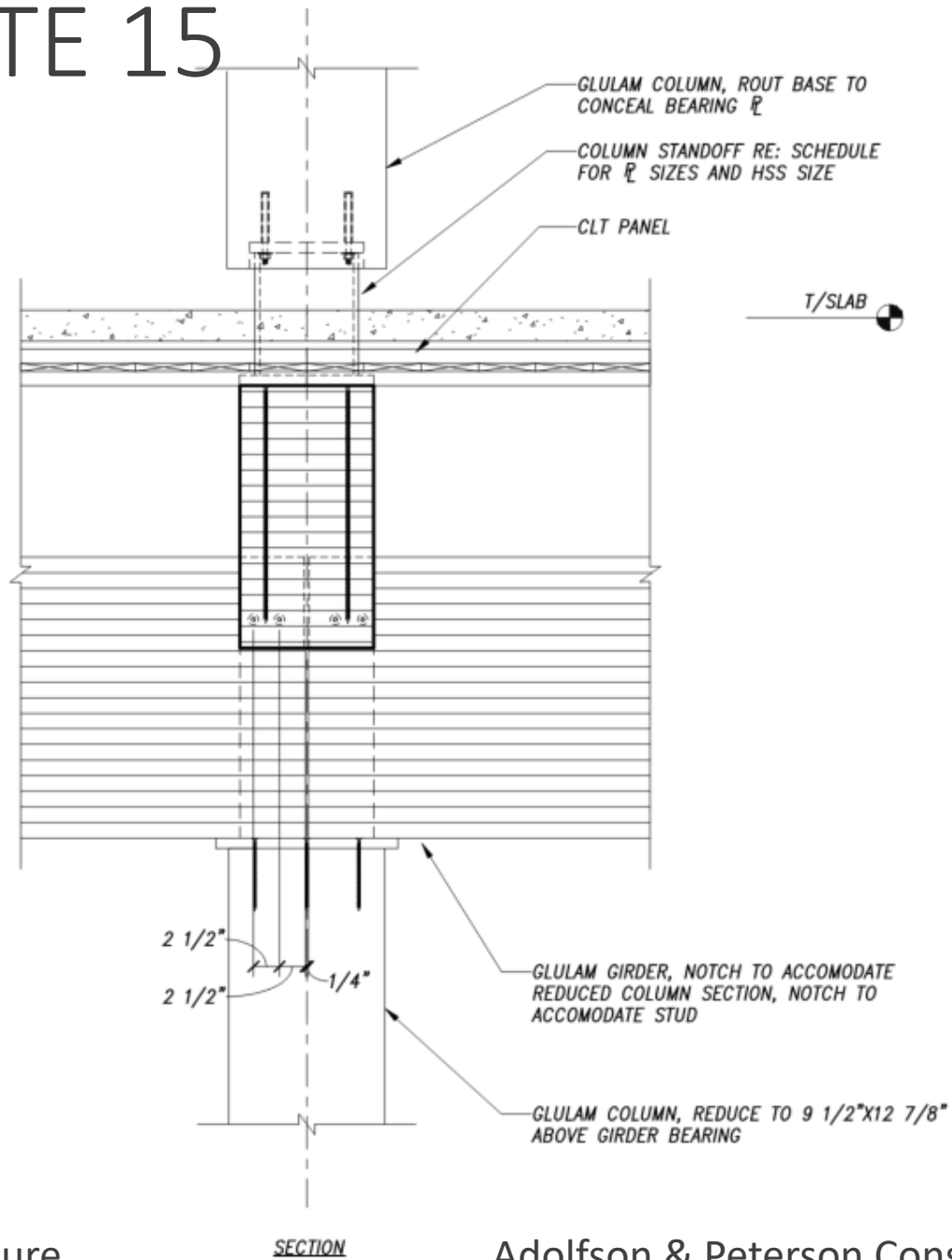
PLATTE 15



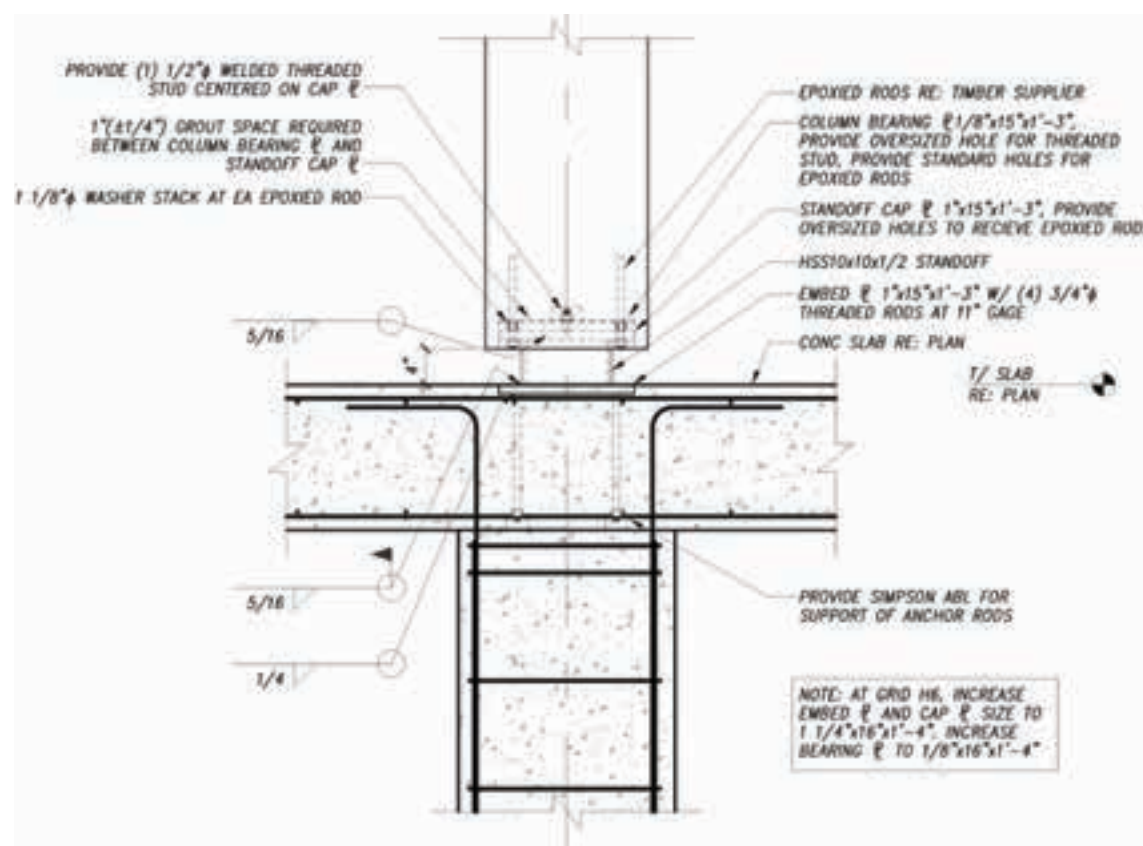
PLATTE 15



PLATTE 15



PLATTE 15



OZ Architecture



Adolfson & Peterson Construction



KL&A & Nordic



PLATTE 15

OZ Architecture

Adolfson & Peterson Con



KL&A & Nordic

PLATTE 15



PLATTE 15

50 ft panels typical
(53 ft max)



