Optimization of Mass Timber Framing

for Residential Towers (and other Project Typologies)

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FOREFRONT
STRUCTURAL ENGINEERS, INC.

interstice

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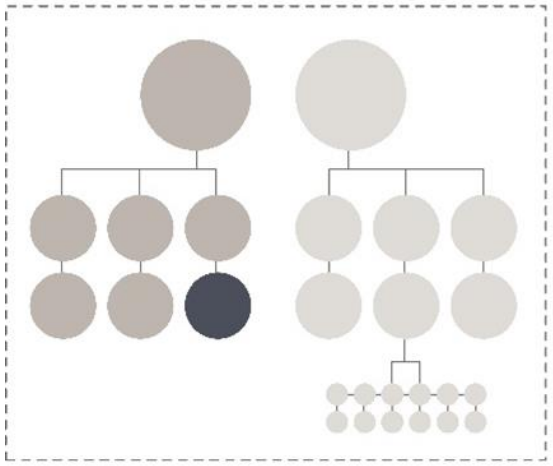
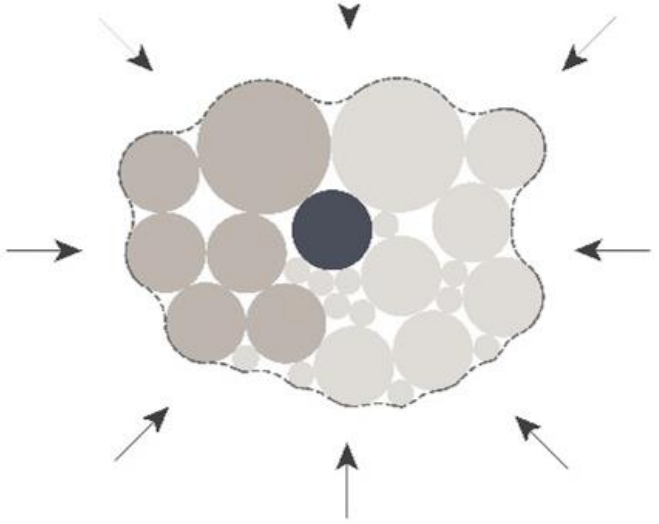
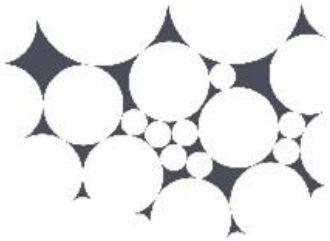
Innovation…



Traditional Project Team

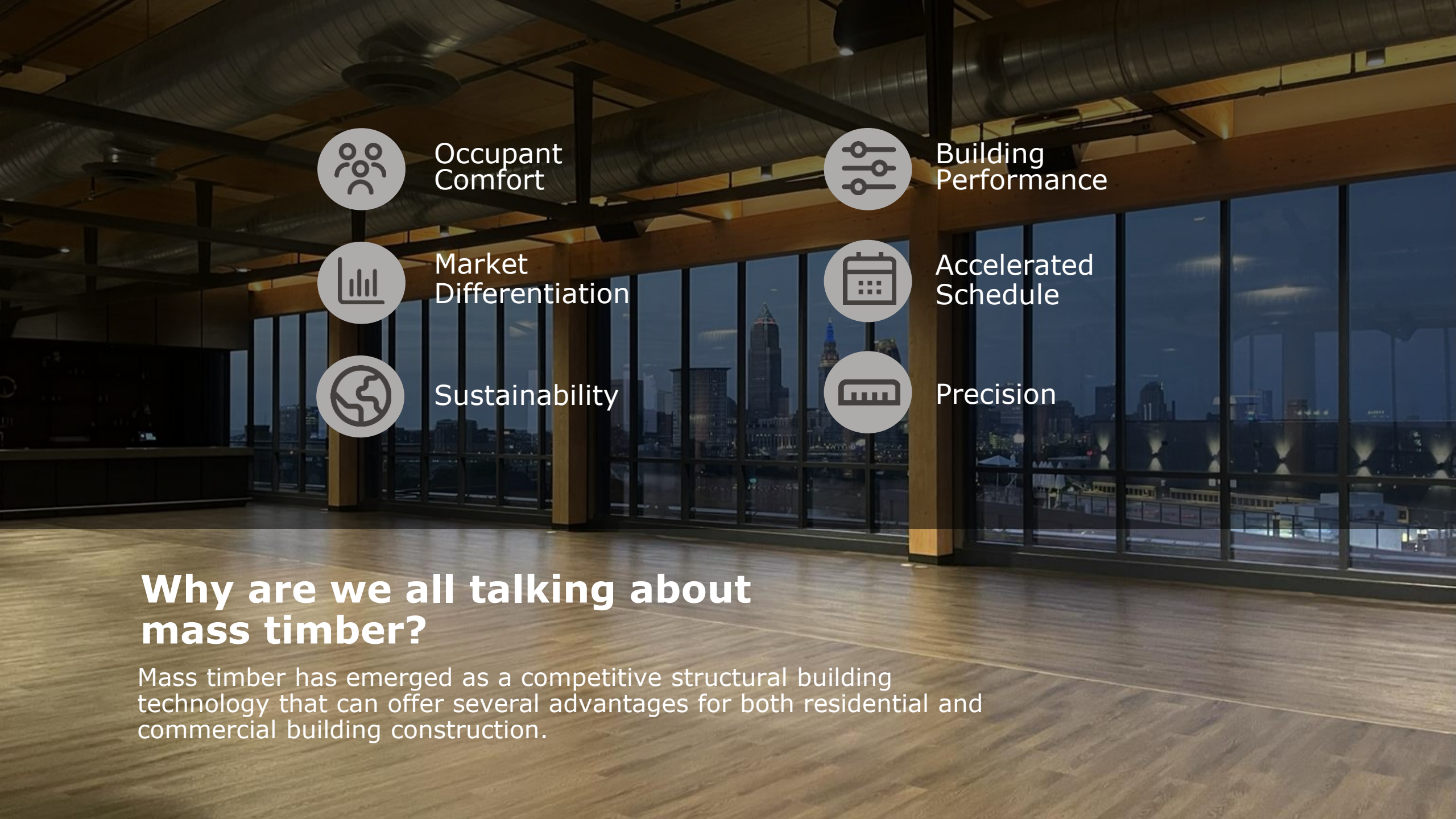


Project Implementation



Gaps / Opportunities

…Exists in the Gaps



Why are we all talking about mass timber?

Mass timber has emerged as a competitive structural building technology that can offer several advantages for both residential and commercial building construction.

