AE Senior Thesis 2004

University of Cincinnati Athletic Center

Structural Redesign of a Perimeter Diagrid Lateral System

Brian Genduso

Structural Option

Topic Outline

1) Building Introduction
2) Structural System Description
3) Problem Statement
4) Design Philosophy
5) Redesign Approach
6) Structural Redesign
7) Daylighting Study
8) Recommendation

Building Introduction

General Information

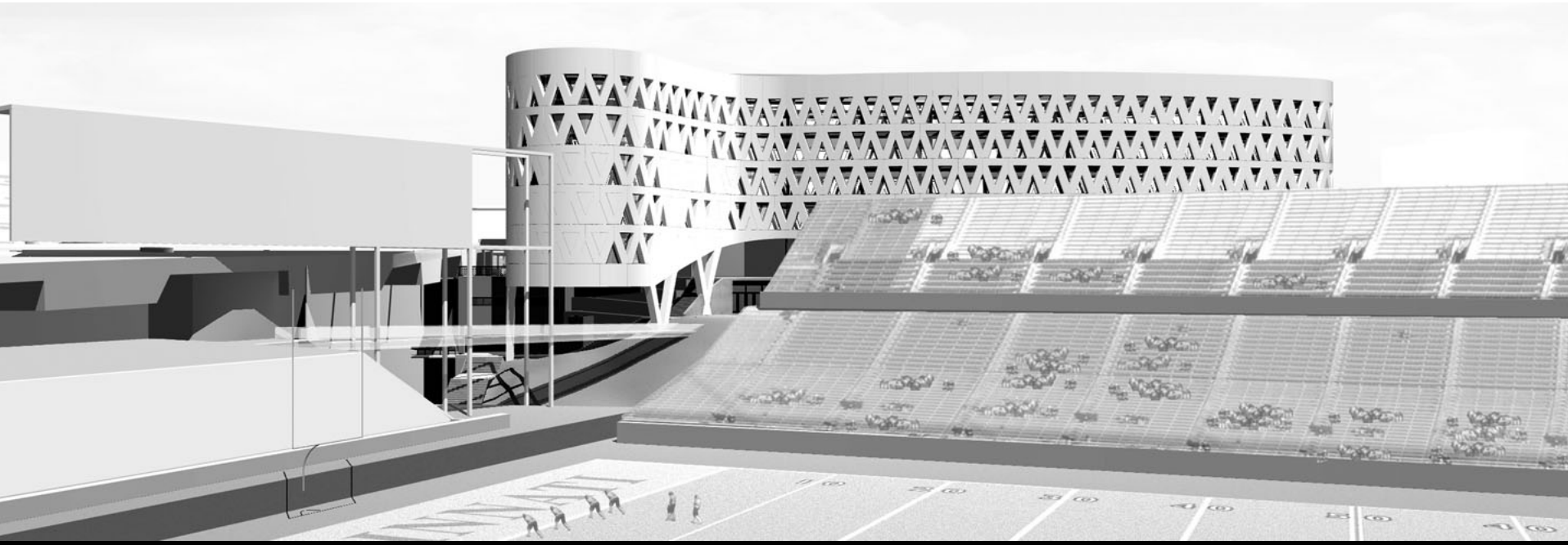
Multi-use

8 stories - 220,000 ft^2

$50.7 million

Design Architect – Bernard Tschumi Architects, New York

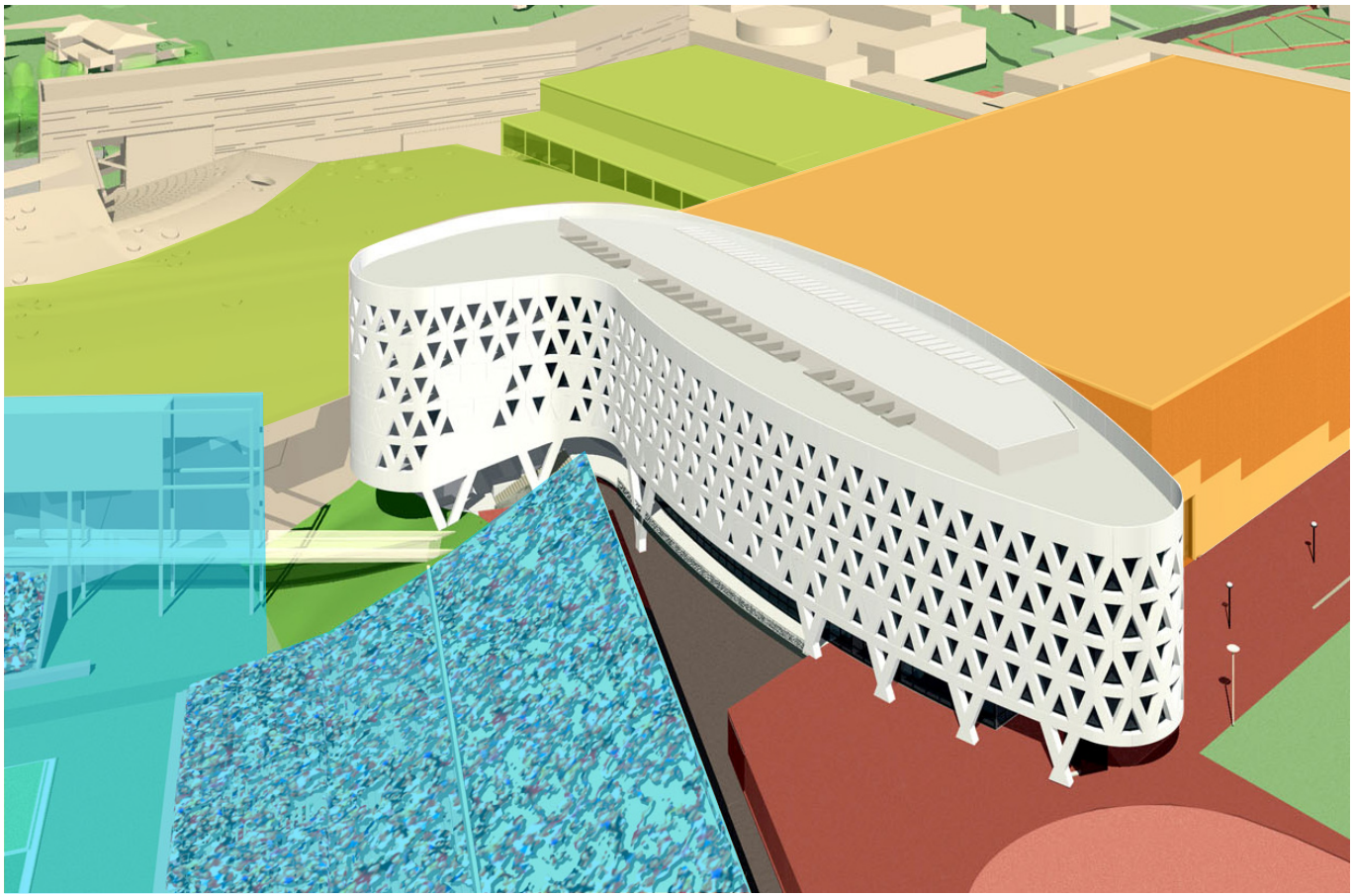
Design Engineer – Arup, New York



Building Introduction

Site

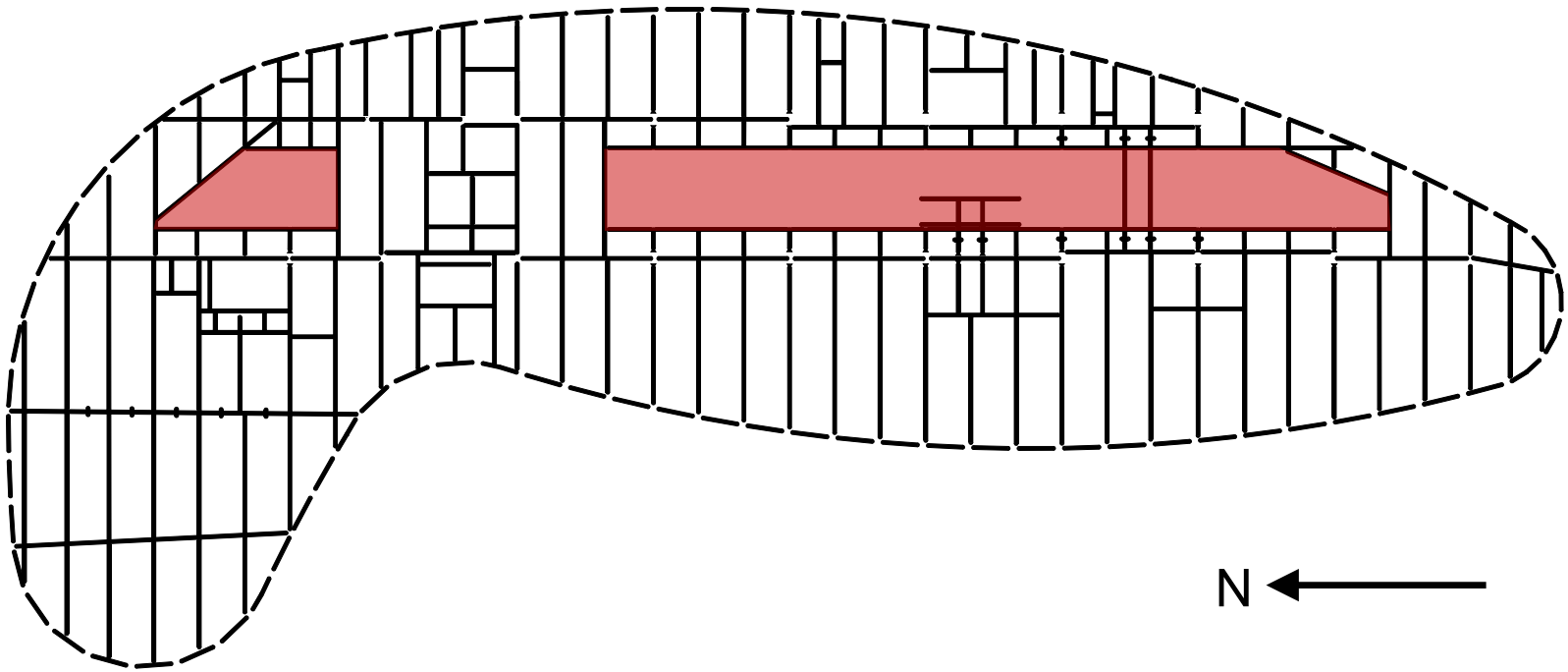
University of Cincinnati “Varsity Village” – Cincinnati, Ohio