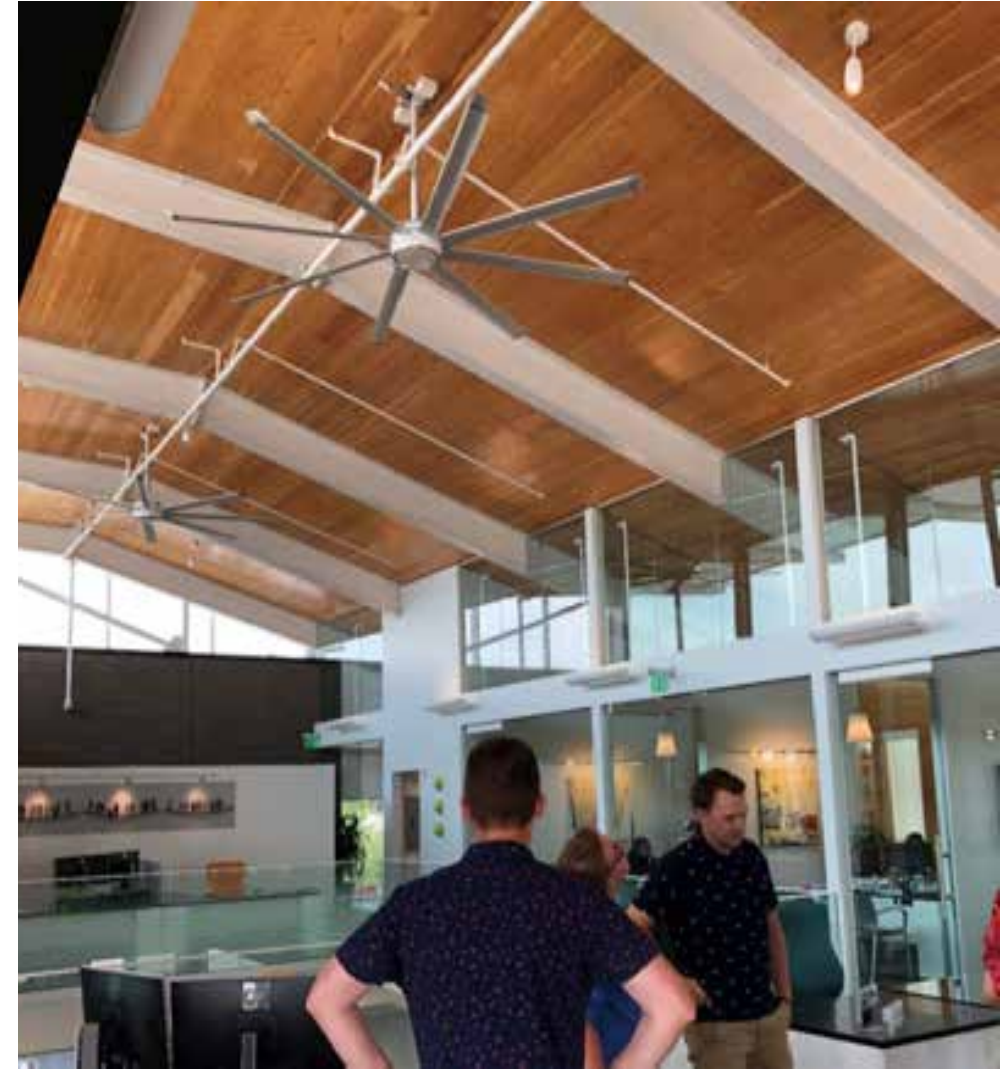
OZ Architecture

Adolfson & Peterson Construction

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PLATTE 15

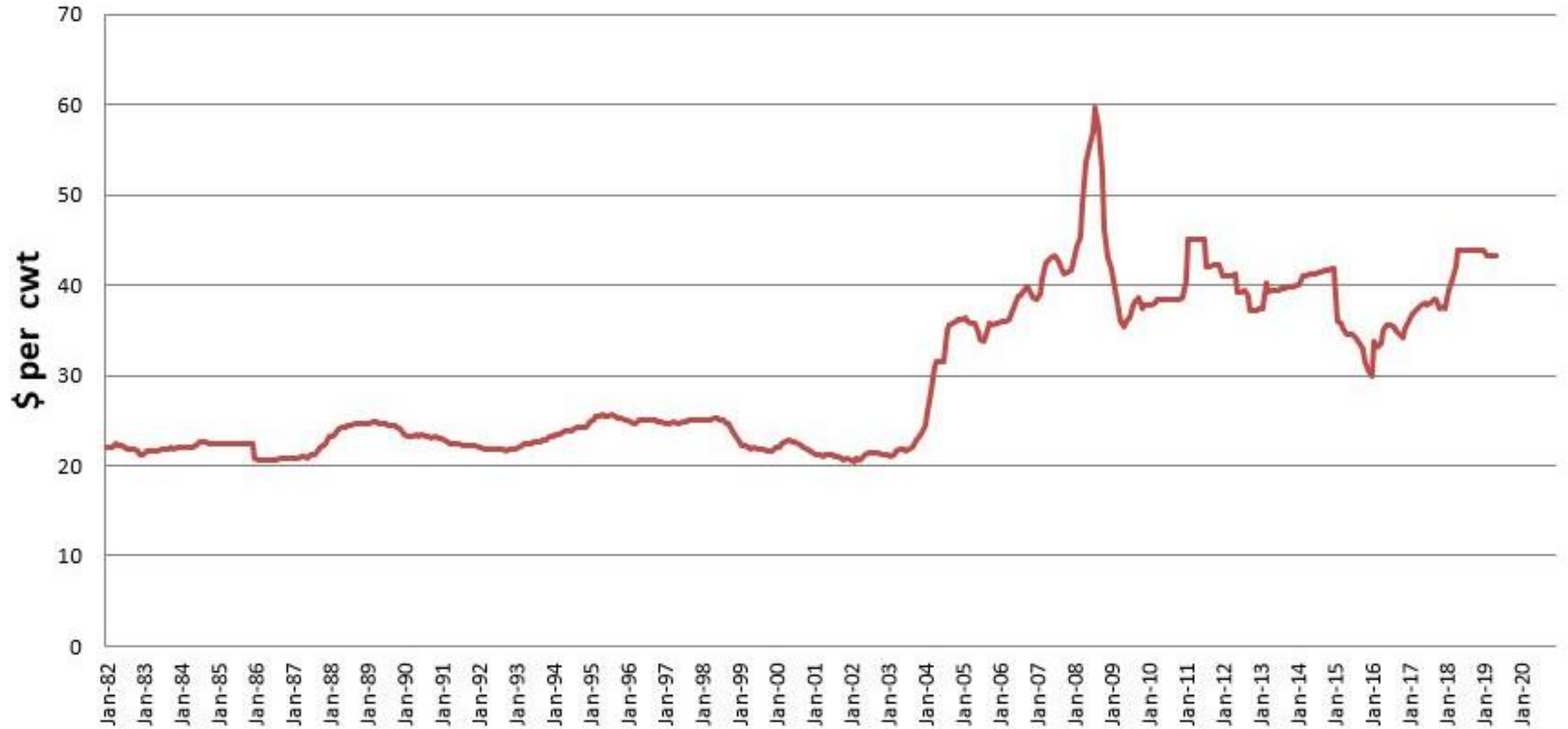
STEEL / TIMBER HYBRIDS



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

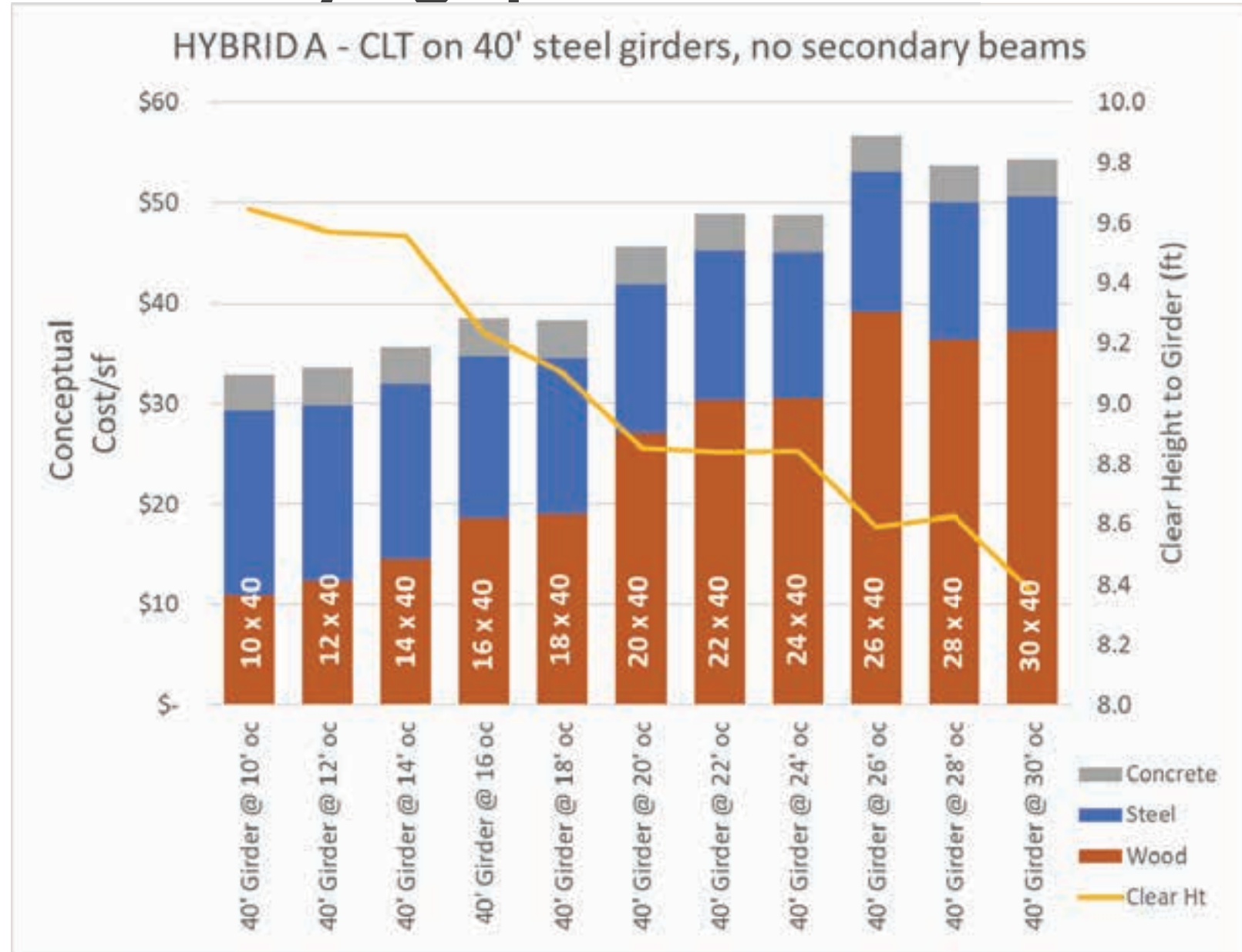
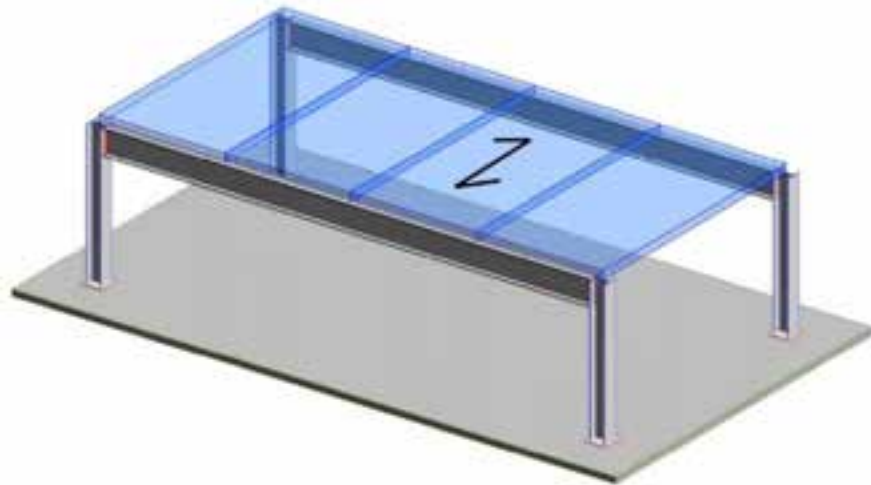
So ...