Case Study:
INTRO Cleveland

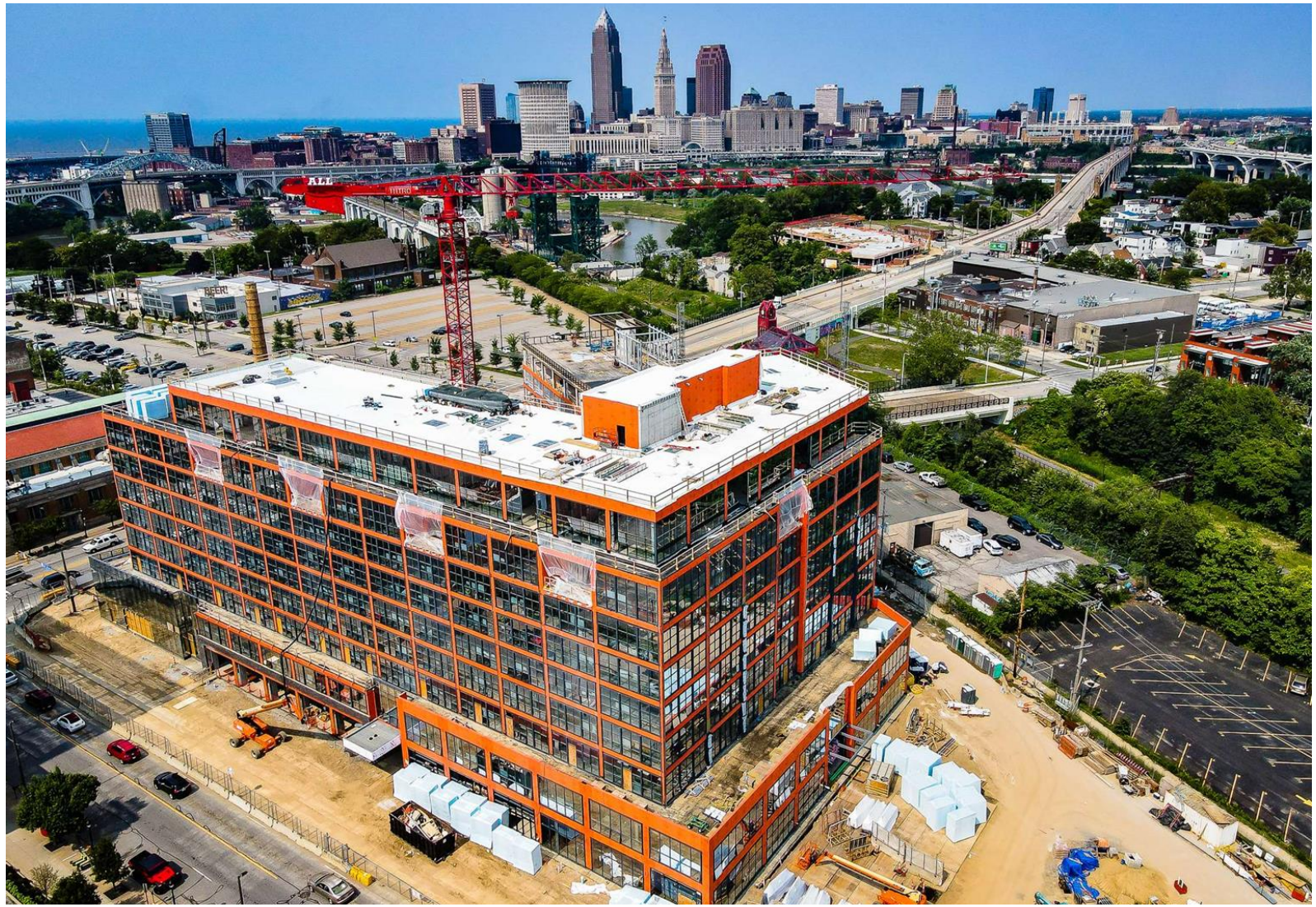
LOCATION
Cleveland, OH

SIZE
500,000 SF

HEIGHT
9 Stories

SYSTEM
Mass Timber / Post-Tensioned Concrete

SECTOR
Residential Mixed-Use



Case Study:
INTRO Cleveland

LOCATION
Cleveland, OH

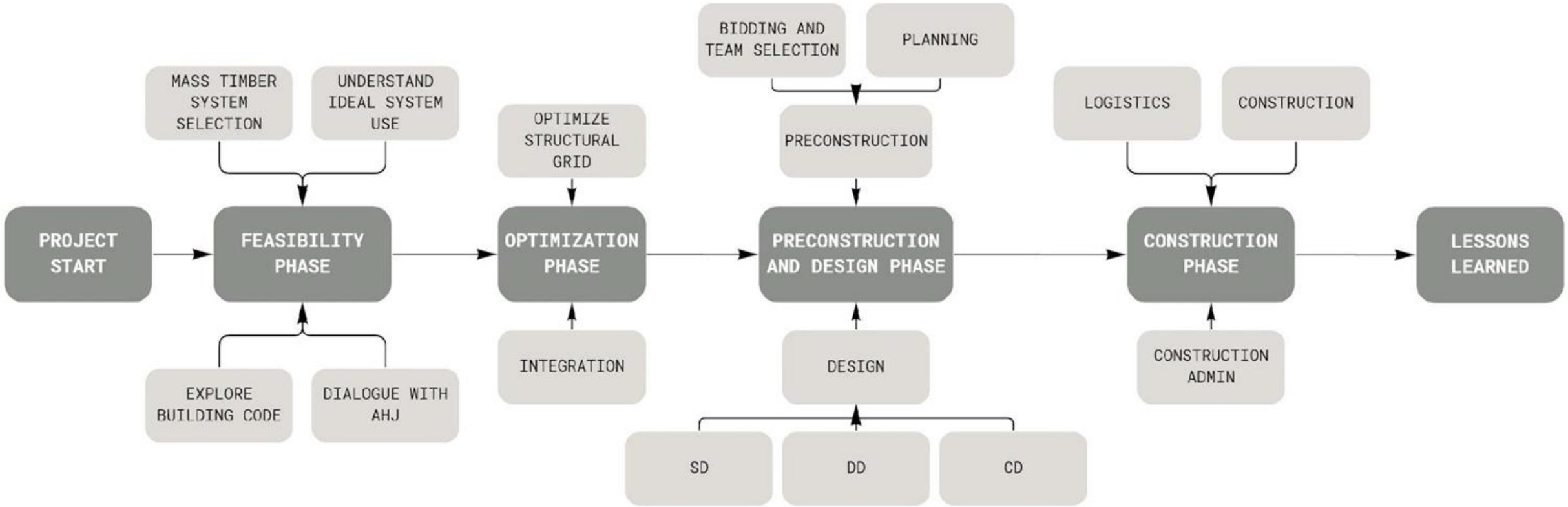
SIZE
765,000 SF

HEIGHT
9 Stories

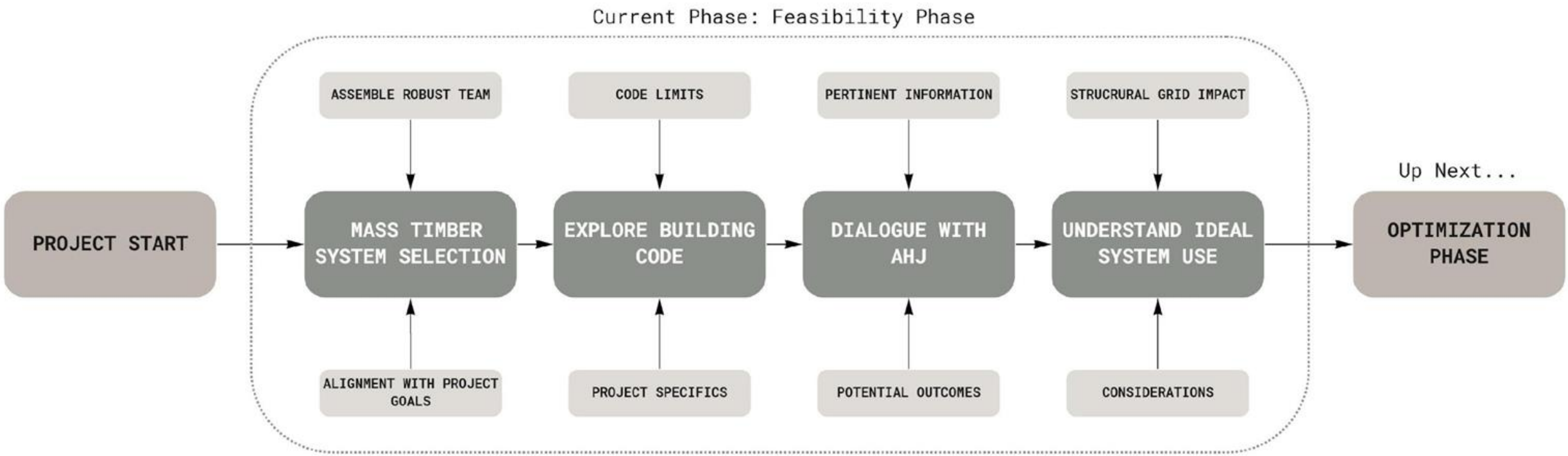
SYSTEM
Mass Timber / Post-Tensioned Concrete

SECTOR
Residential Mixed-Use

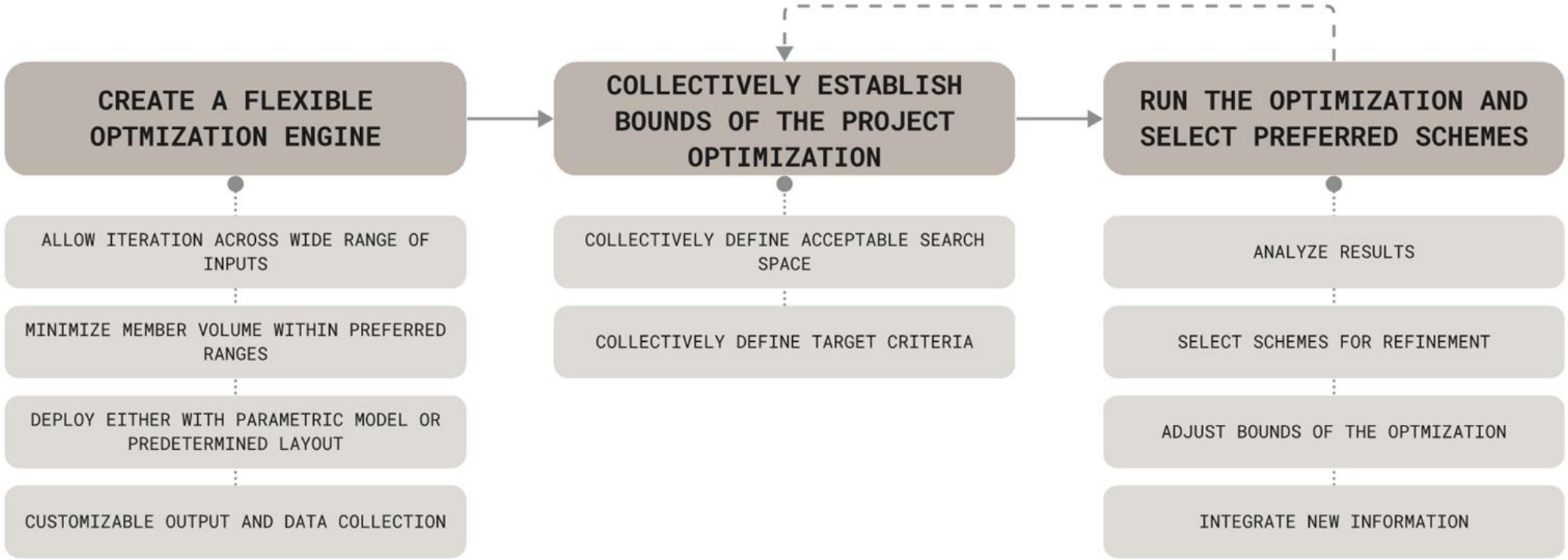
Establishing a Project Delivery Framework



Feasibility Phase

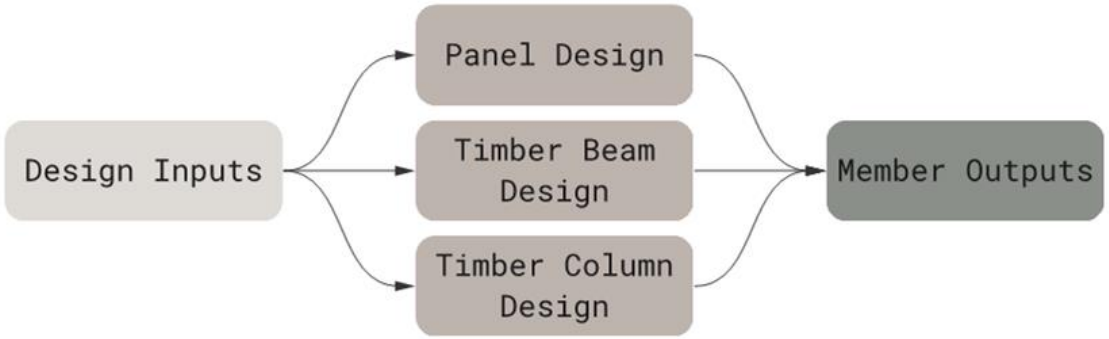


Establishing an Optimization Process

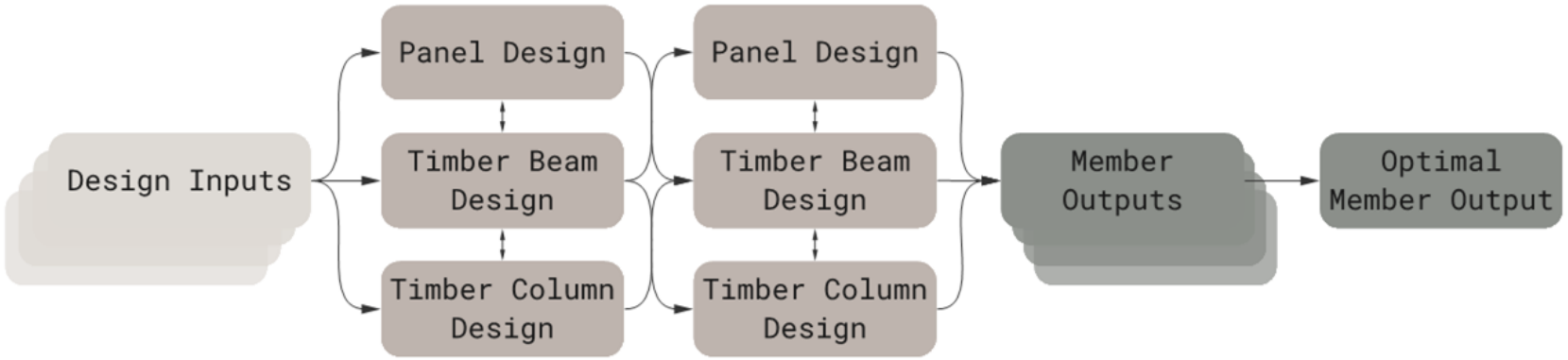


The Optimization Engine

Traditional Design Workflow

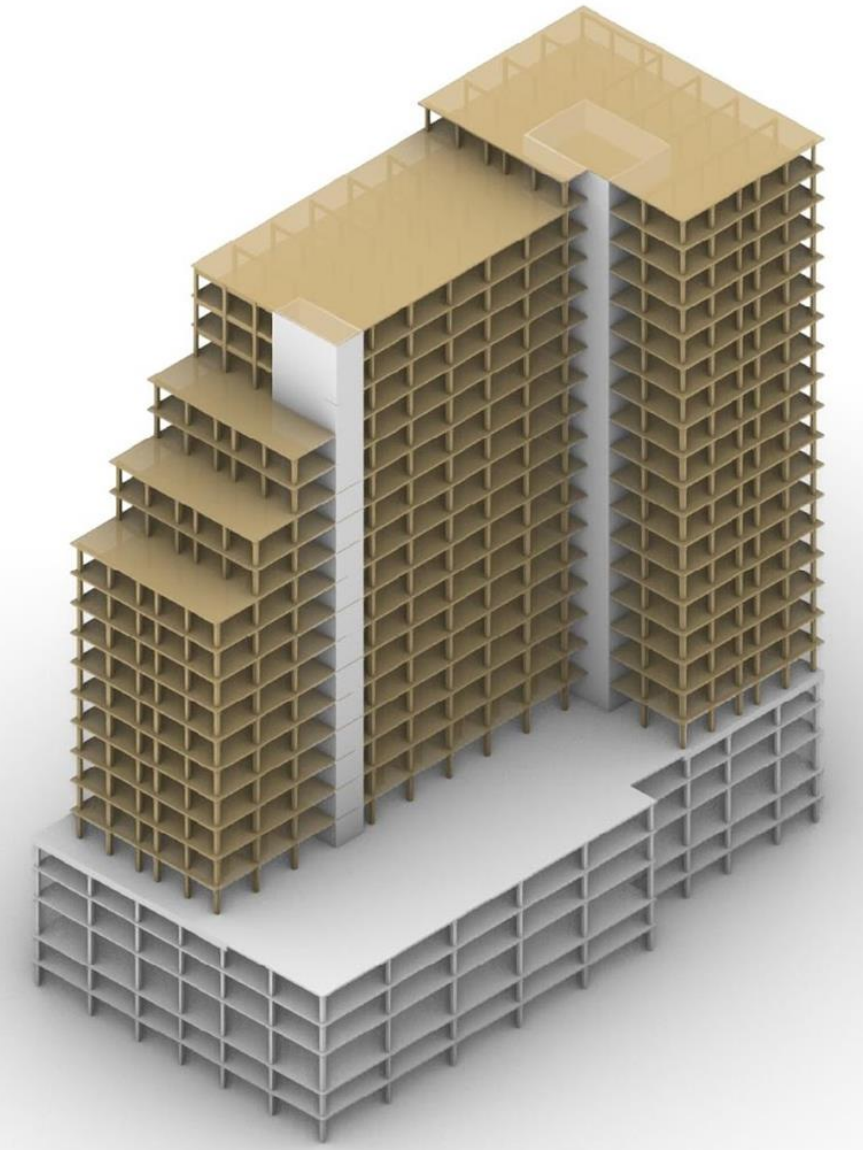


Optimization Workflow



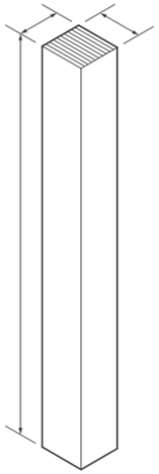
Optimization Process

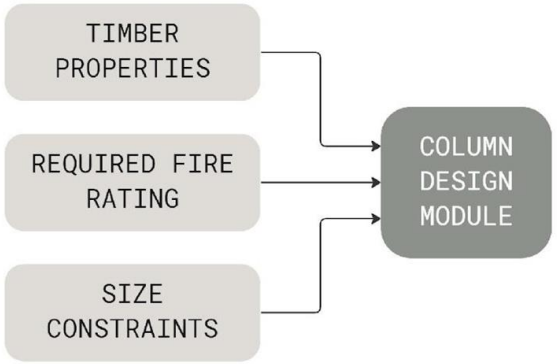
- Optimize Each Member
- Optimize Floor Systems
- Optimize Vertical Systems
- Apply Real World Constraints
- Collaborate