Building Introduction

Architectural Layout

- Curved perimeter
- 5-story atrium
- Partially above existing facilities



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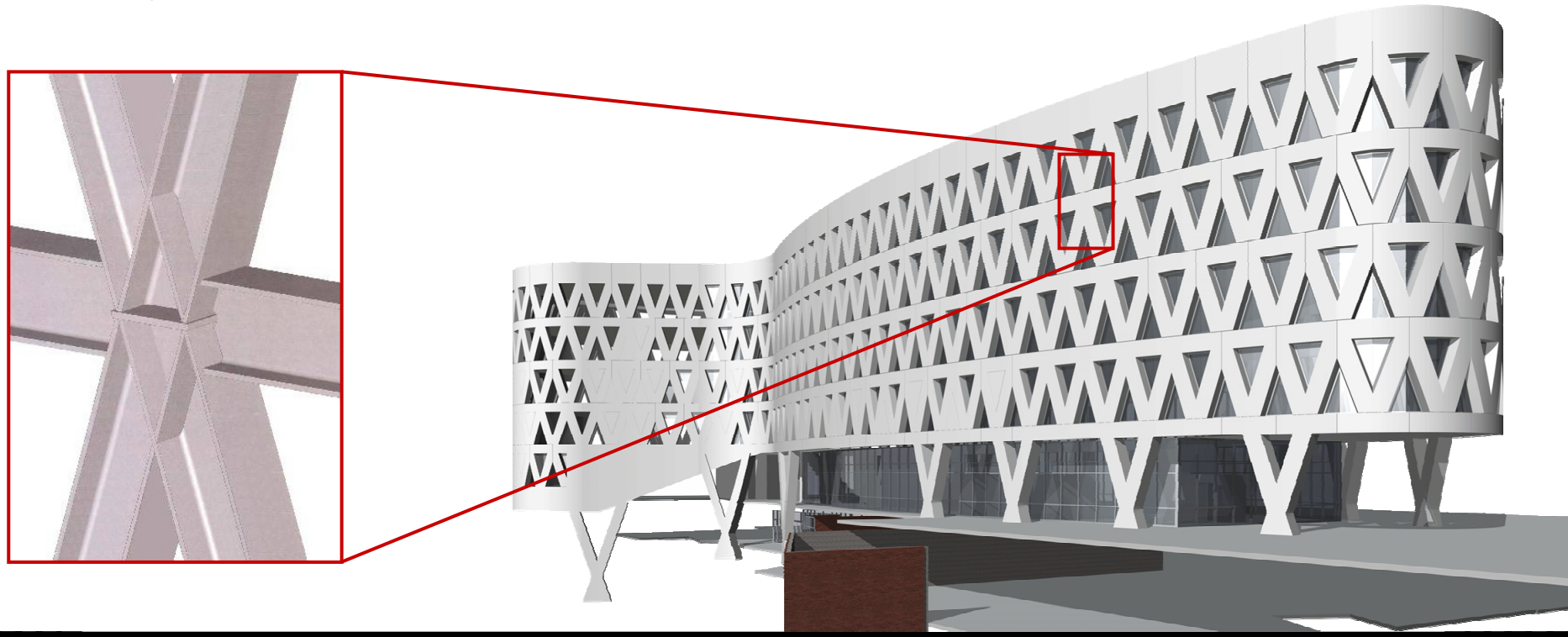
Structural System Description