Fewer larger pieces are usually
more economical than many
small pieces

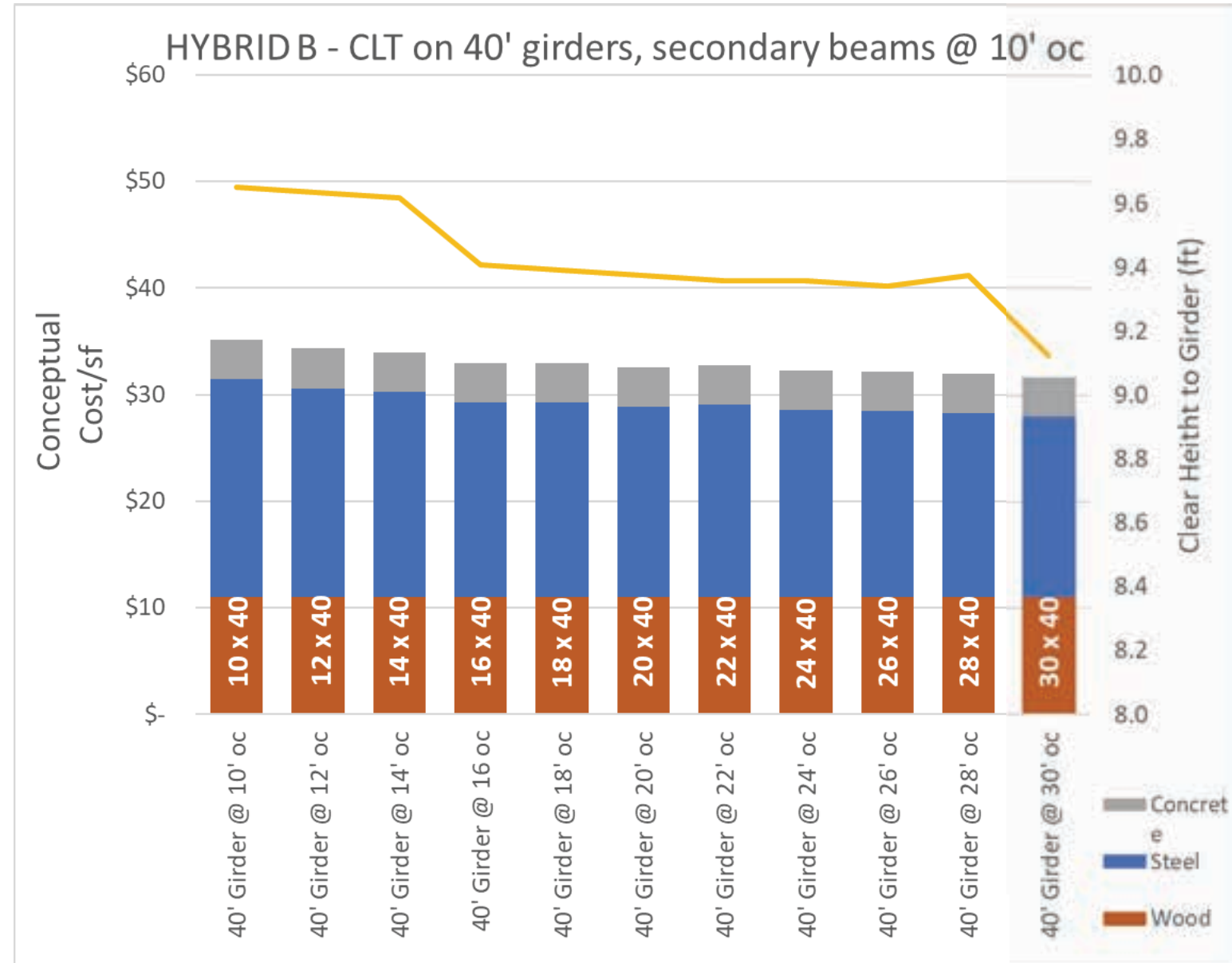
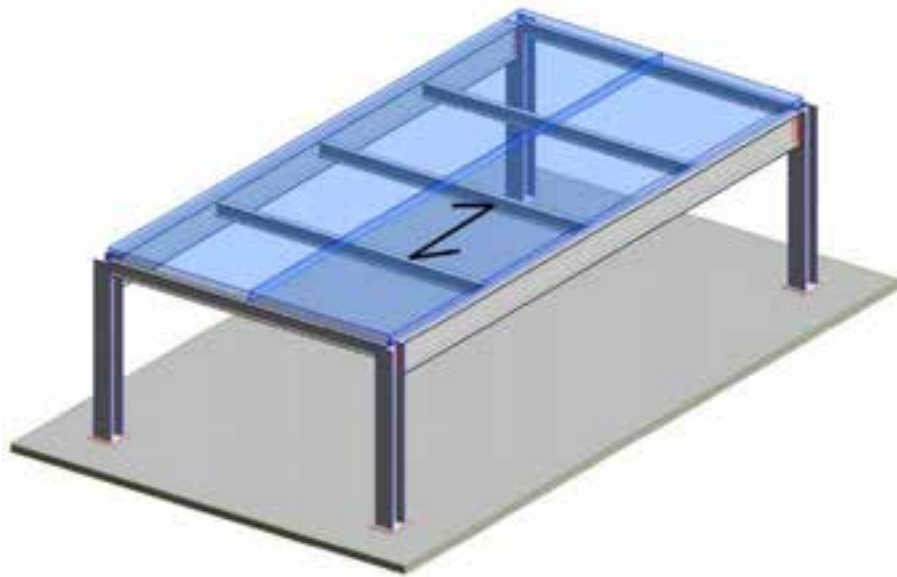


W10x26 spanning 20 ft	\$1,161 / pc	\$ 4,255 / ton
W16x40 spanning 30 ft	\$ 1,705 / pc	\$ 2,707 / ton
W24x84 spanning 50 ft	\$ 3,906 / pc	\$ 1,771 / ton

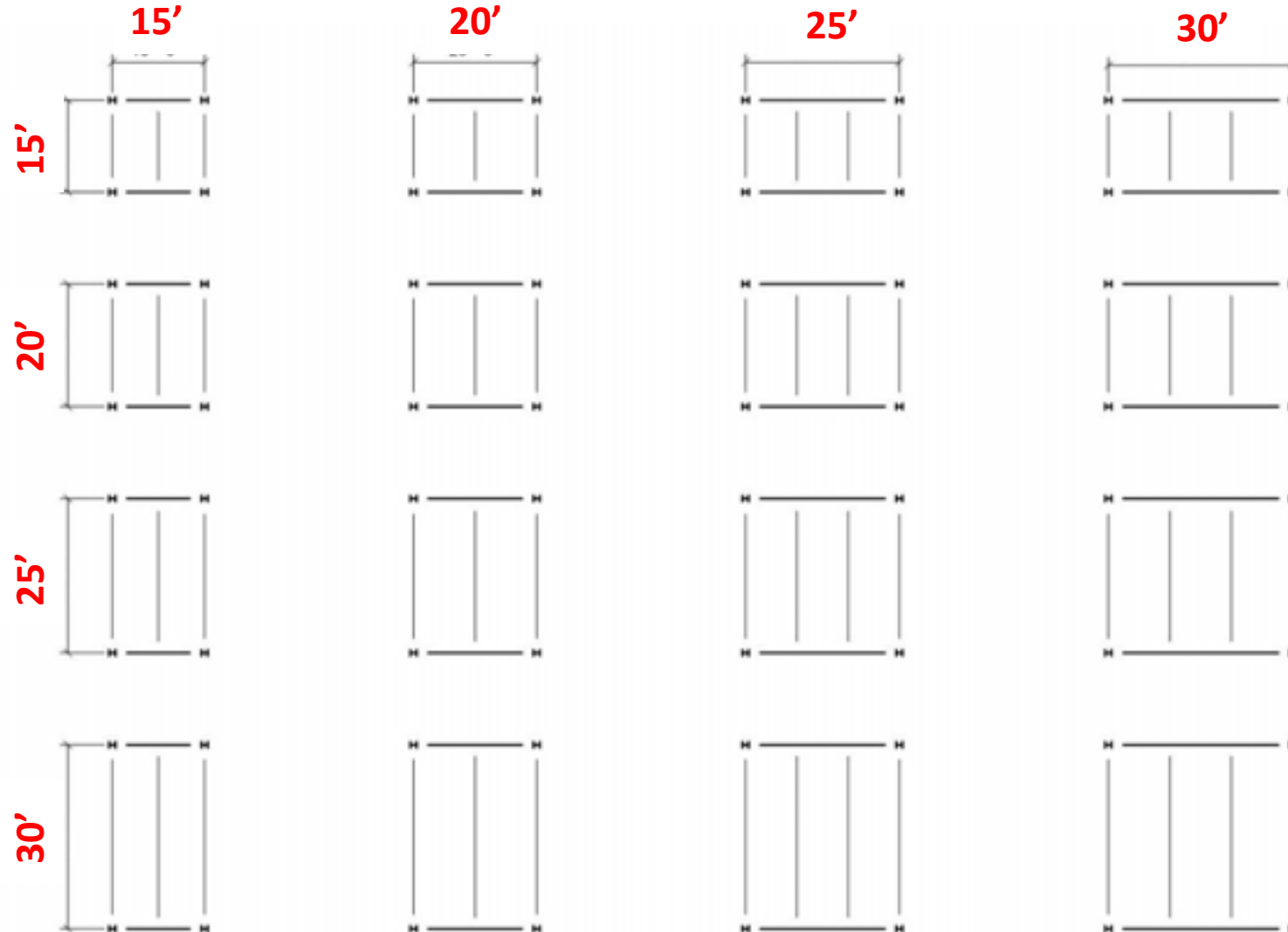
Steel bent with CLT of varying spans between



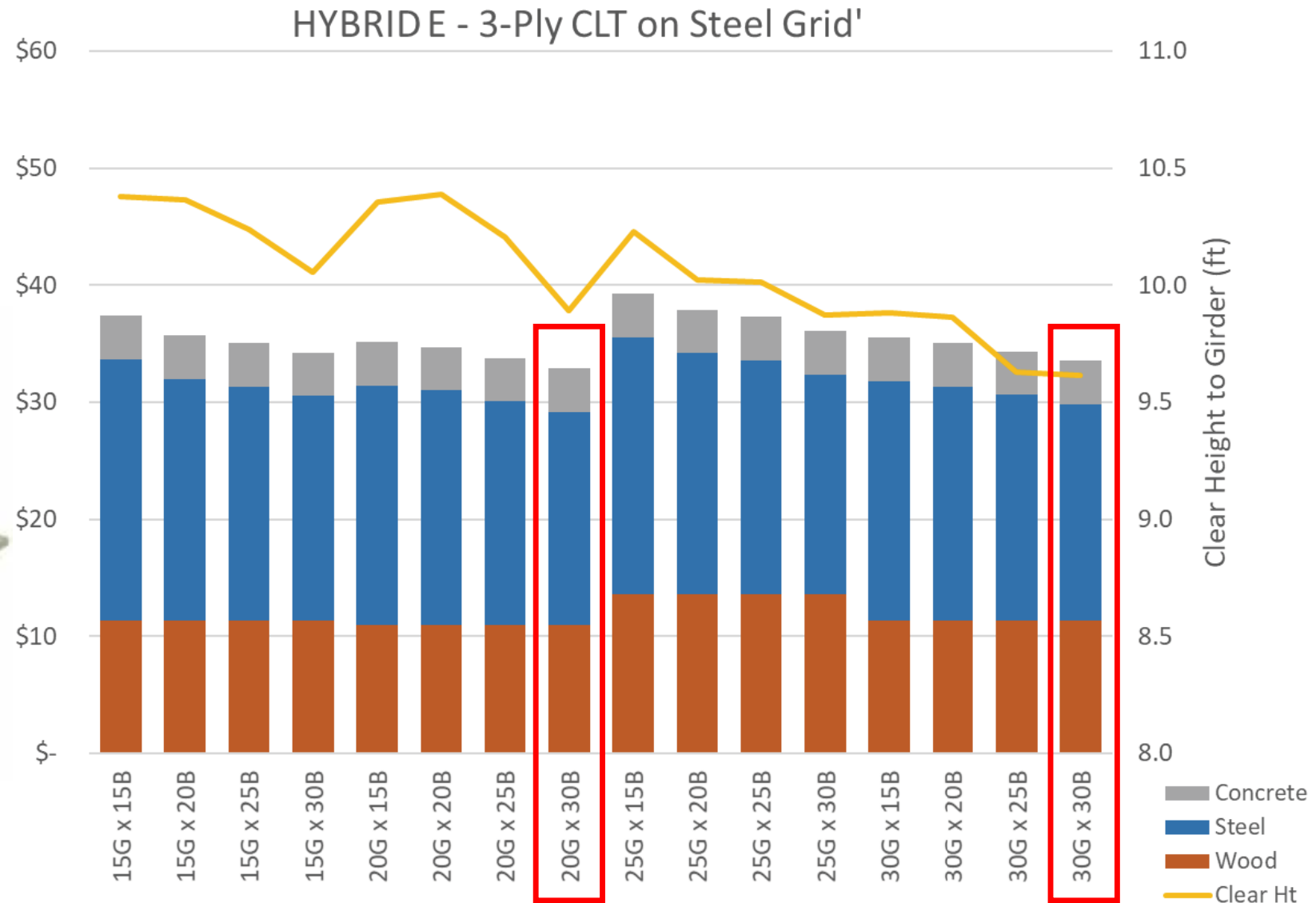
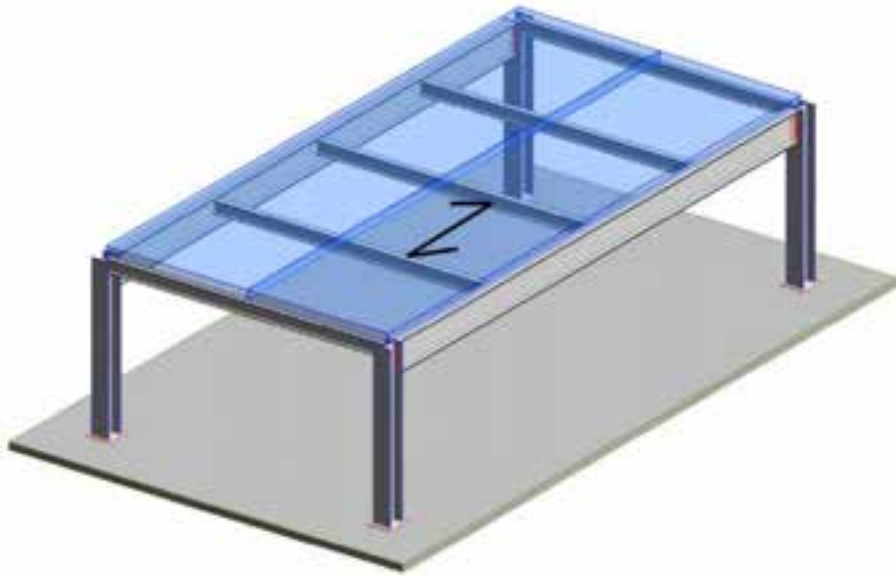
Steel frame with beams @ 10 ft o.c., CLT spans 10 ft