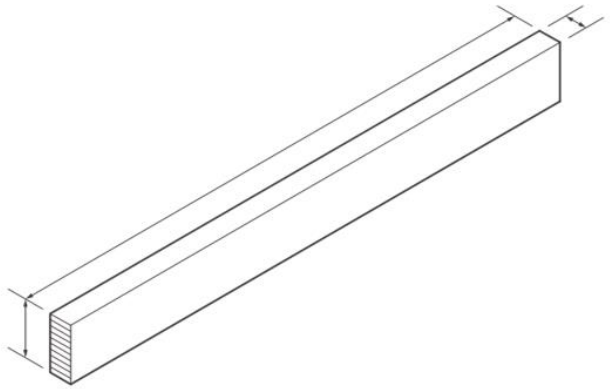
Member Optimization

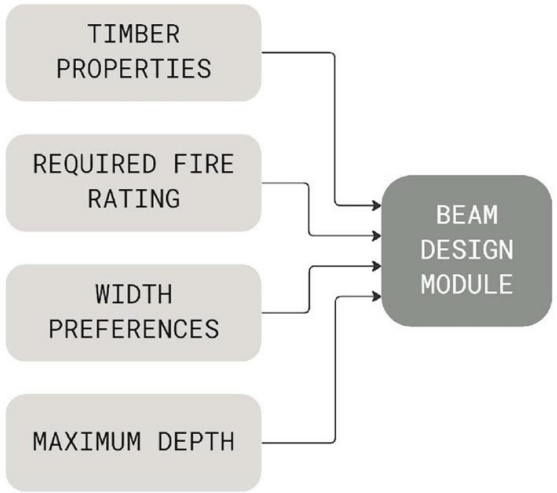
Column Element



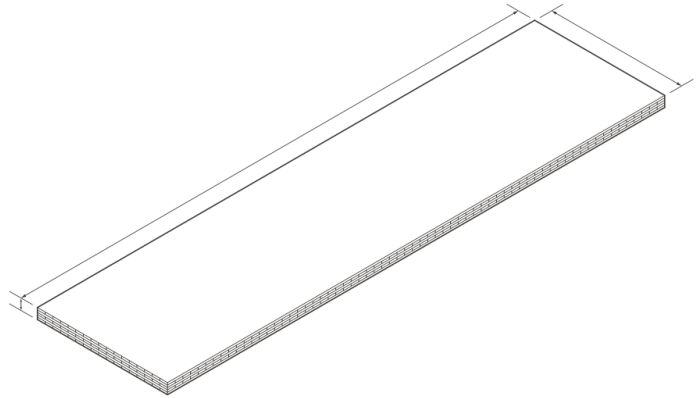


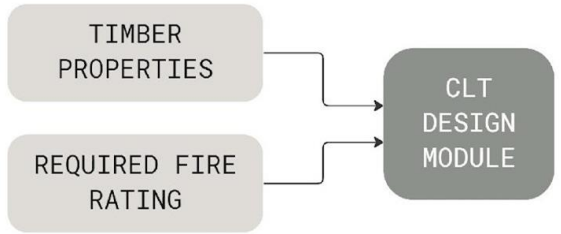
Beam Element





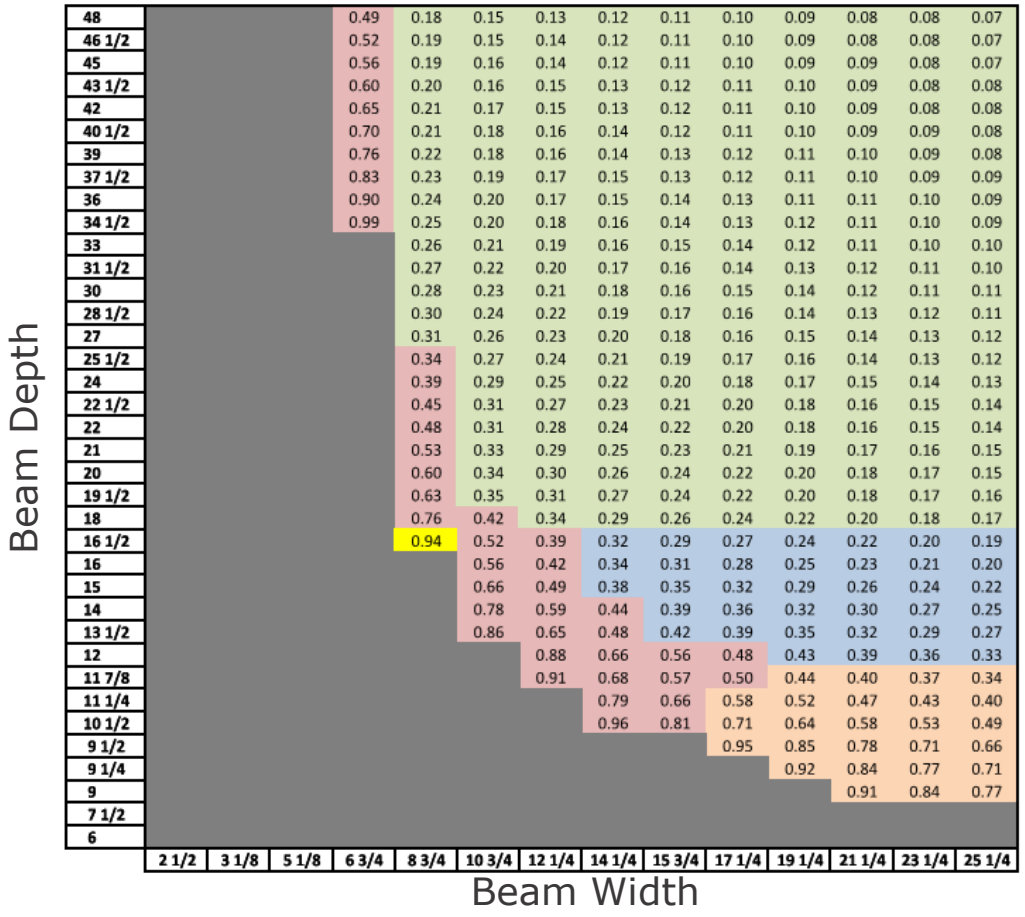
Panel Element





Strength, Serviceability, Fire

Beam Demand Capacity Ratio Envelope



Beam Depth	2 1/2	3 1/8	5 1/8	6 3/4	8 3/4	10 3/4	12 1/4	14 1/4	15 3/4	17 1/4	19 1/4	21 1/4	23 1/4	25 1/4
48				0.49	0.18	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.08	0.07
46 1/2				0.52	0.19	0.15	0.14	0.12	0.11	0.10	0.09	0.08	0.08	0.07
45				0.56	0.19	0.16	0.14	0.12	0.11	0.10	0.09	0.09	0.08	0.07
43 1/2				0.60	0.20	0.16	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.08
42				0.65	0.21	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.08
40 1/2				0.70	0.21	0.18	0.16	0.14	0.12	0.11	0.10	0.09	0.09	0.08
39				0.76	0.22	0.18	0.16	0.14	0.13	0.12	0.11	0.10	0.09	0.08
37 1/2				0.83	0.23	0.19	0.17	0.15	0.13	0.12	0.11	0.10	0.09	0.09
36				0.90	0.24	0.20	0.17	0.15	0.14	0.13	0.11	0.11	0.10	0.09
34 1/2				0.99	0.25	0.20	0.18	0.16	0.14	0.13	0.12	0.11	0.10	0.09
33					0.26	0.21	0.19	0.16	0.15	0.14	0.12	0.11	0.10	0.10
31 1/2					0.27	0.22	0.20	0.17	0.16	0.14	0.13	0.12	0.11	0.10
30					0.28	0.23	0.21	0.18	0.16	0.15	0.14	0.12	0.11	0.11
28 1/2					0.30	0.24	0.22	0.19	0.17	0.16	0.14	0.13	0.12	0.11
27					0.31	0.26	0.23	0.20	0.18	0.16	0.15	0.14	0.13	0.12
25 1/2					0.34	0.27	0.24	0.21	0.19	0.17	0.16	0.14	0.13	0.12
24					0.39	0.29	0.25	0.22	0.20	0.18	0.17	0.15	0.14	0.13
22 1/2					0.45	0.31	0.27	0.23	0.21	0.20	0.18	0.16	0.15	0.14
22					0.48	0.31	0.28	0.24	0.22	0.20	0.18	0.16	0.15	0.14
21					0.53	0.33	0.29	0.25	0.23	0.21	0.19	0.17	0.16	0.15
20					0.60	0.34	0.30	0.26	0.24	0.22	0.20	0.18	0.17	0.15
19 1/2					0.63	0.35	0.31	0.27	0.24	0.22	0.20	0.18	0.17	0.16
18					0.76	0.42	0.34	0.29	0.26	0.24	0.22	0.20	0.18	0.17
16 1/2					0.94	0.52	0.39	0.32	0.29	0.27	0.24	0.22	0.20	0.19
16						0.56	0.42	0.34	0.31	0.28	0.25	0.23	0.21	0.20
15						0.66	0.49	0.38	0.35	0.32	0.29	0.26	0.24	0.22
14						0.78	0.59	0.44	0.39	0.36	0.32	0.30	0.27	0.25
13 1/2						0.86	0.65	0.48	0.42	0.39	0.35	0.32	0.29	0.27
12							0.88	0.66	0.56	0.48	0.43	0.39	0.36	0.33
11 7/8							0.91	0.68	0.57	0.50	0.44	0.40	0.37	0.34
11 1/4								0.79	0.66	0.58	0.52	0.47	0.43	0.40
10 1/2								0.96	0.81	0.71	0.64	0.58	0.53	0.49
9 1/2										0.95	0.85	0.78	0.71	0.66
9 1/4											0.92	0.84	0.77	0.71
9												0.91	0.84	0.77
7 1/2														
6														

Serviceability Controlled

Bending Controlled

Shear Controlled

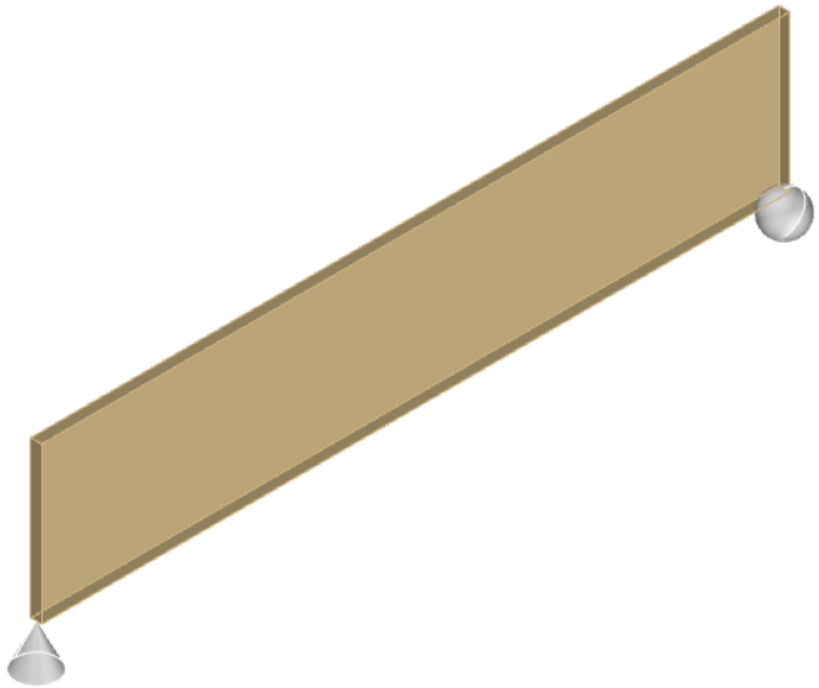
Fire Controlled

Minimum Area Section

Impact of Beam Width

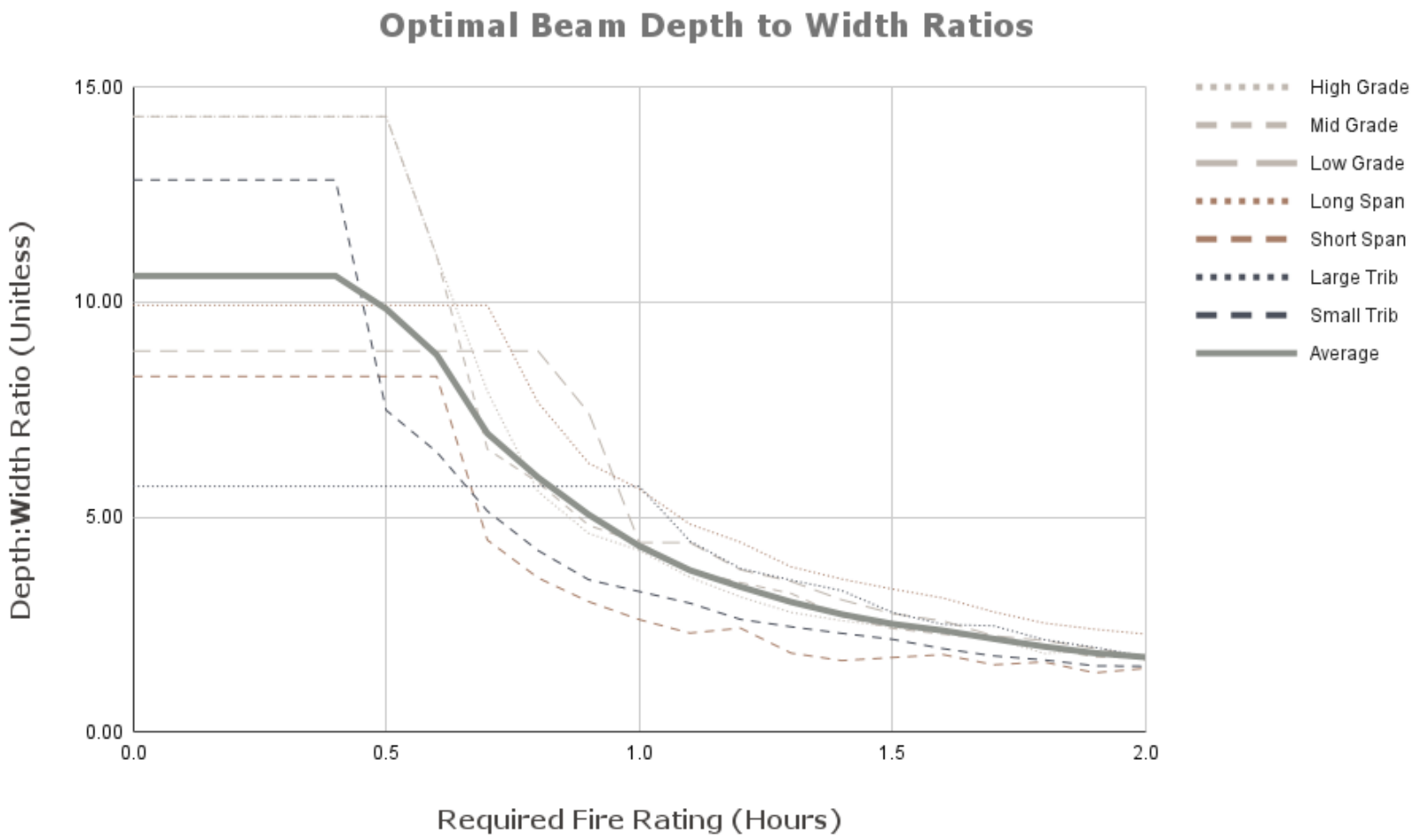
- 4 Million Optimized Beam Designs
- Deeper is better, unless…
- Fire chars both sides of the beam