Diagrid

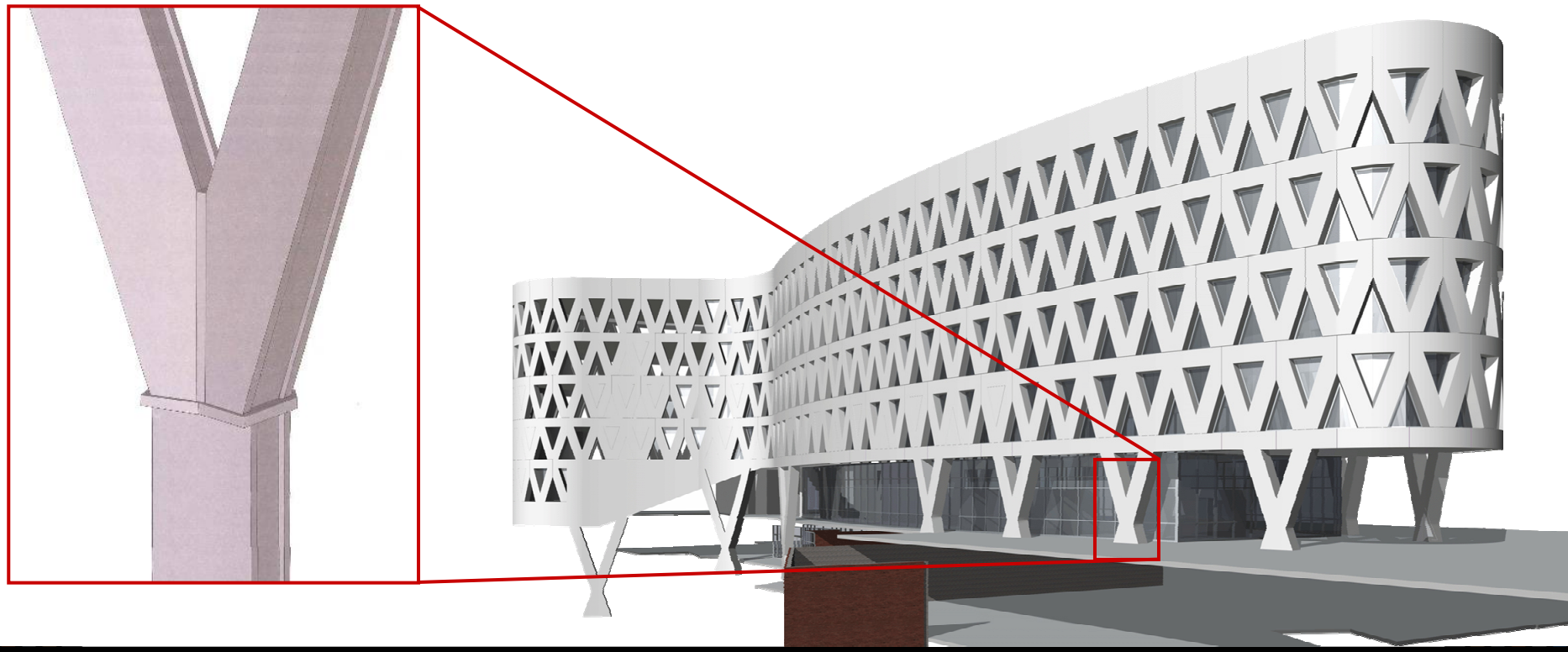
- Triangulated “deep beam” frame
- Functions as both gravity and lateral system
- Constructed from steel wide flange shapes
- Welded or bolted for full rigidity
- Fully insulated and clad in precast concrete