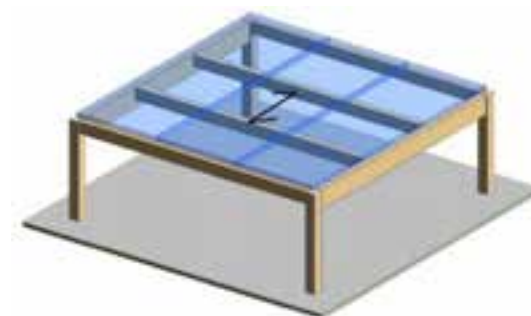
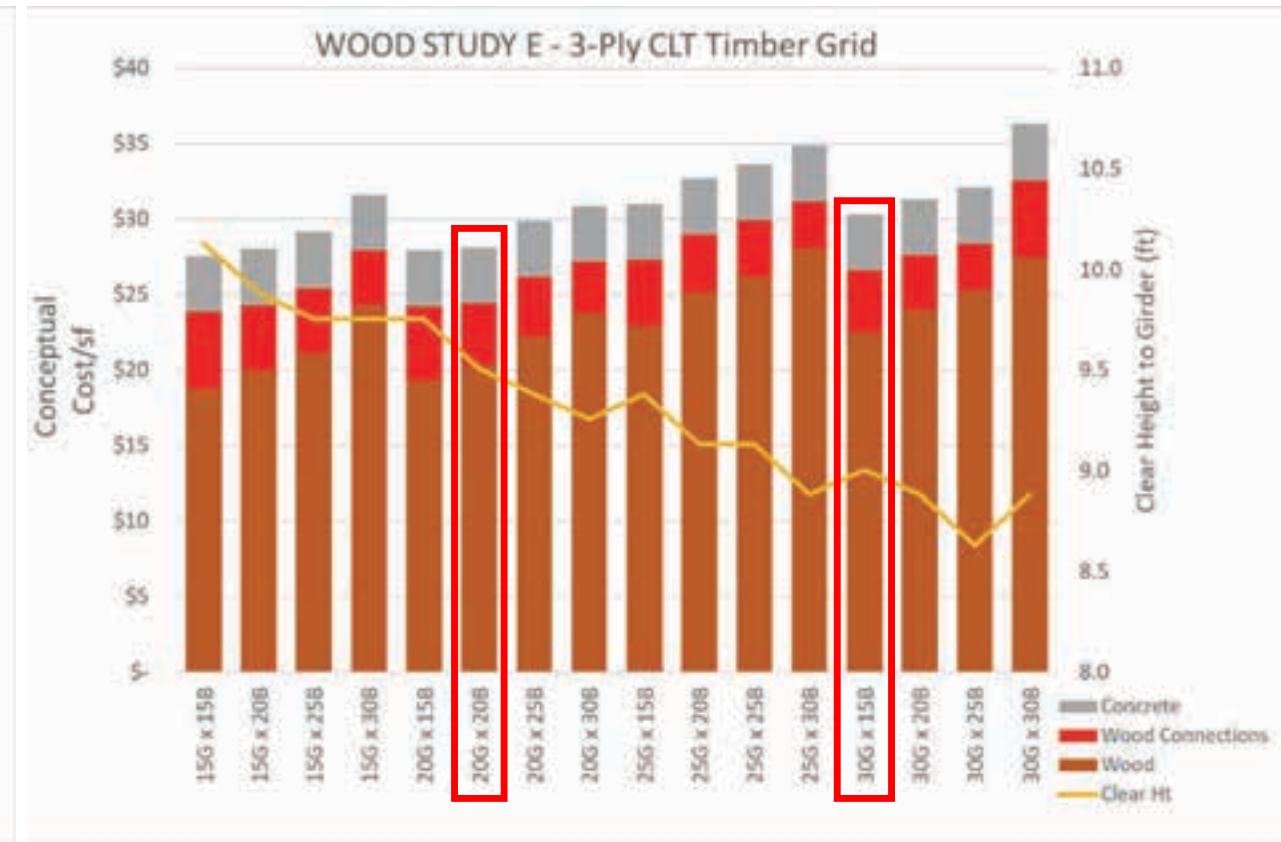
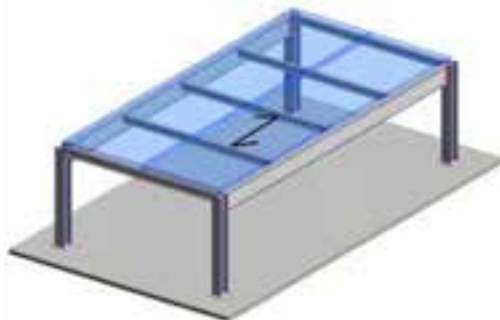
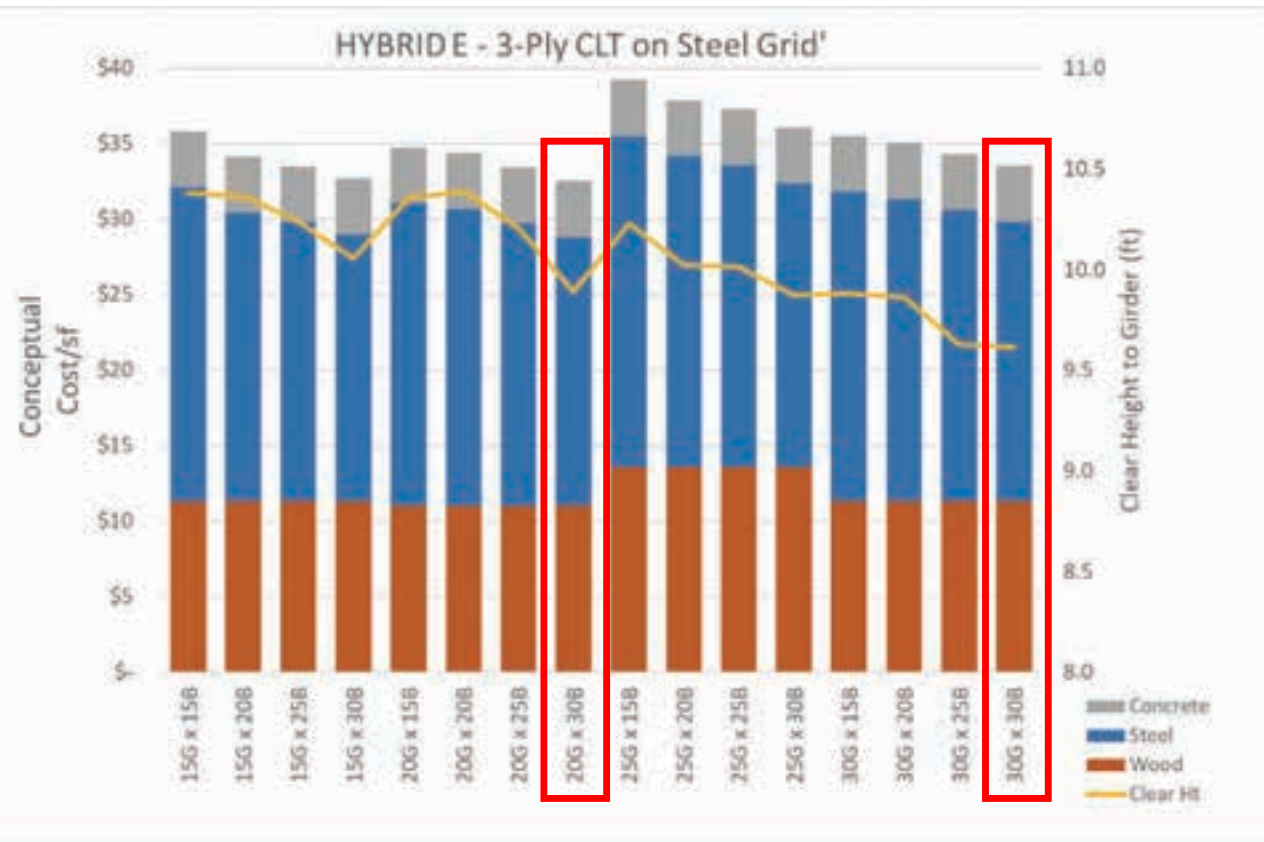
Hybrid Bay Study: 15x15 up to 30x30