Material Grade: 20F-1.5E
Required Fire Rating: 0 Hours
Span: 18'
Tributary Width: 20'
Loading: Residential
Minimum Area Beam Size: 3.125 X45



Impact of Beam Width

- 4 Million Optimized Beam Designs
- Deeper is better, unless…
- Fire chars both sides of the beam



Fire Rating and Taller Buildings

- Fire has large impact for lighter loaded columns
- As load increases, fire impact reduces

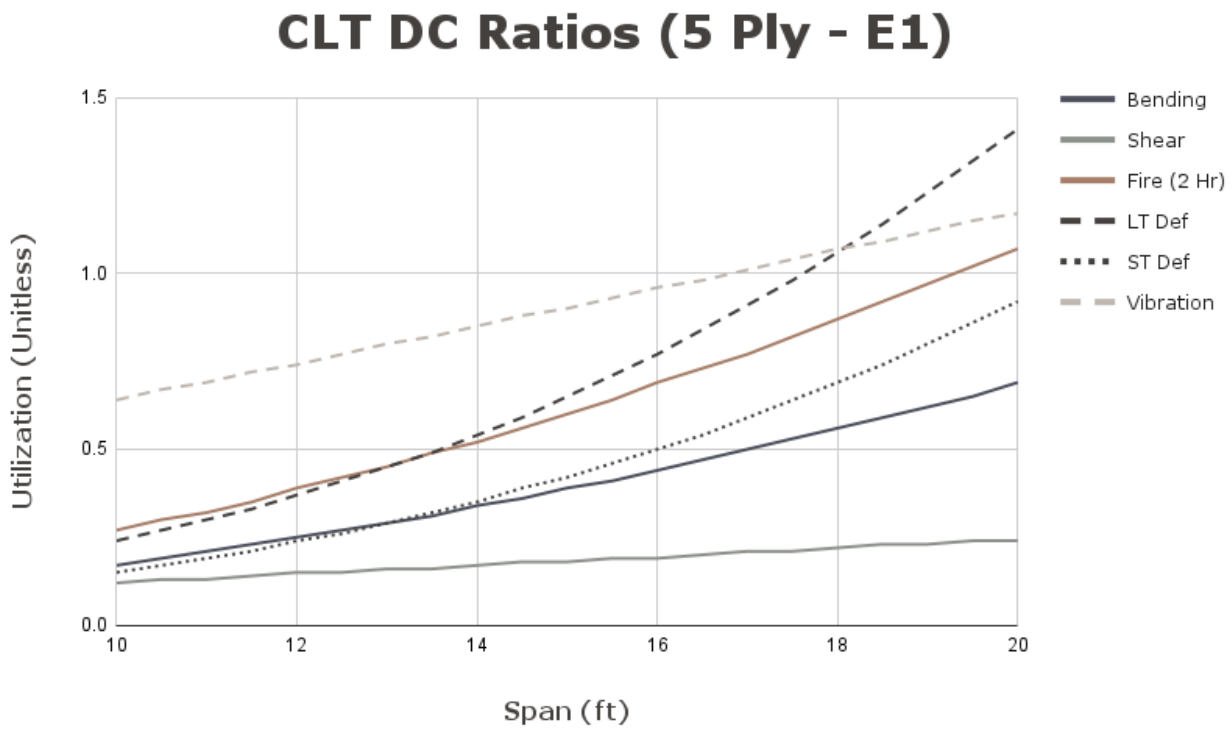
Story Number	Required Fire Rating			
	0 Hour	1 Hour	2 Hour	3 Hour
23	8.75	10.75	14.25	15.75
22	10.75	10.75	14.25	17.25
21	10.75	12.25	14.25	17.25
20	12.25	12.25	15.75	17.25
19	12.25	14.25	15.75	19.25
18	14.25	14.25	15.75	19.25
17	14.25	14.25	17.25	19.25
16	15.75	15.75	17.25	19.25
15	15.75	15.75	17.25	19.25
14	17.25	17.25	17.25	21.25
13	17.25	17.25	19.25	21.25
12	19.25	19.25	19.25	21.25
11	19.25	19.25	19.25	21.25
10	19.25	19.25	19.25	21.25
9	21.25	21.25	21.25	23.25
8	21.25	21.25	21.25	23.25
7	21.25	21.25	21.25	23.25
6	21.25	21.25	21.25	23.25
5	23.25	23.25	23.25	23.25
4	23.25	23.25	23.25	23.25
3	23.25	23.25	23.25	25.25
2	23.25	23.25	23.25	25.25
1	25.25	25.25	25.25	25.25

Minimum Square Column Size

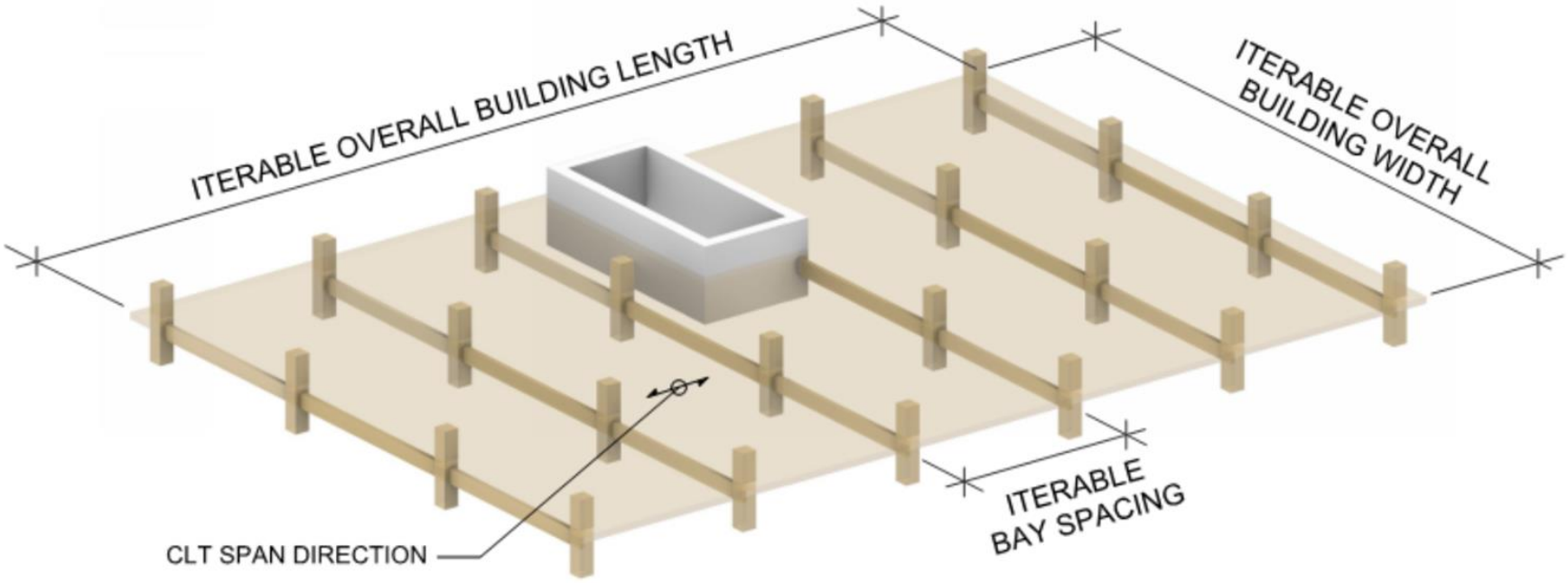
CLT Panel Evaluation

CLT DC Ratios (5 Ply)

Span (ft)	Bending	Shear	Fire	LT Def	ST Def	Vibration
10	0.17	0.12	0.27	0.24	0.15	0.64
10.5	0.19	0.13	0.30	0.27	0.17	0.67
11	0.21	0.13	0.32	0.30	0.19	0.69
11.5	0.23	0.14	0.35	0.33	0.21	0.72
12	0.25	0.15	0.39	0.37	0.24	0.74
12.5	0.27	0.15	0.42	0.41	0.26	0.77
13	0.29	0.16	0.45	0.45	0.29	0.80
13.5	0.31	0.16	0.49	0.49	0.32	0.82
14	0.34	0.17	0.52	0.54	0.35	0.85
14.5	0.36	0.18	0.56	0.59	0.39	0.88
15	0.39	0.18	0.60	0.65	0.42	0.90
15.5	0.41	0.19	0.64	0.71	0.46	0.93
16	0.44	0.19	0.69	0.77	0.50	0.96
16.5	0.47	0.20	0.73	0.84	0.54	0.98
17	0.50	0.21	0.77	0.91	0.59	1.01
17.5	0.53	0.21	0.82	0.98	0.64	1.04
18	0.56	0.22	0.87	1.06	0.69	1.07
18.5	0.59	0.23	0.92	1.14	0.74	1.09
19	0.62	0.23	0.97	1.23	0.80	1.12
19.5	0.65	0.24	1.02	1.32	0.86	1.15
20	0.69	0.24	1.07	1.41	0.92	1.17