Structural System Description

V Columns

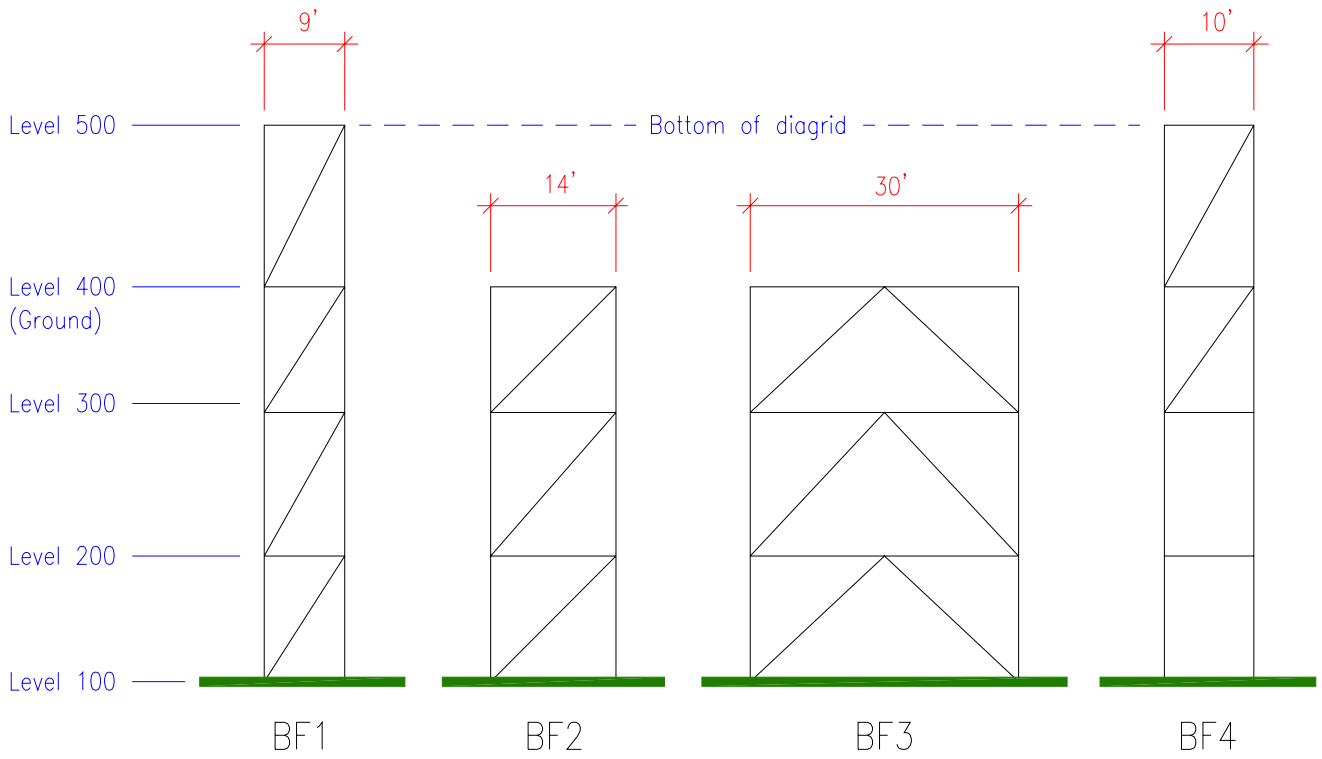
- Fabricated from heavy wide-flanges or built-up boxes
- Rigidly connect to the diagrid and substructure
- Help transfer lateral load, primarily in North-South direction



Structural System Description

Braced Frames

- Four types
- Help carry lateral load from bottom of diagrid to foundation
- East-West direction only



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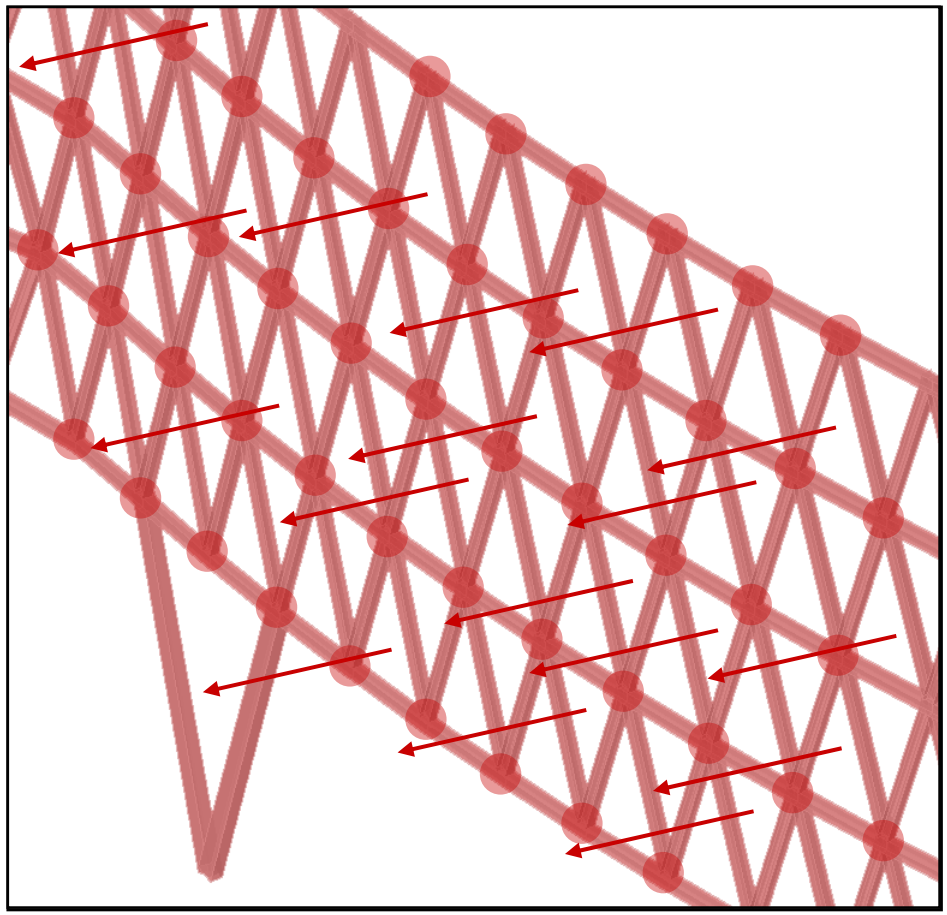
Problem Statement