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



Hybrid vs Wood Grid



Case Study 5 - Colorado Boulder Office

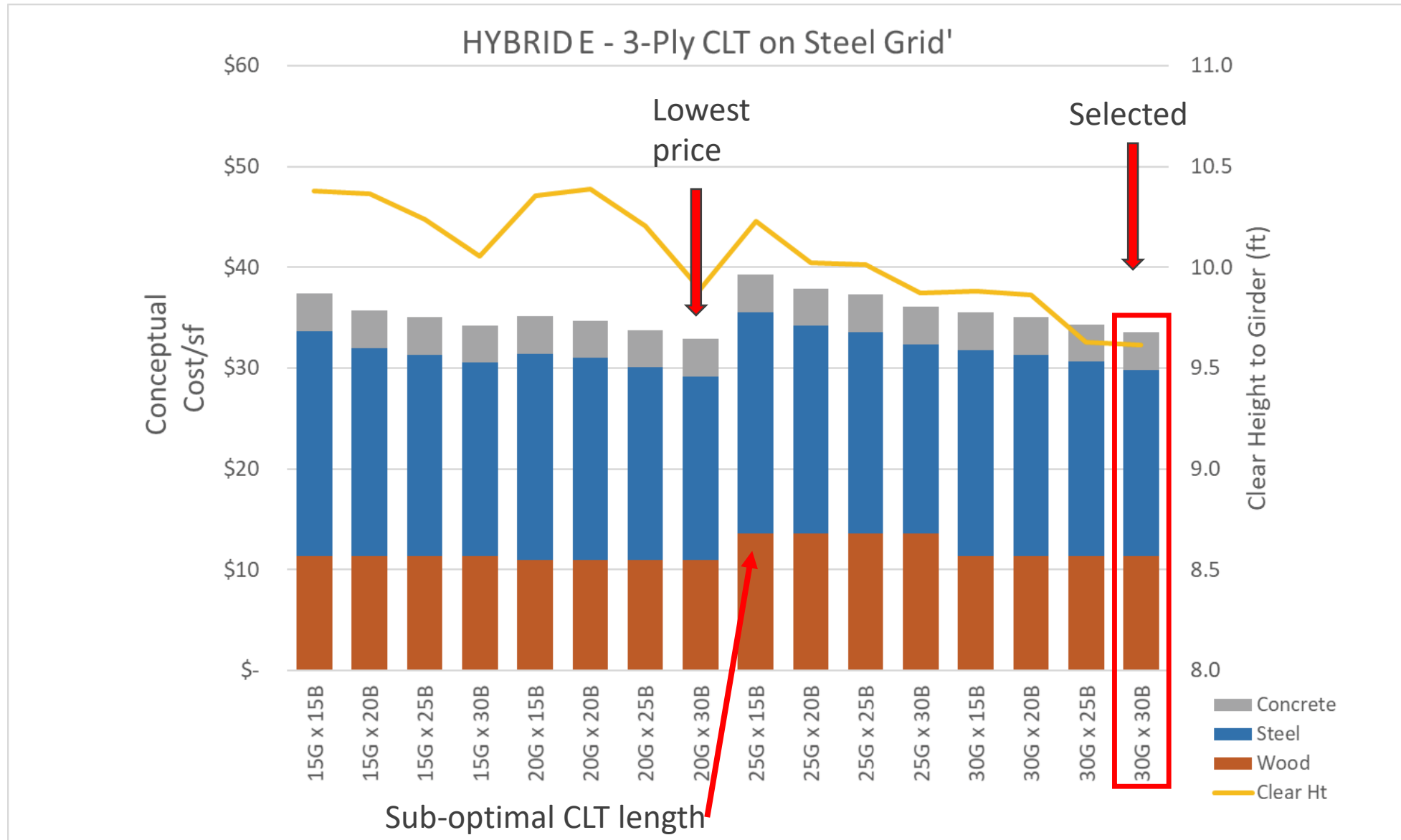
In which we explore hybrid solutions

Boulder Office



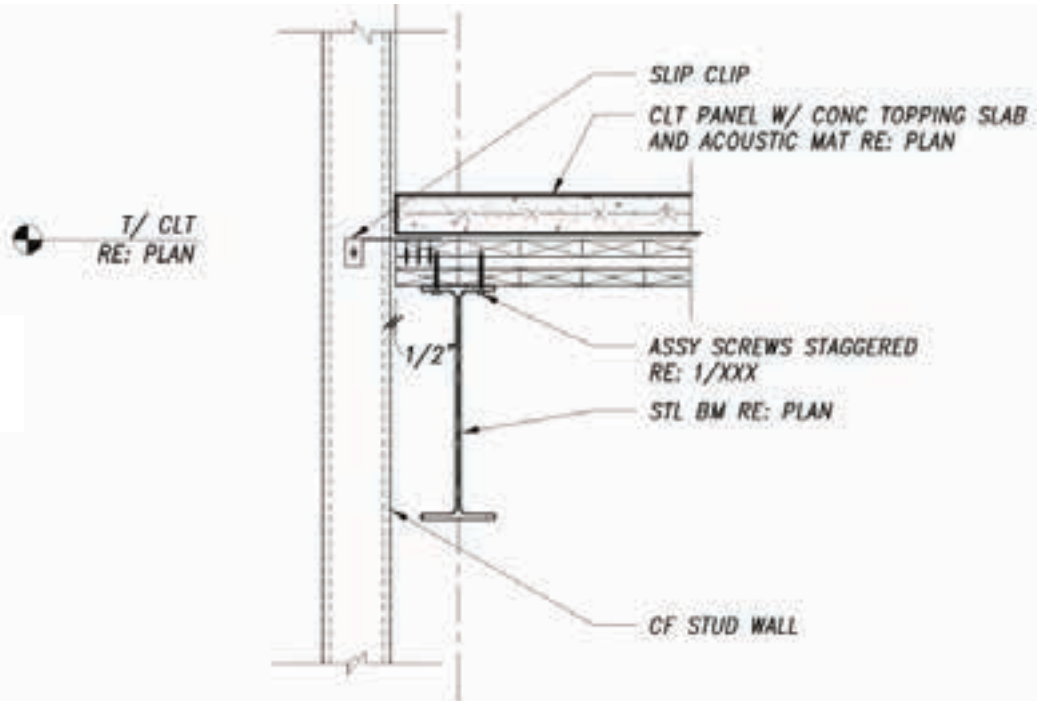
- Type III-B Construction
- 2-Stories
- Hybrid steel frame with CLT floors
- 30 x 30 grid

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



Typical Connections

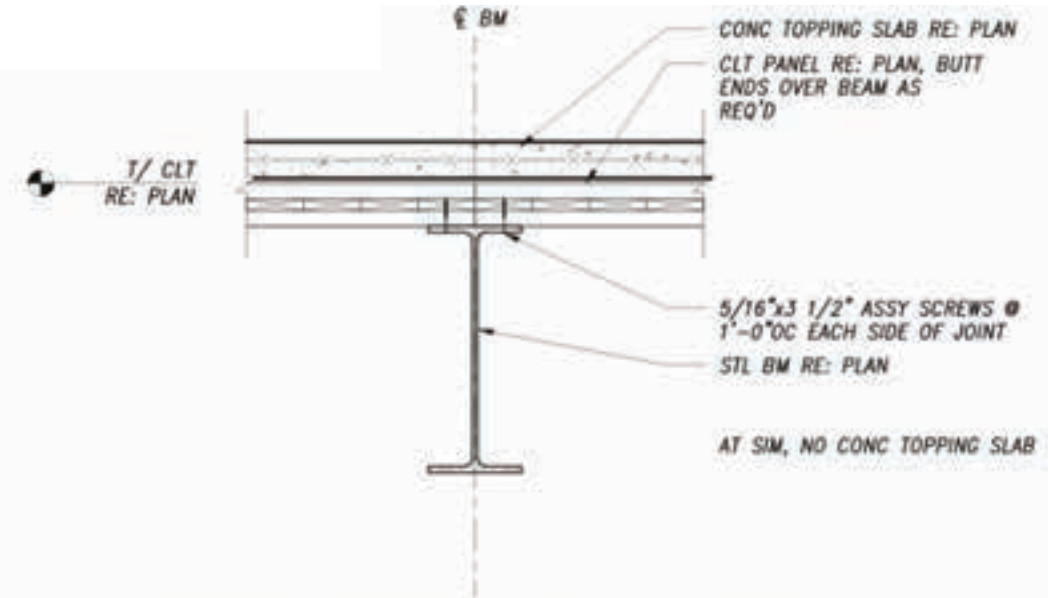
- Type III-B Construction
- Hybrid steel frame with CLT floors
- 30 x 30 grid



14

CLT EDGE AT CFS WALL - SECOND FLOOR

3/4" = 1'-0"



10

TYPICAL CLT PANEL TO BEAM

3/4" = 1'-0"