System Optimization: Floor Framing

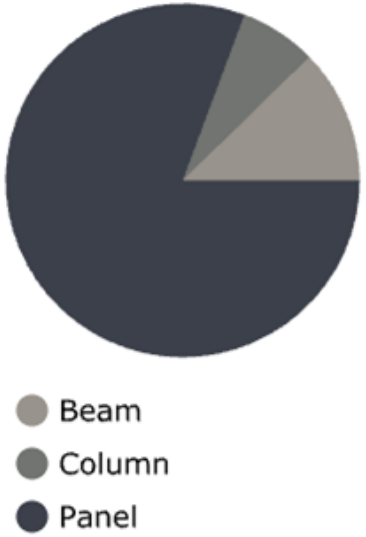


System Optimization: Floor Framing

5 Ply CLT

890 ft3 GLT Beam
508 ft3 GLT Column
5,835 ft3 CLT Panel

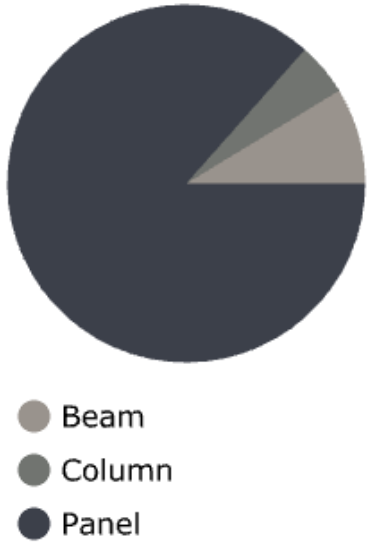
7,233ft3 Total



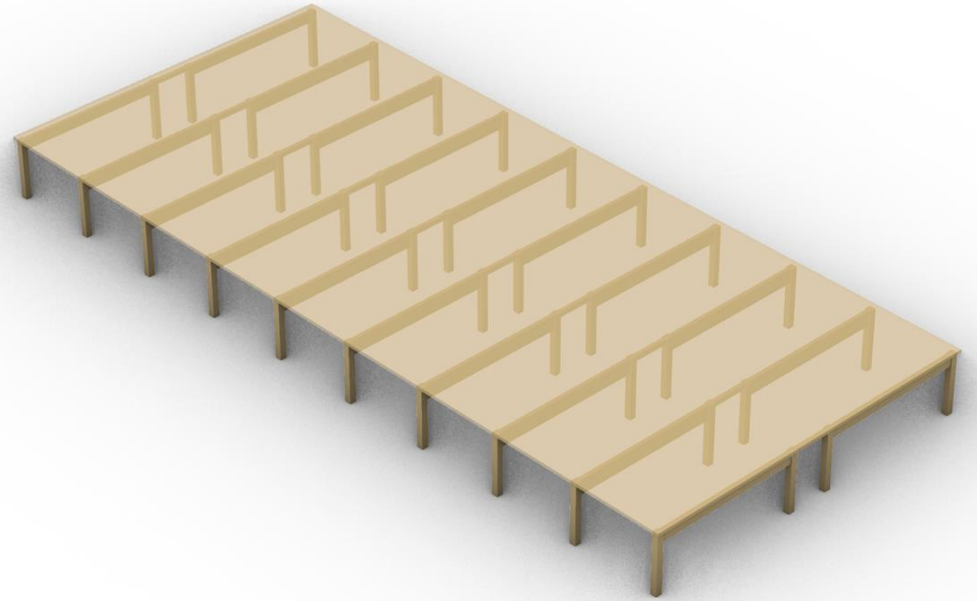
7 Ply CLT

820 ft3 GLT Beam
451 ft3 GLT Column
8,168 ft3 CLT Panel

9,439ft3 Total

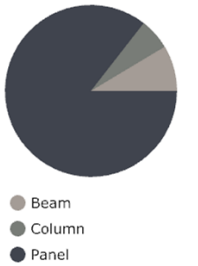


30% Volume Increase



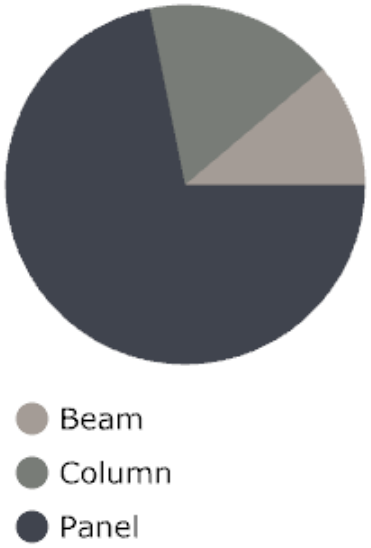
System Optimization: Vertical Framing

820 ft3 GLT Beam
562 ft3 GLT Column
8,168 ft3 CLT Panel
9,550ft3 Total



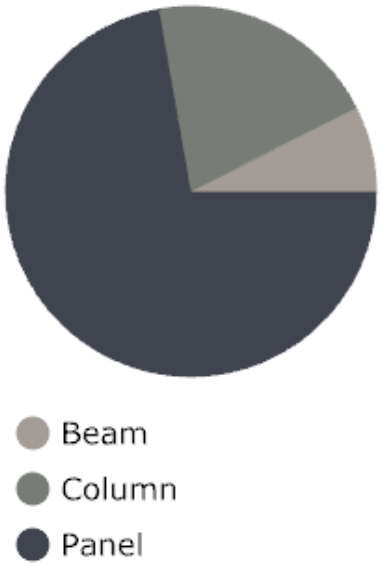
3 Bays

21,736 ft3 GLT Beam
33,177 ft3 GLT Column
140,030 ft3 CLT Panel
194,943ft3 Total



5 Bays

14,478 ft3 GLT Beam
39,339 ft3 GLT Column
140,030 ft3 CLT Panel
193,847ft3 Total

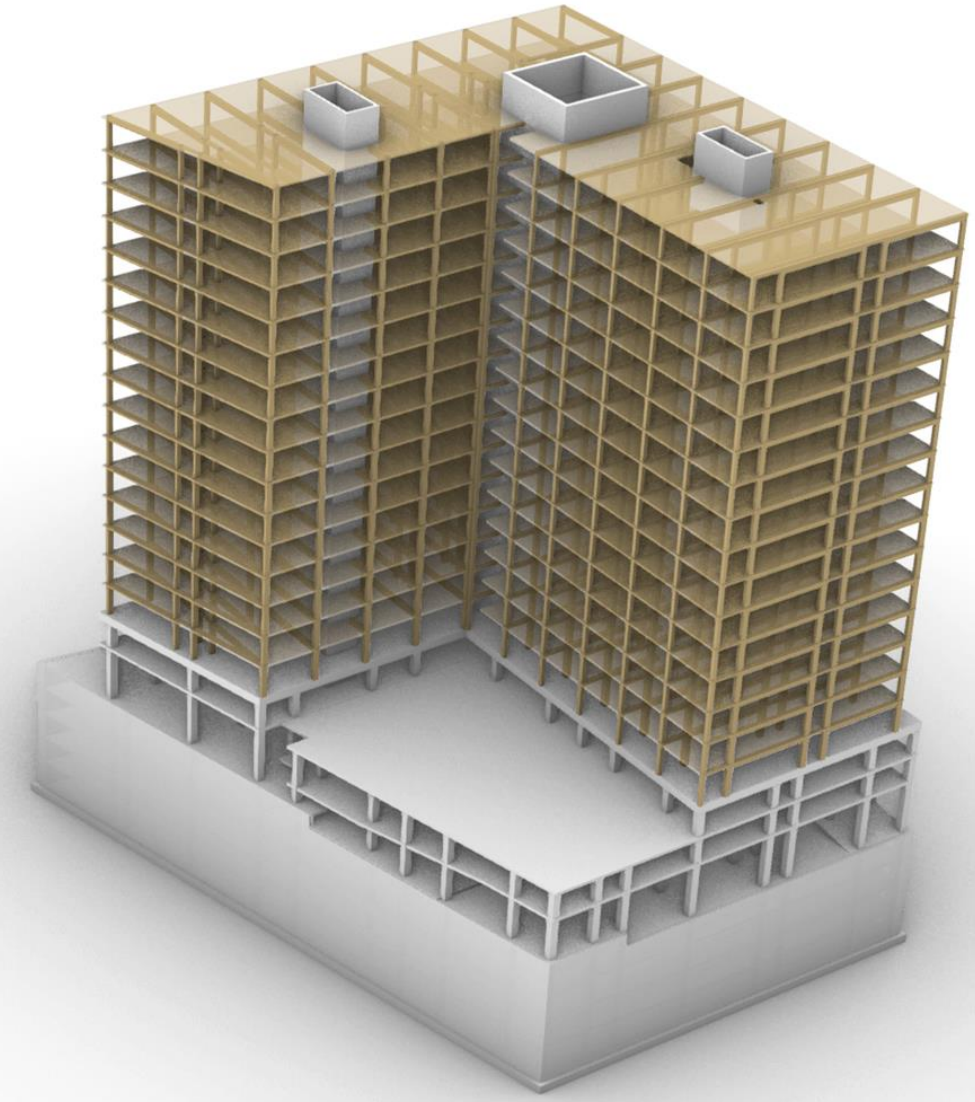


2% Framing Volume Decrease
+Shallow Corridor

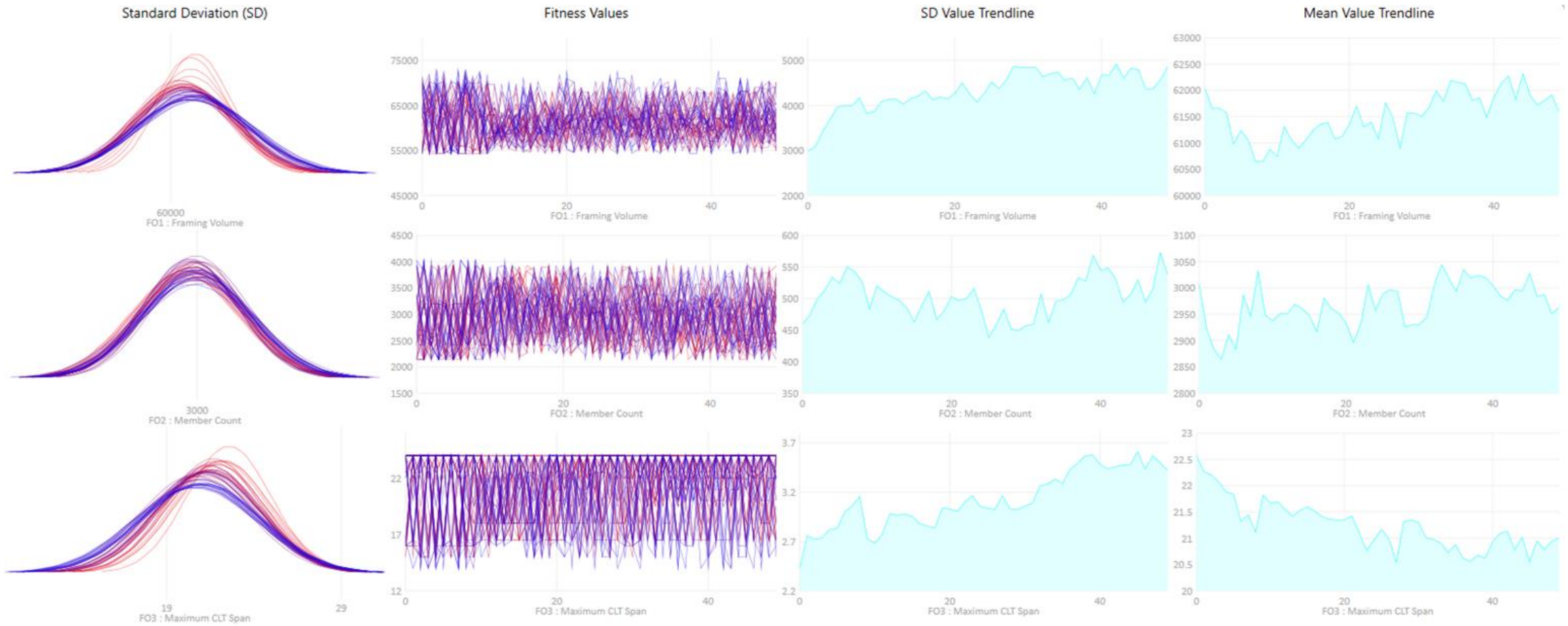
Project Optimization

- Early iteration and collaboration is key
- Architectural and site requirements influence layout options
- Establish collective goals

47,773 ft3 GLT Beam
28,942 ft3 GLT Column
213,616 ft3 CLT Panel
290,331ft3 Total

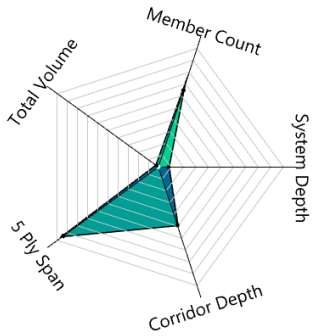


Analyzing Data



Establish Optimization Criteria

Lowest Volume



Total Volume
Rank 0

Generation 39 // Ind. 5

Total Volume
Rank: 0 / 2500
Fitness Value: 54291

Member Count
Rank: 1601 / 2500
Fitness Value: 3196

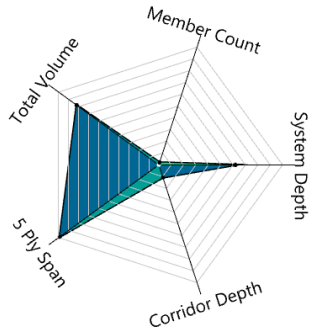
System Depth
Rank: 156 / 2500
Fitness Value: 16

Corridor Depth
Rank: 1197 / 2500
Fitness Value: 16

5 Ply Span
Rank: 2346 / 2500
Fitness Value: 19.548427

High Member Count

Lowest Member Count



Member Count
Rank 0

Generation 38 // Ind. 5

Total Volume
Rank: 2039 / 2500
Fitness Value: 65776

Member Count
Rank: 0 / 2500
Fitness Value: 2142

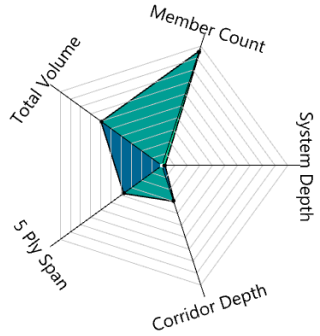
System Depth
Rank: 1527 / 2500
Fitness Value: 24

Corridor Depth
Rank: 221 / 2500
Fitness Value: 11.875

5 Ply Span
Rank: 2469 / 2500
Fitness Value: 19.548427

High Volume

Lowest Depth



System Depth
Rank 0

Generation 41 // Ind. 7

Total Volume
Rank: 1458 / 2500
Fitness Value: 62237

Member Count
Rank: 2372 / 2500
Fitness Value: 3825

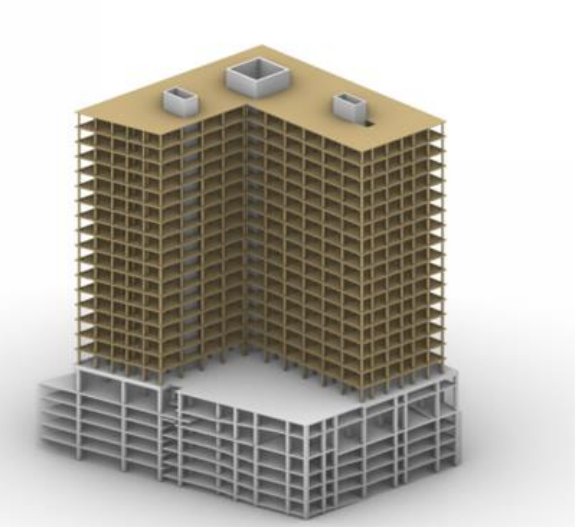
System Depth
Rank: 0 / 2500
Fitness Value: 14