Three main concerns

- Heavy diagrid
- Connection intensive
- Limited views



Problem Statement

Goals

Address the three main concerns

1) Reduce structure weight
2) Reduce connection complexity
3) Maximize viewable window space

Additionally

- Increase overall structural efficiency
- Decrease overall building cost
- Ensure construction feasibility
- Minimize interior impact
- Maintain building shape
- Maintain floor height

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Design Philosophy

Become an "architect-engineer"

- Aesthetic quality
- Practical application

Innovative architecture demands innovative engineering solutions!

Unique yet sensible

- Alter the look and feel
- Maintain shape, height, space layout

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Redesign Approach

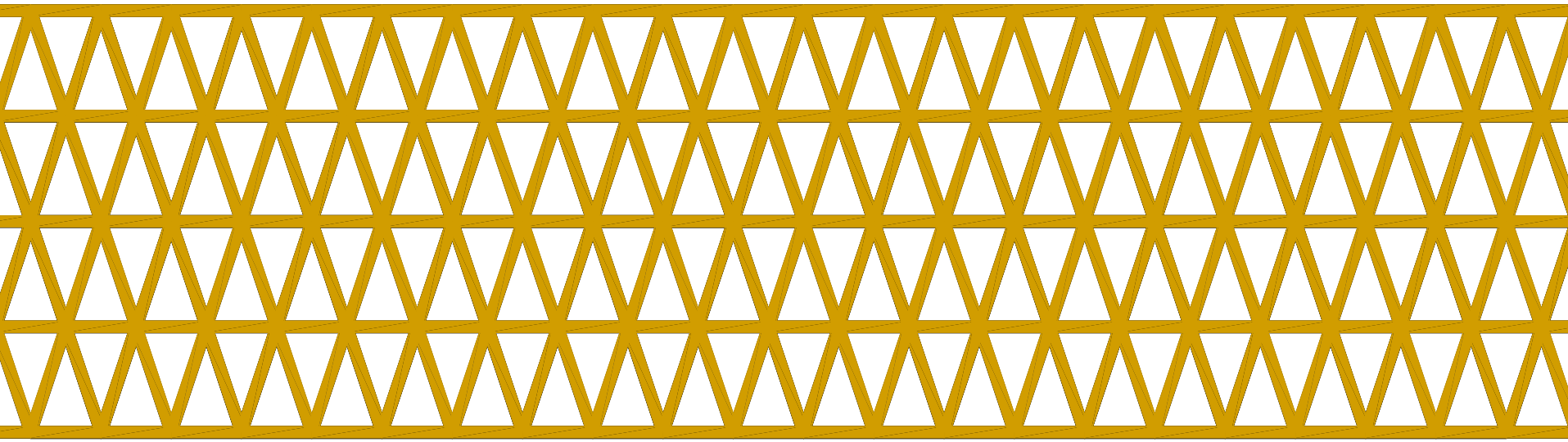
Solution Area Concept

Solution Area I - Changing the material

Solution Area II – Modifying the geometry

Solution Area III – Removing it altogether

Progressively disruptive!