Case Study 6 - Colorado Denver RiNo Office

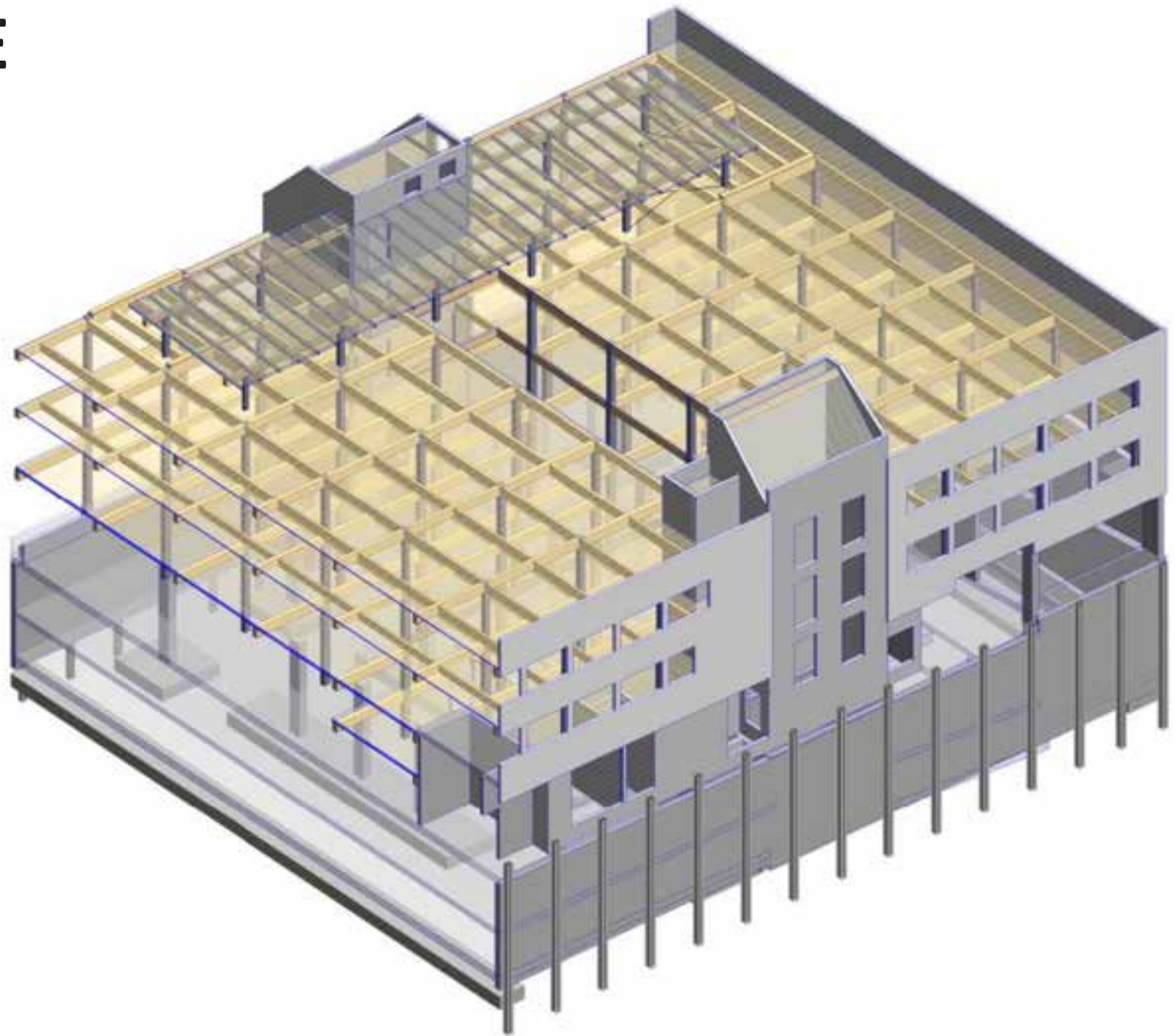
In which we raise the floor

DENVER RiNo OFFICE

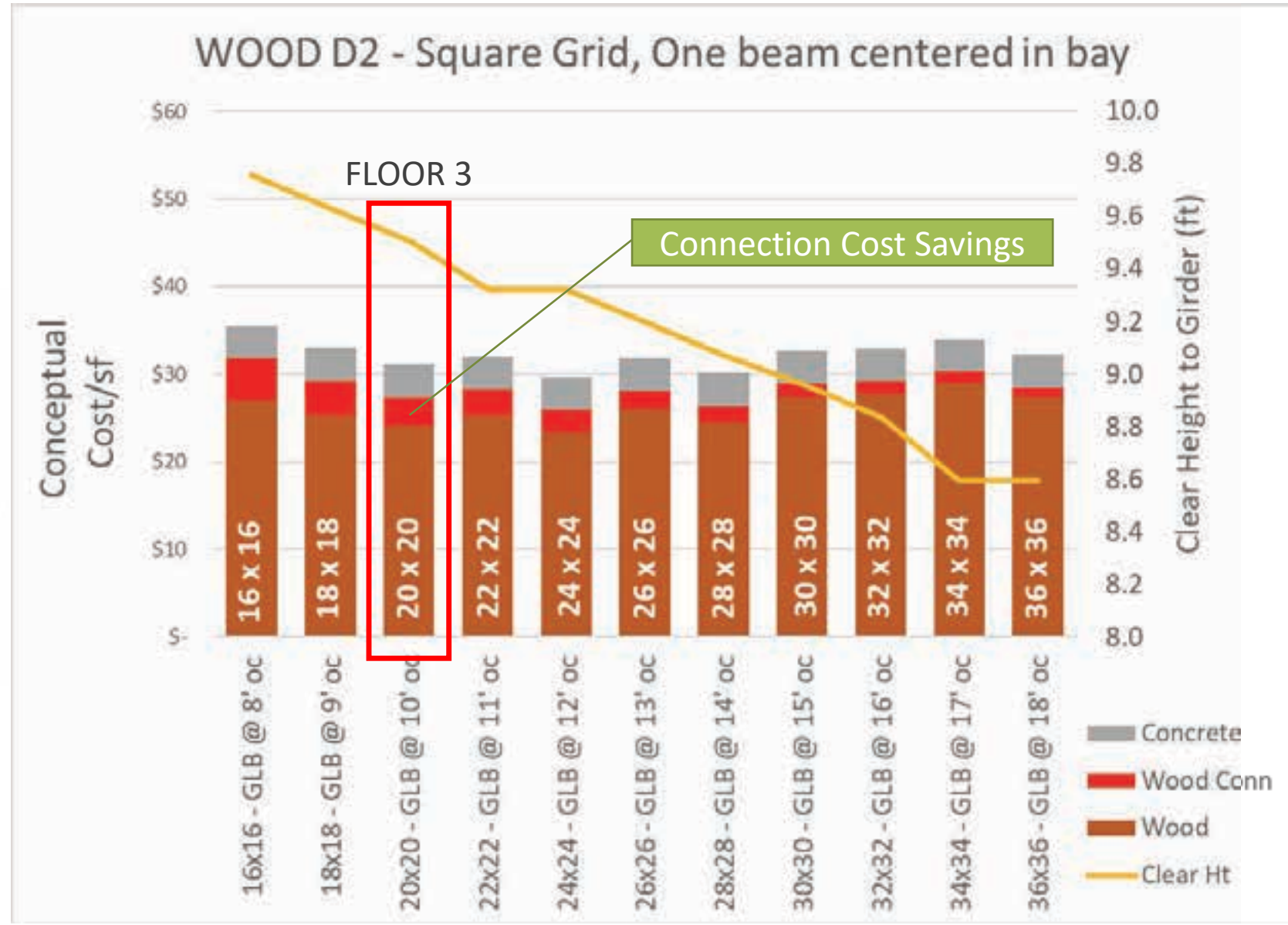
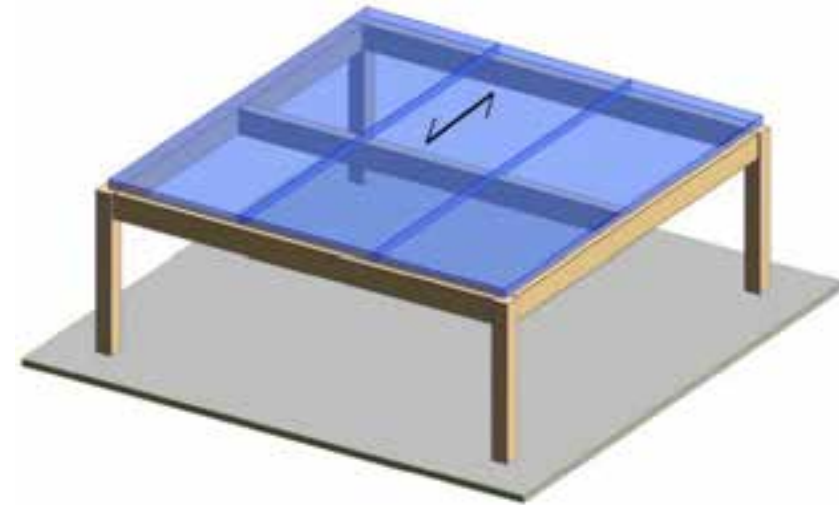


DENVER RiNo OFFICE

- 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)