Corridor Depth
Rank: 697 / 2500
Fitness Value: 14

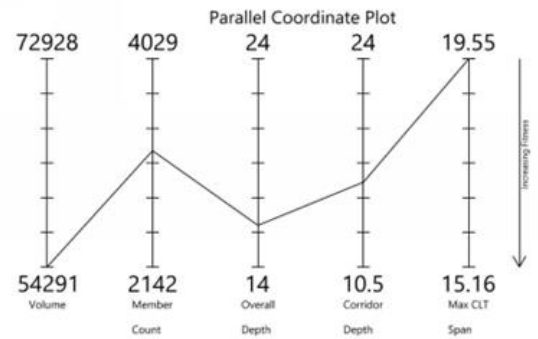
5 Ply Span
Rank: 896 / 2500
Fitness Value: 17.155

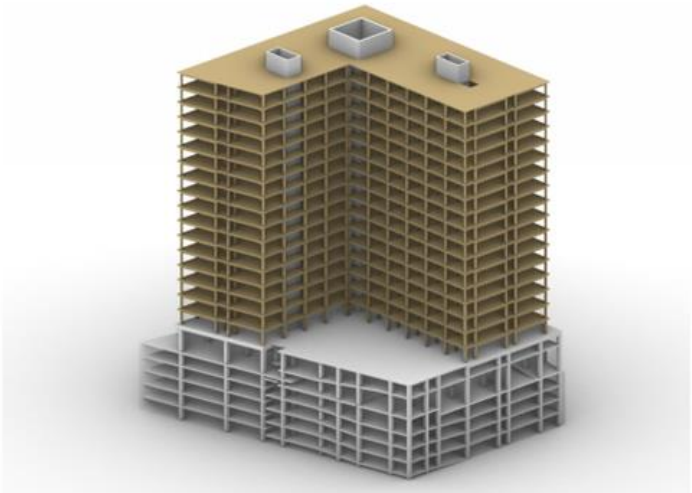
Highest Member Count

Explore Options

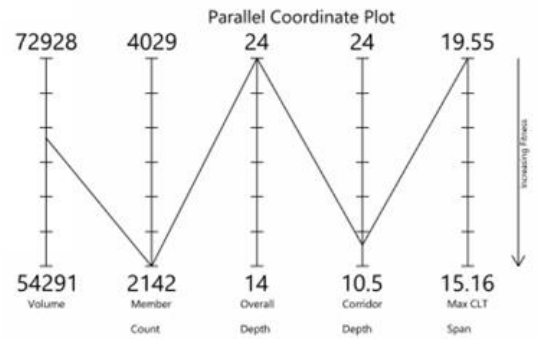


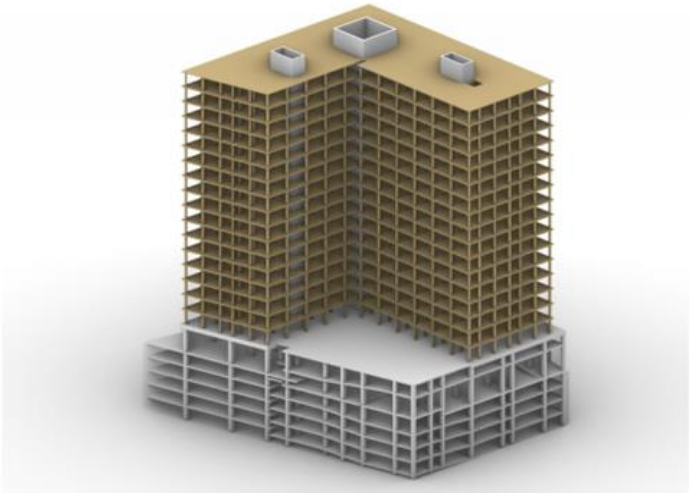
LEAST VOLUME



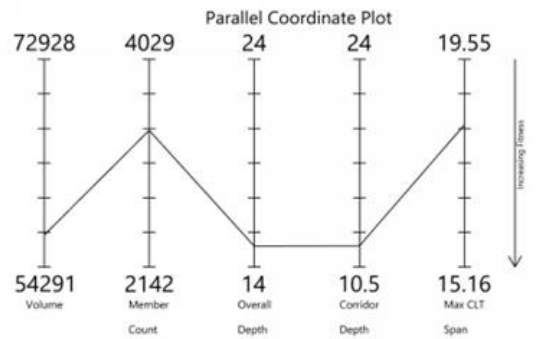


LEAST MEMBERS

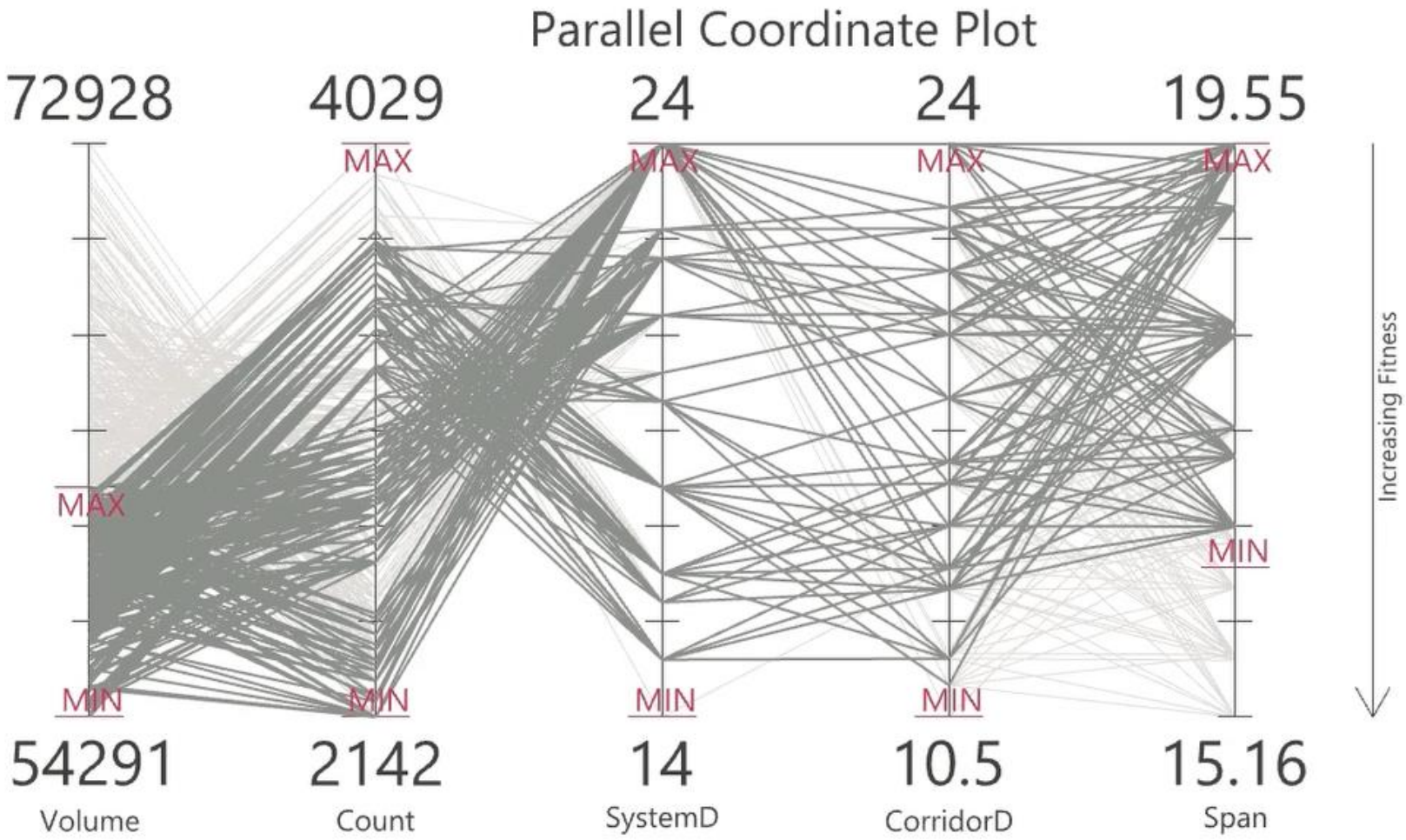




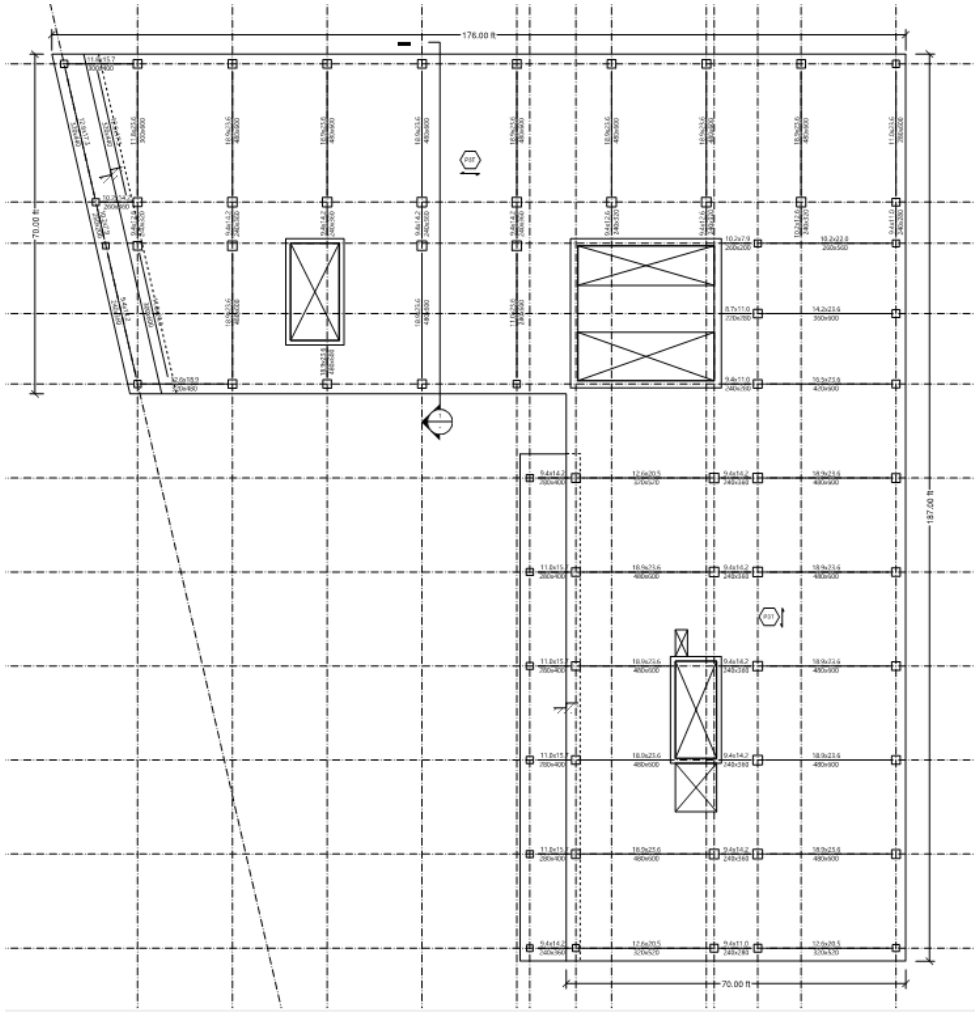
LOWEST AVERAGE



Filter Results



Documentation and Pricing



TYPICAL TOWER FRAMING PLAN

SCALE: 3/32" = 1'-0"