Redesign Approach

Breadth Areas

Daylighting Study

- Façade will change
- Attempt to integrate daylighting into new exterior
- Qualitative assessment

Construction Study

- Erection sequence
- Material layout planning
- Not discussed

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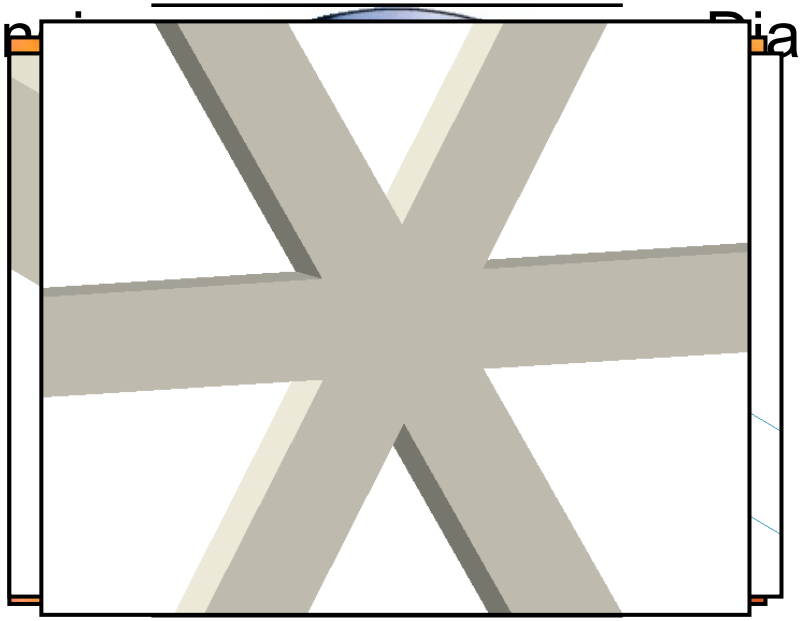
Structural Redesign

5 different materials

- Steel wide flange
- Round/rectangular HSS
- Glulam timber
- Precast concrete
- Cast-in-place concrete

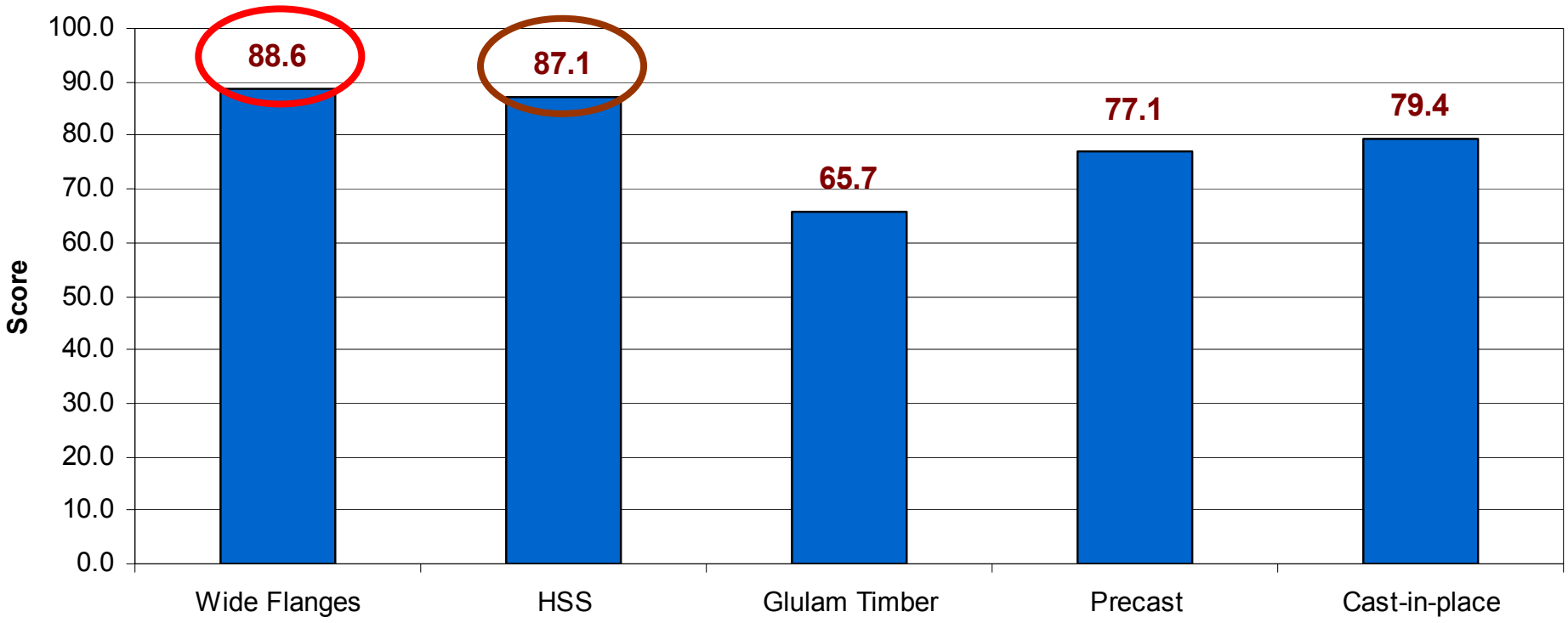
Solution Area I

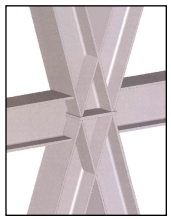
Chan[illegible] Diagrid

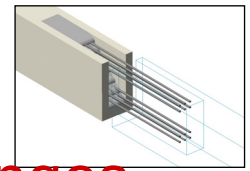
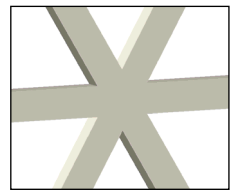