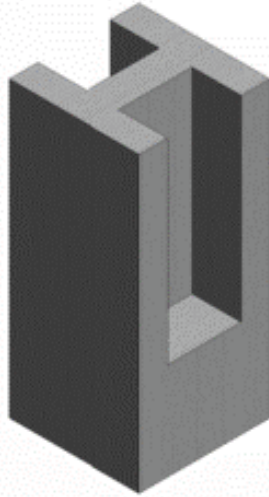


Square bay, CLT with 2 equal (varying) spans

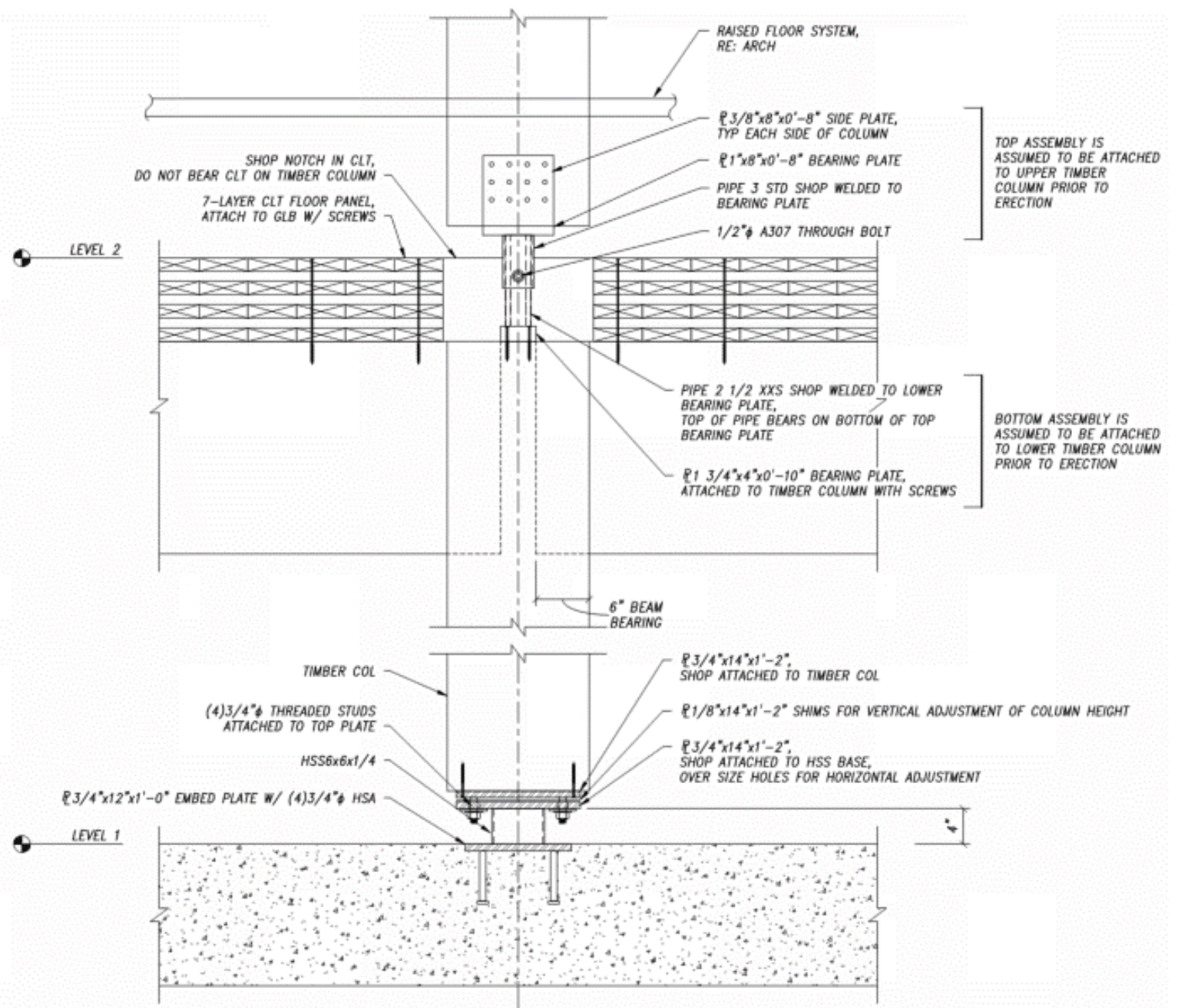


DENVER RiNo OFFICE

- 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

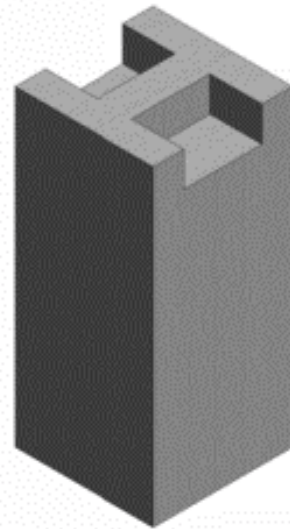


ISOMETRIC VIEW OF TIMBER COLUMN TOP AT LEVEL 2

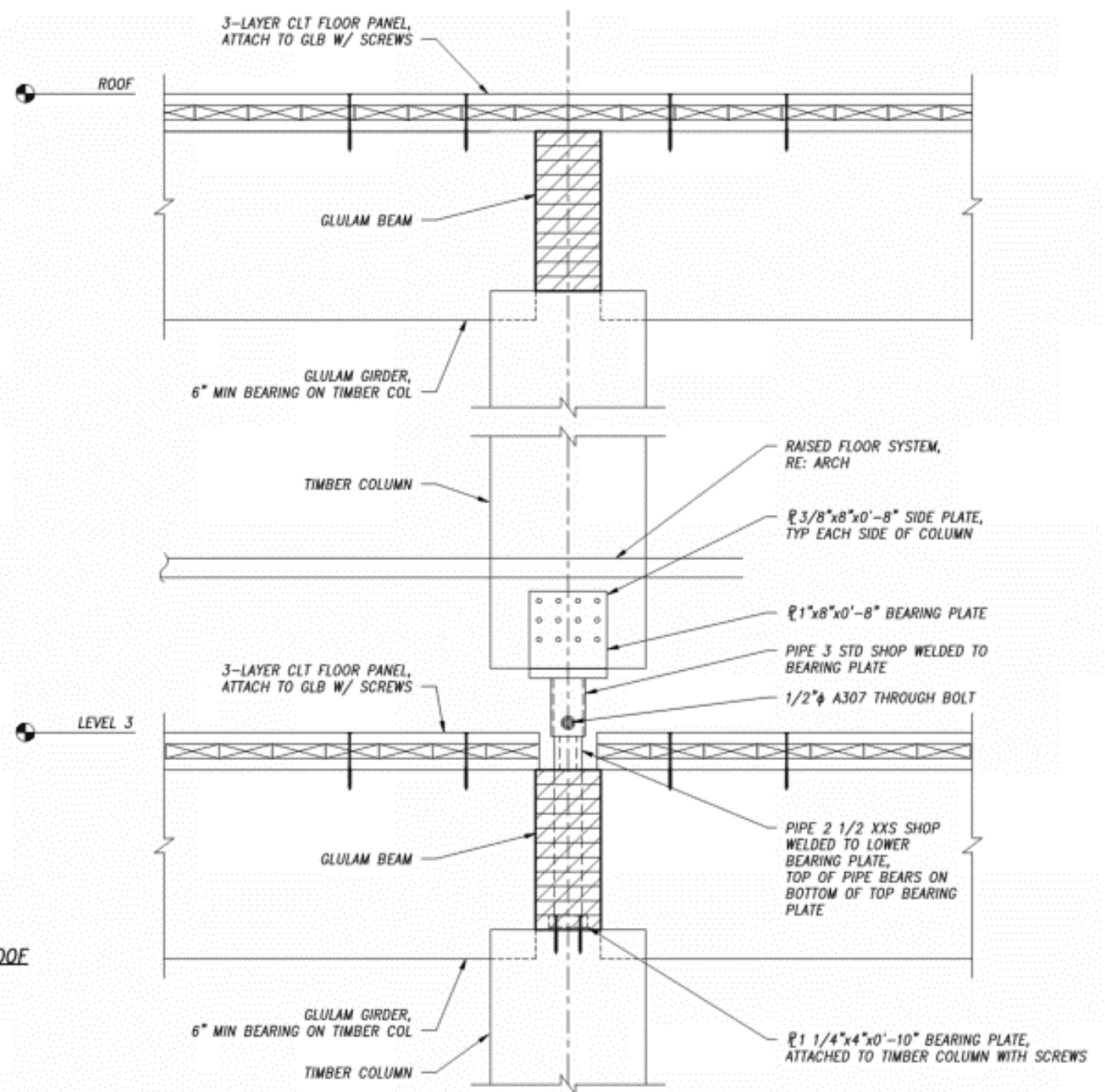


DENVER RiNo OFFICE

- 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



ISOMETRIC VIEW OF TIMBER
COLUMN TOP AT LEVELS 3 AND ROOF



Case Study 7 - Colorado Denver University Pioneer Career Achievement Center (DU PCAC)

In which we search for the sweet spot

Denver University – PCAC

Pioneer Career Achievement Center

Early design images



Denver University – PCAC

Pioneer Career Achievement Center

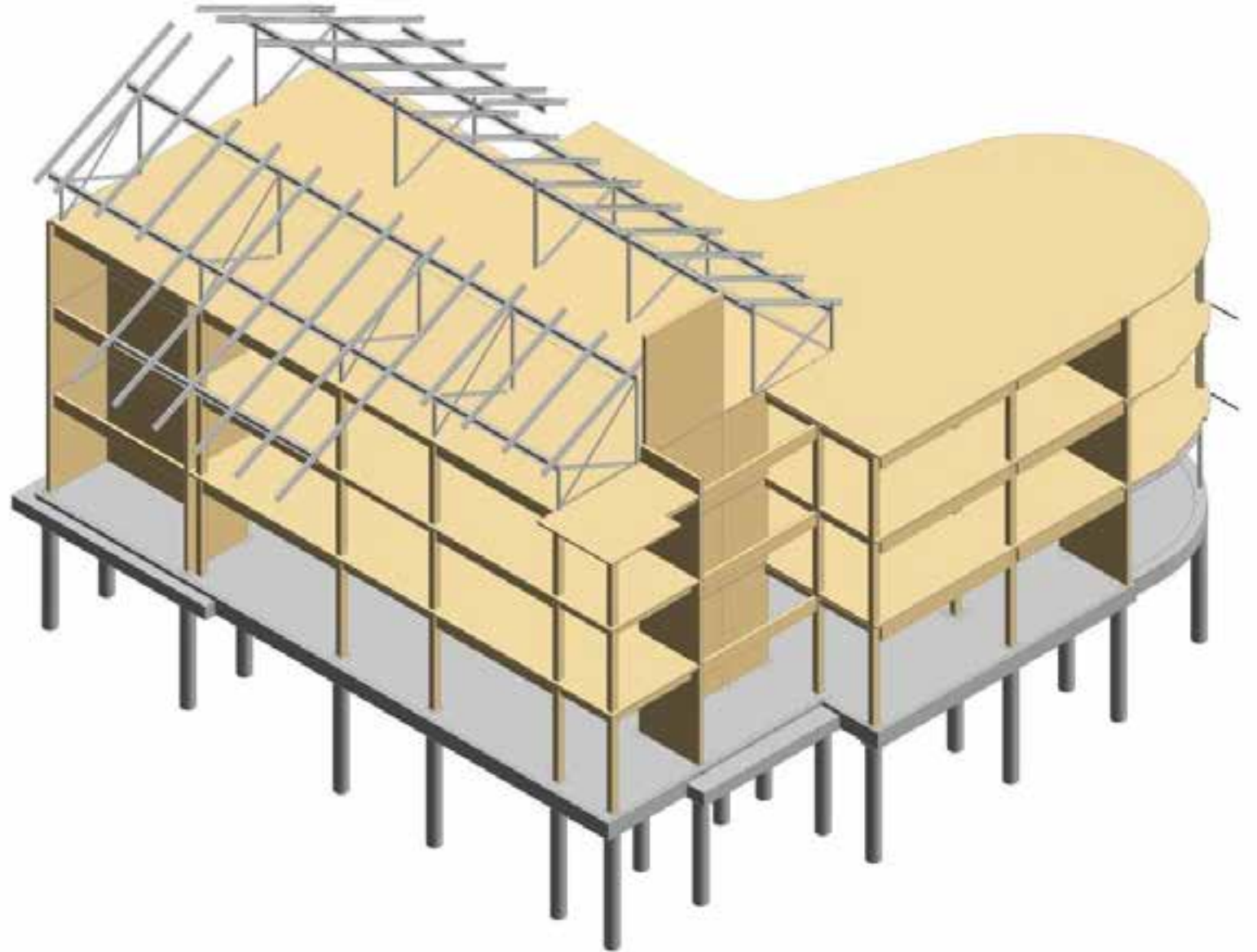
- Grid 24 ft x 24 ft
- 3-ply Doug Fir CLT floors
- 5-ply Doug Fir CLT shear walls
- Doug Fir glulam beams
- Doug Fir glulam columns