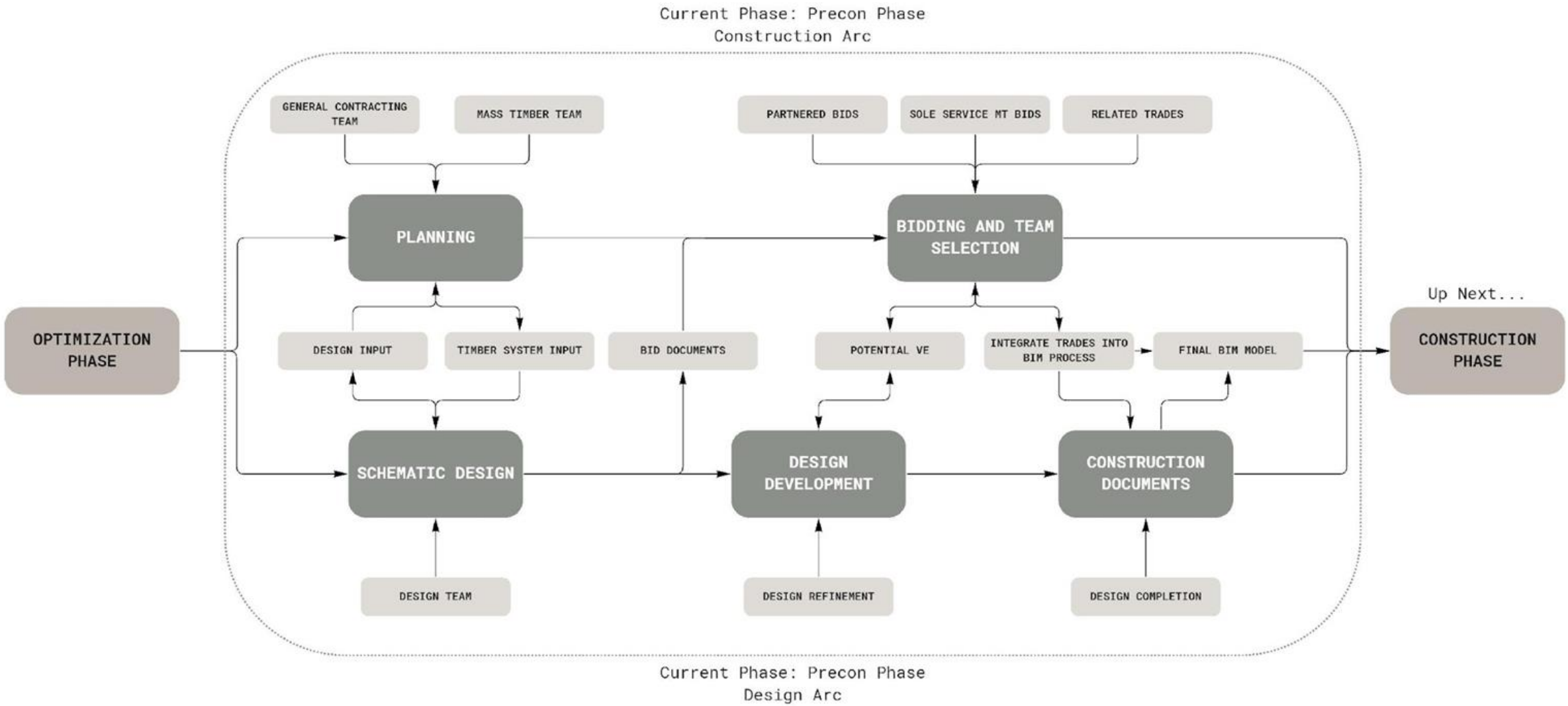
LEGEND:

P3T — INDICATES BBS 125 200 AB CLT PANEL (7.9" THICKNESS) WITH 3/8" ACOUSTIC MAT AND 2 1/8" NORMAL WEIGHT CONCRETE TOPPING REINFORCED WITH 3.0 PCY OF EUCLID CHEMICALS TUF-STRAND SF FIBERS.

#x# / #x# — INDICATES GLULAM TIMBER BEAM SIZE IN INCHES / MM. SEE QUANTITY INFORMATION FOR TOTAL VOLUME AND PIECE COUNT

	Pricing Information					
Member Type	Column		Beam		Panel	
Material	GL30h		GL30h		CLT BBS 125 200	
Piece Count	1181		973			
Quantity	30,600 ft^3	867 m^3	43,900 ft^3	1243 m^3	347,620 ft^2	32,295 m^2

Pre-Construction Phase

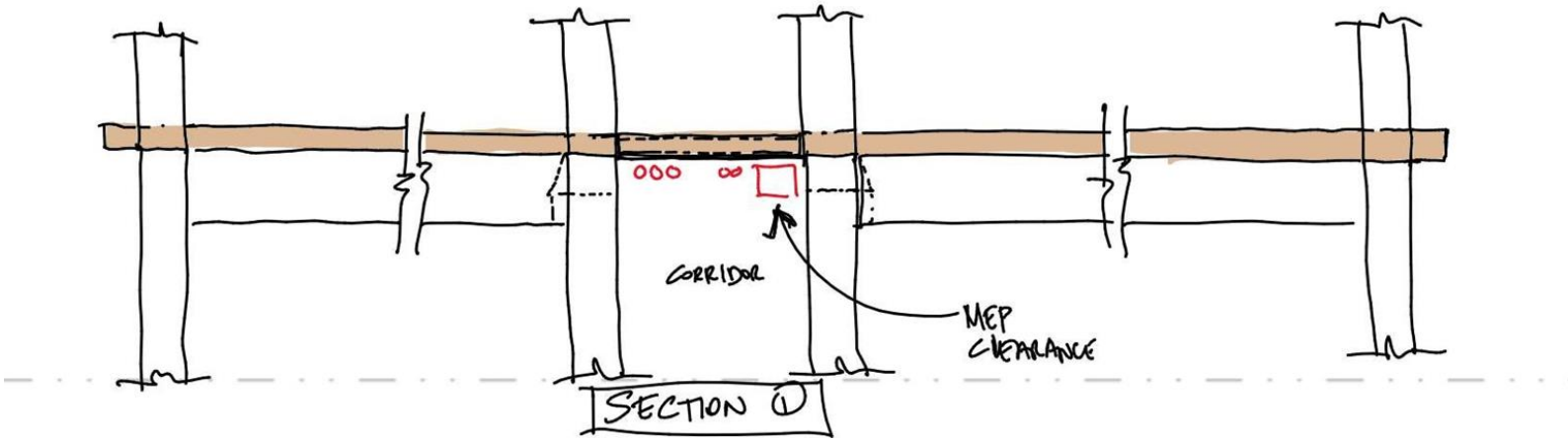


Common Challenges

- MEP Penetrations
- Trade Coordination

Common Challenges

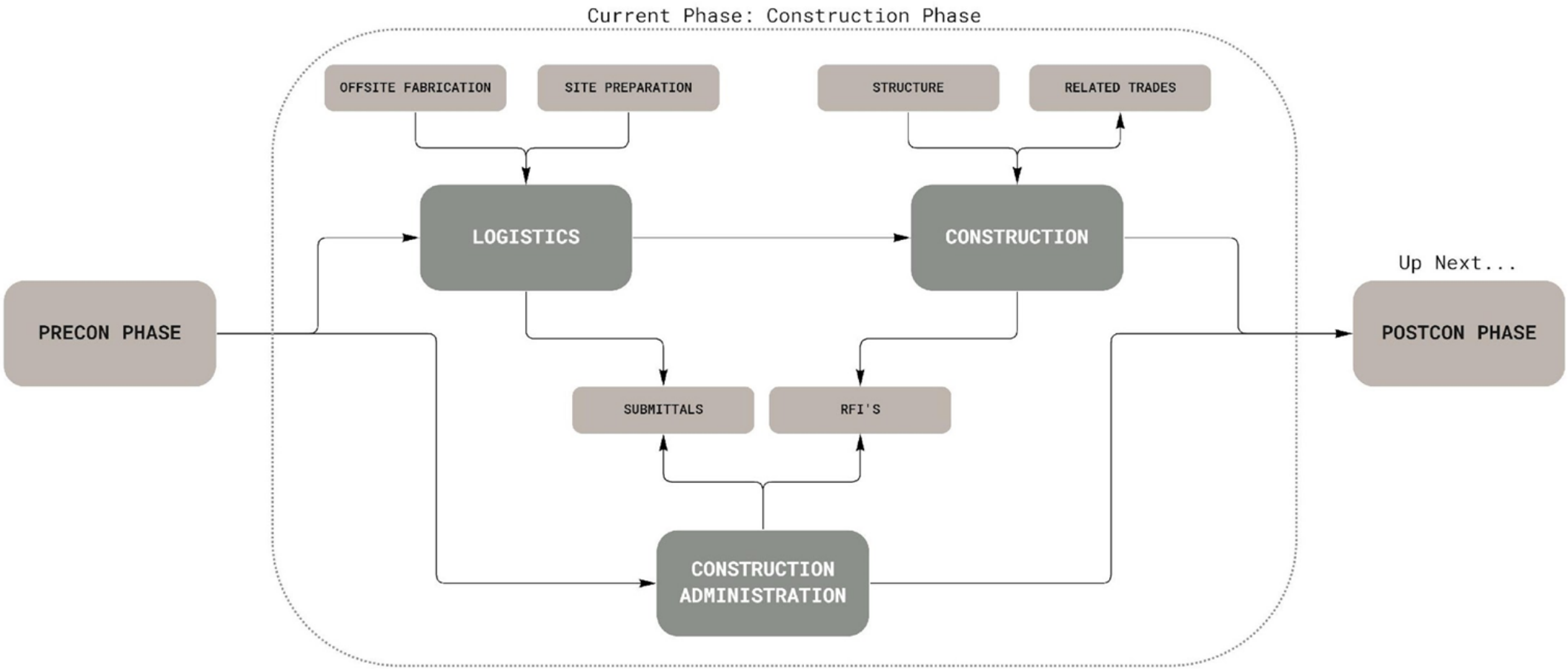
- Large Duct Banks
- Beam Penetrations



Window Wall / Curtain Wall Attachment

Connection Efficiency

Construction Phase

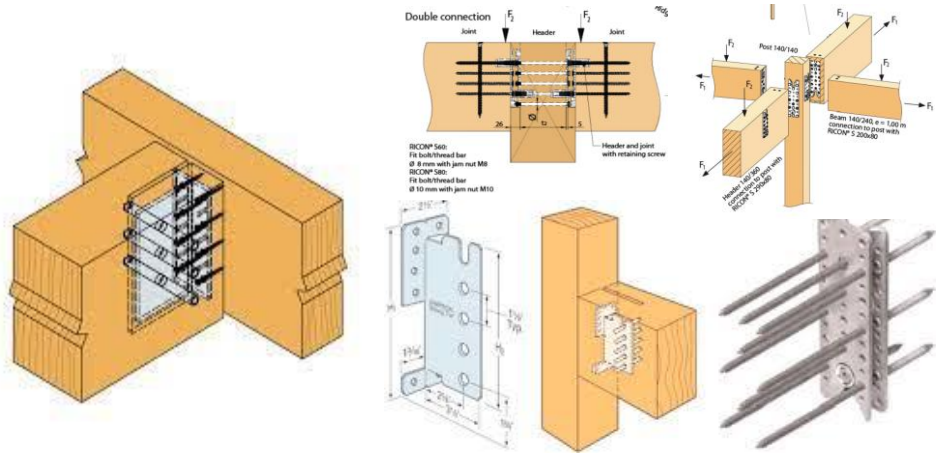


Schedule Impact

- Erection Logistics
- Off Site Fabrication

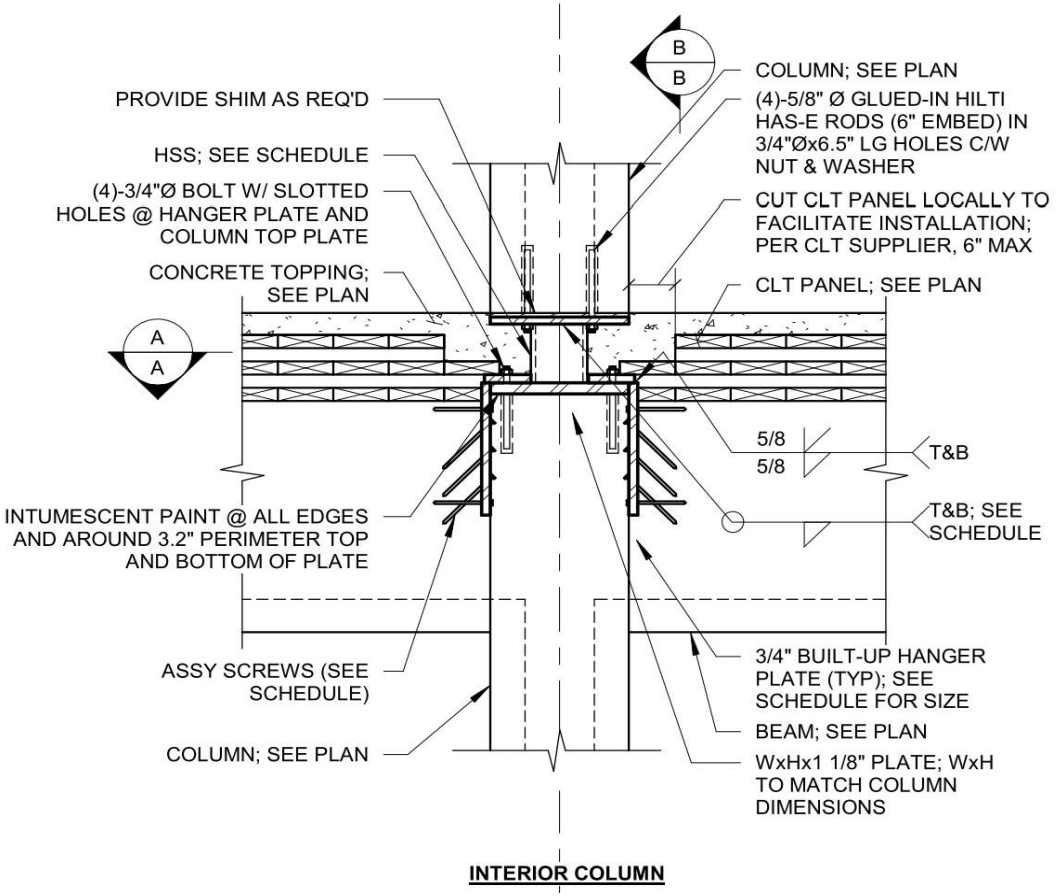
Schedule Impact: Connection Considerations

Simple Bearing Connections



Trade Ready Connections

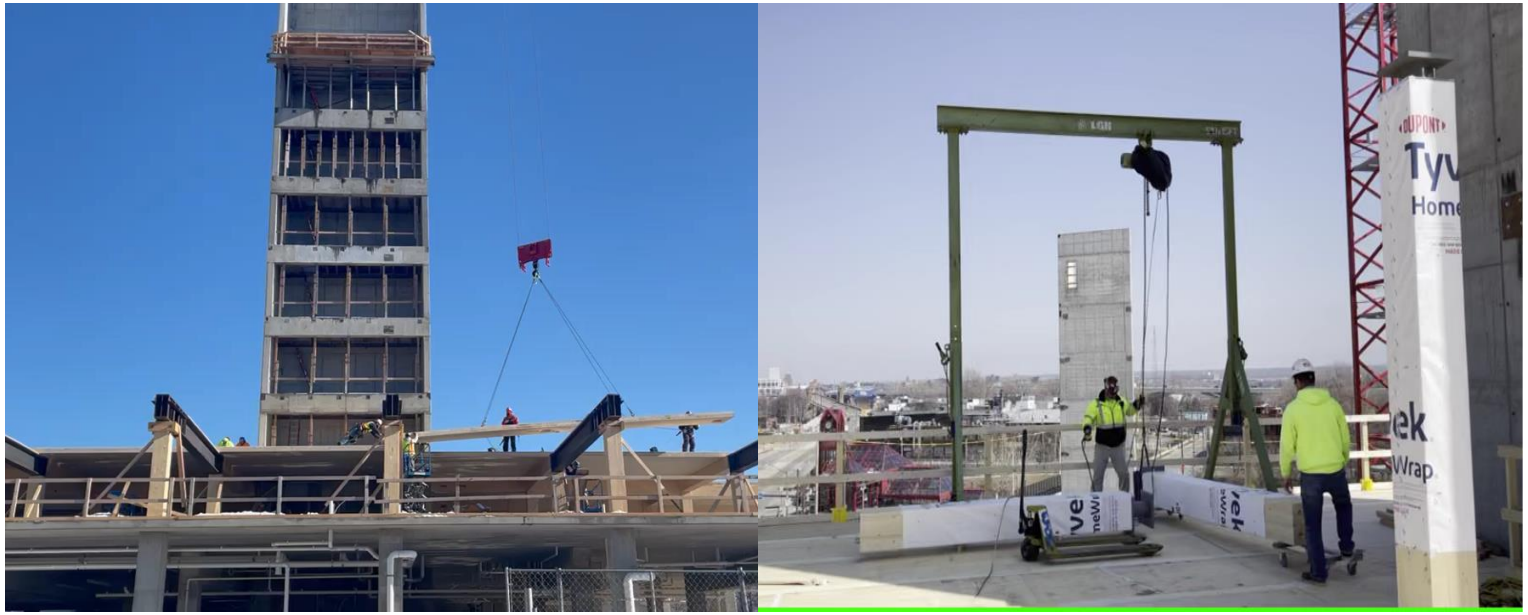
Schedule Impact: Connection Considerations



Custom Connections

Logistics Considerations

- Mockups
- Rigging
- Laydown Areas
- Temporary Water Protection



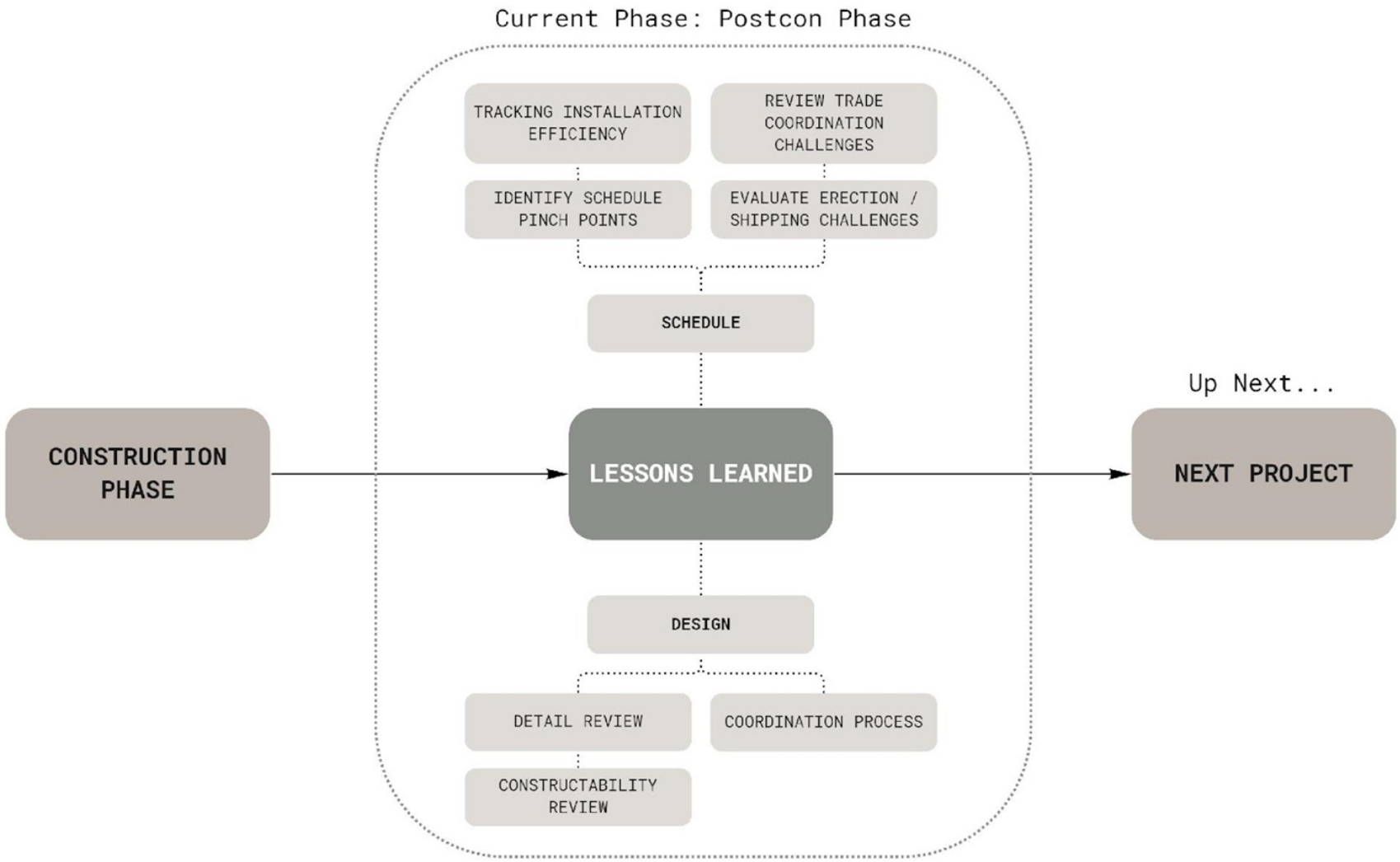
Tower Crains and Mobile Rigging

Logistics Considerations

- Mockups
- Rigging
- Laydown Areas
- Temporary Water Protection

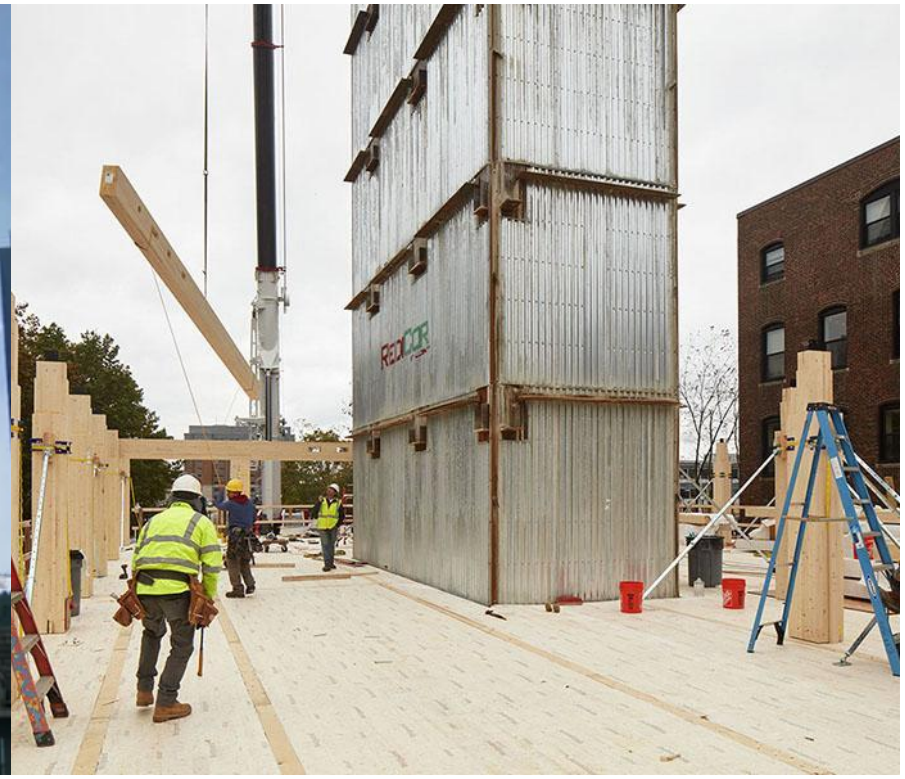
Laydown Area

Post-Construction Phase



Lessons Learned…

- Further Prefabrication
- Trade Mentality
- Embrace Technology



…Opportunities

Lessons Learned…

- Prefabrication
- Trade Mentality
- Embrace Technology

(Rig like and ironworker, handle like a carpenter)

…Opportunities

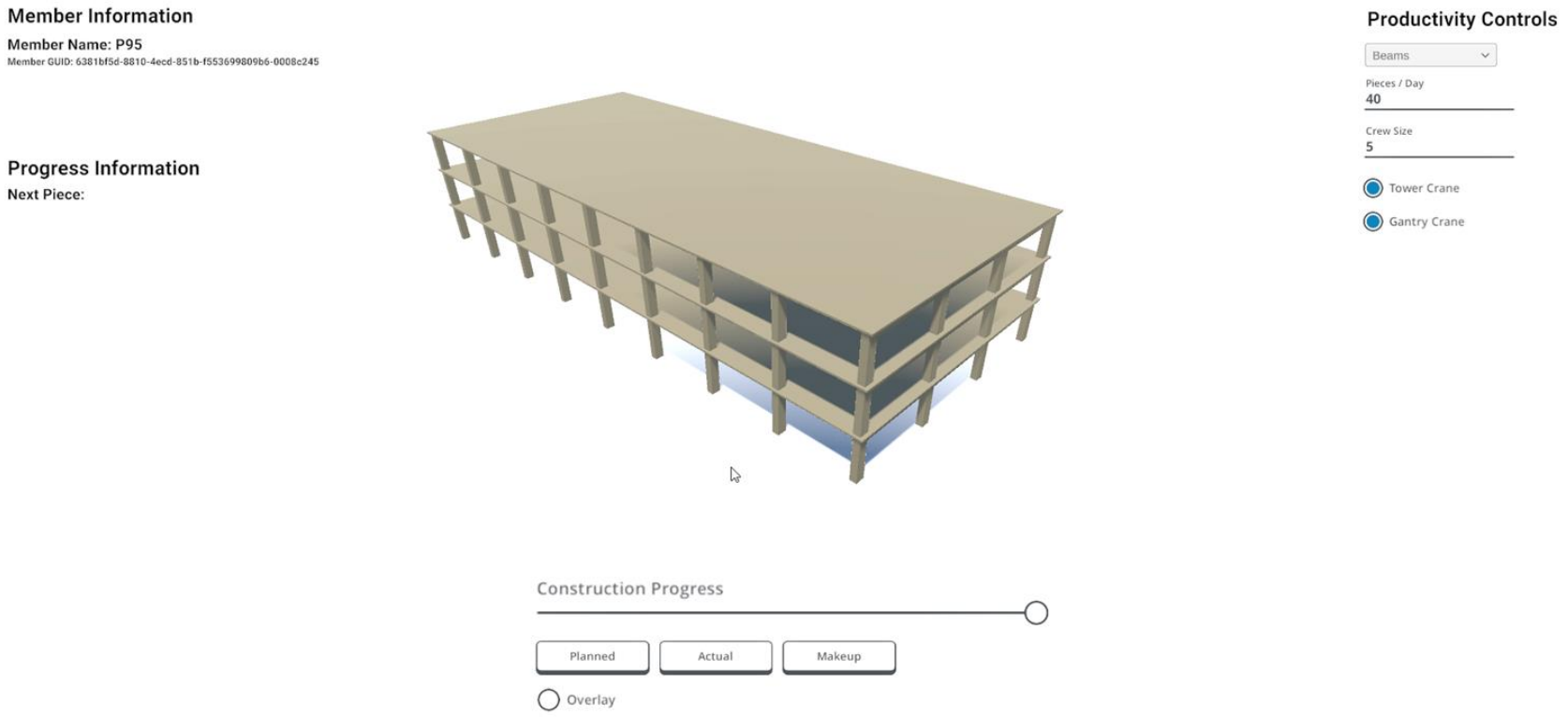
Lessons Learned...

- Prefabrication
- Trade Mentality
- Embrace Technology

...Opportunities

Lessons Learned...

- Prefabrication
- Trade Mentality
- Embrace Technology



...Opportunities

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