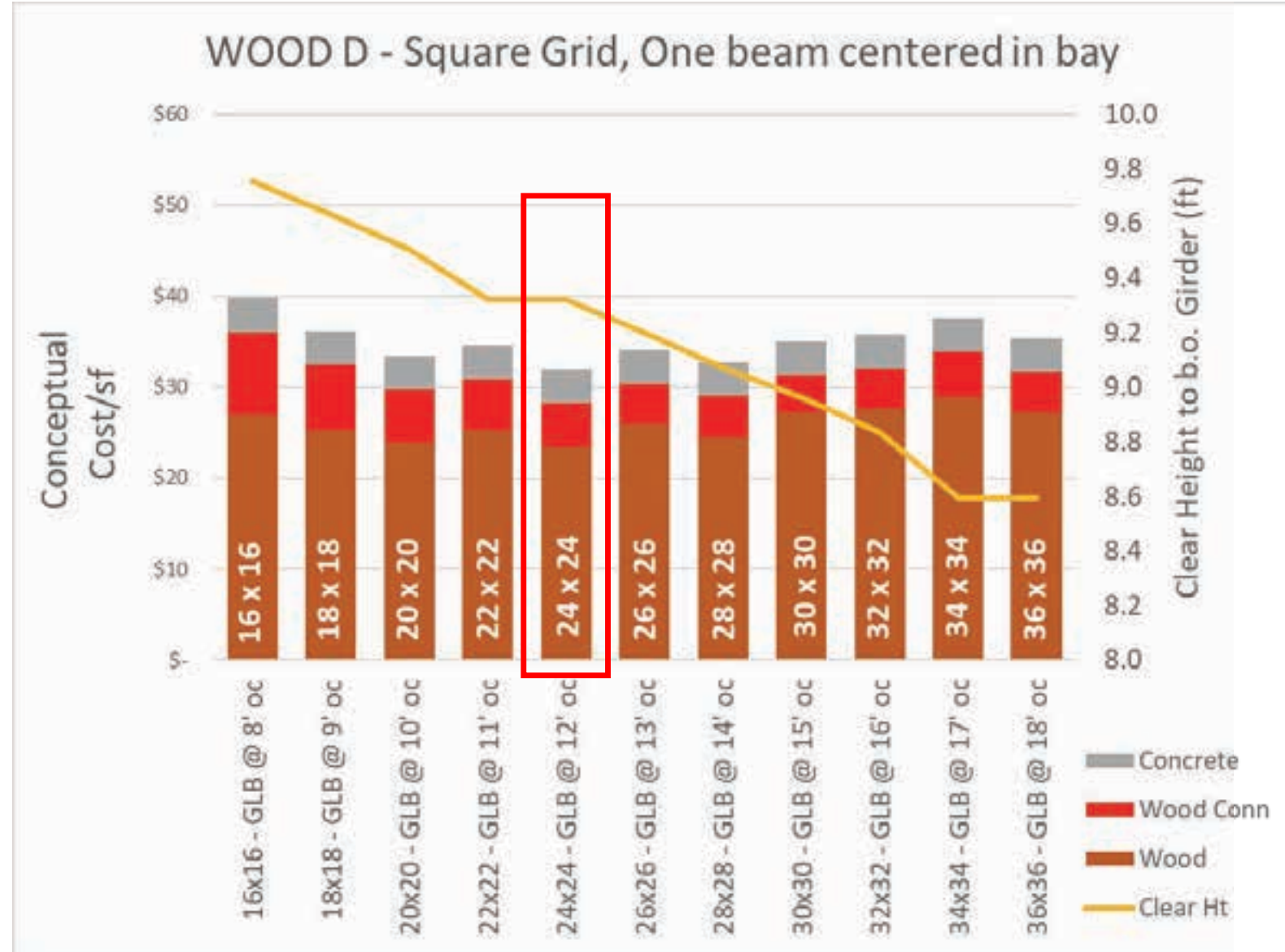
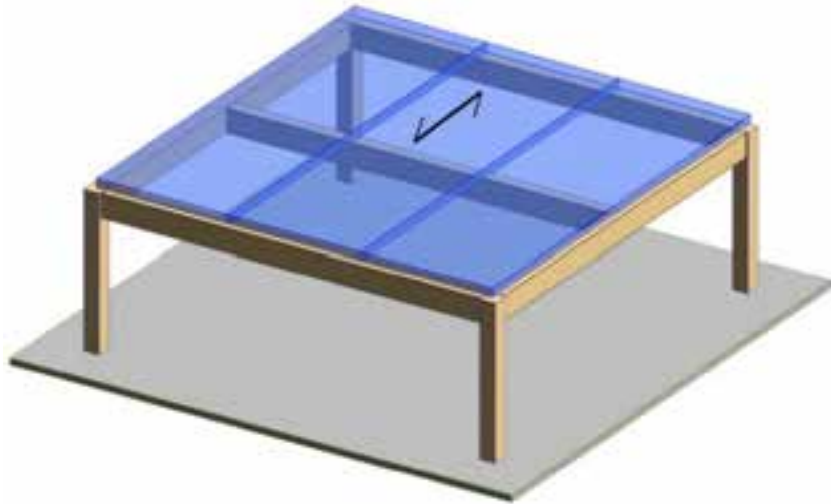
Denver University – PCAC

Pioneer Career Achievement Center

- 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

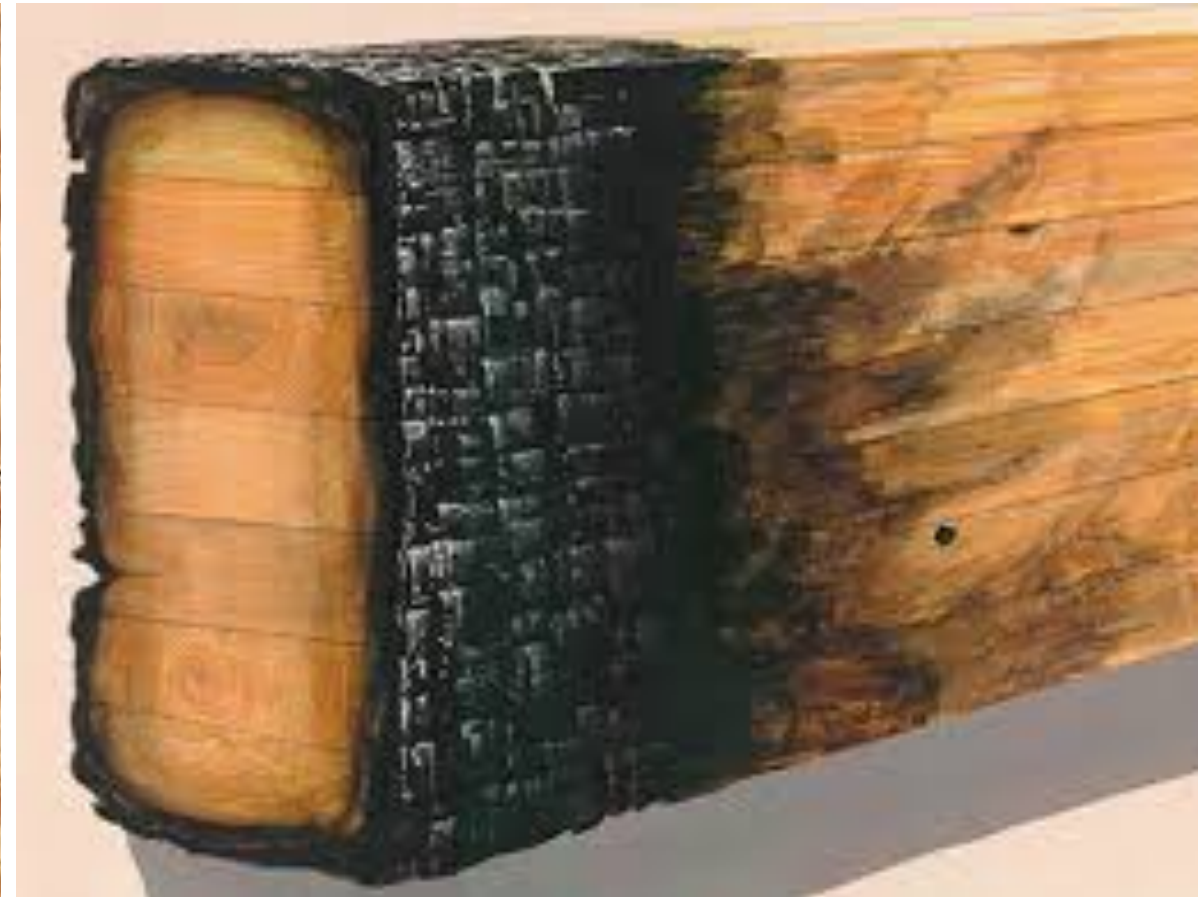
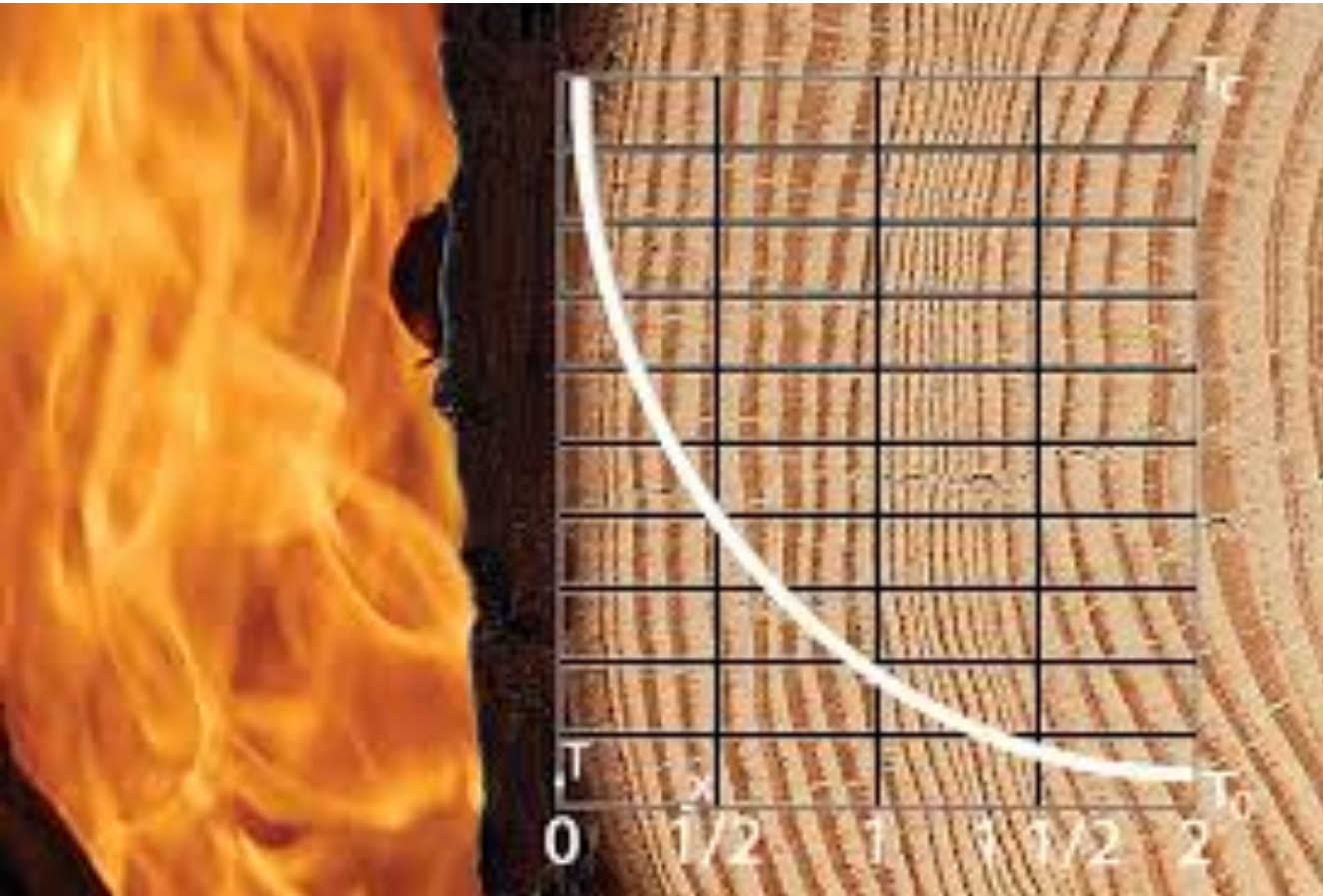
Proposed IBC Table 601

Fire Resistant Rated Construction

BUILDING ELEMENT		Type I		Type II		Type III		Type IV				Type V	
		A	B	A	B	A	B	A	B	C	HT	A	B
Primary structural frame		3	2	1	0	1	0	3	2	2	HT	1	0
Bearing walls	Exterior	3	2	1	0	2	2	3	2	2	2	1	0
	Interior	3	2	1	0	1	0	3	2	2	1/HT	1	0
Nonbearing walls	Exterior	See Table 602											
	Interior	0	0	0	0	0	0	0	0	0	See Section 2304.11.2	0	0
Floor		2	2	1	0	1	0	2	2	2	HT	1	0
Roof		1.5	1	1	0	1	0	1.5	1	1	HT	1	0



Tall Wood requires design for fire rated assemblies



Loading Dock - MEP



T3 - MEP



Photo courtesy of David Hanley

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

> QUESTIONS?

This concludes The American Institute
of Architects Continuing Education
Systems Course



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