Structural Redesign

Results





Stick with steel wide flanges

Structural Redesign

Two main ways to accomplish this:

1) Open up the grid

2) Adjust configuration

John Hancock Center

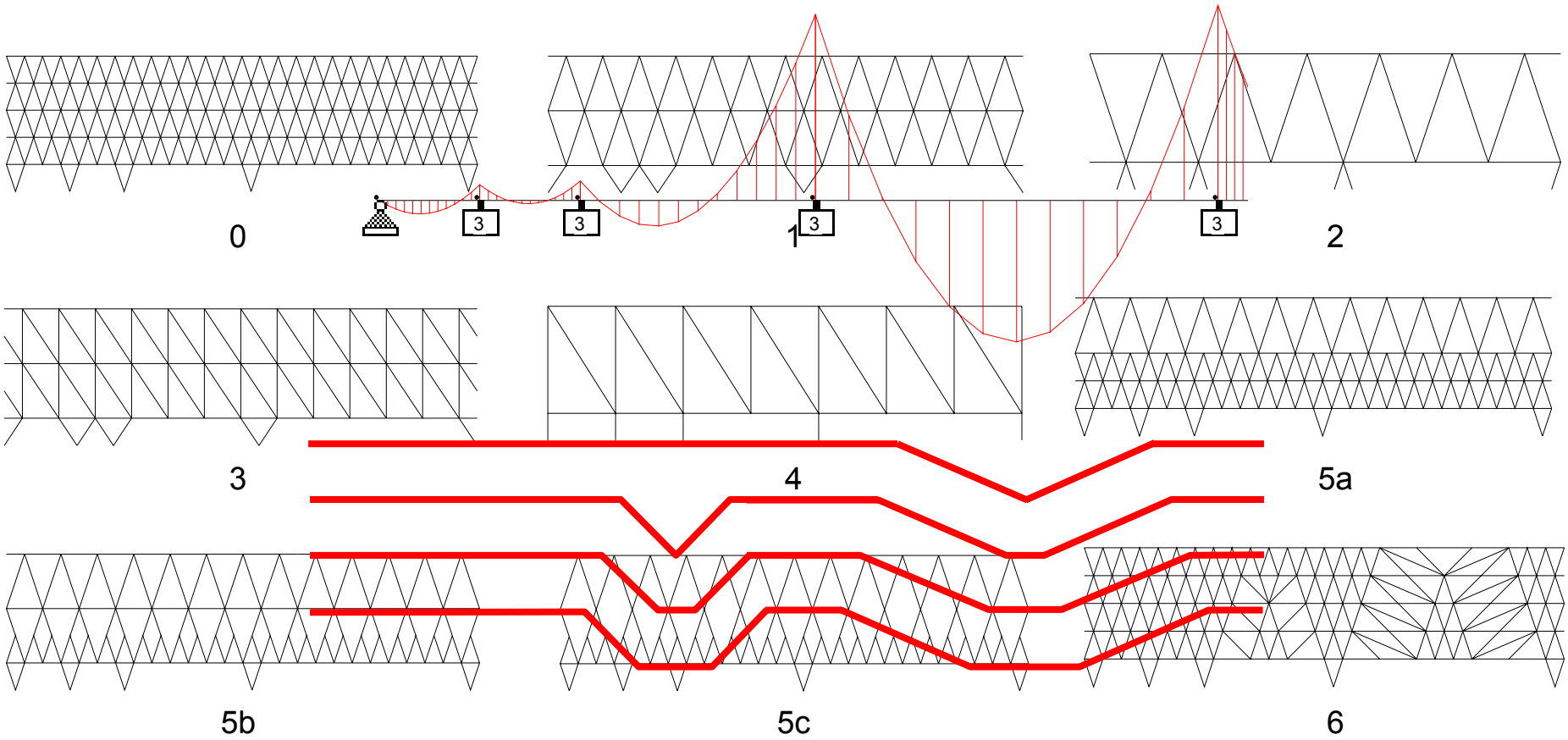
tion Ar

the Diagrid

Central China Television Tower

Structural Redesign

Configurations



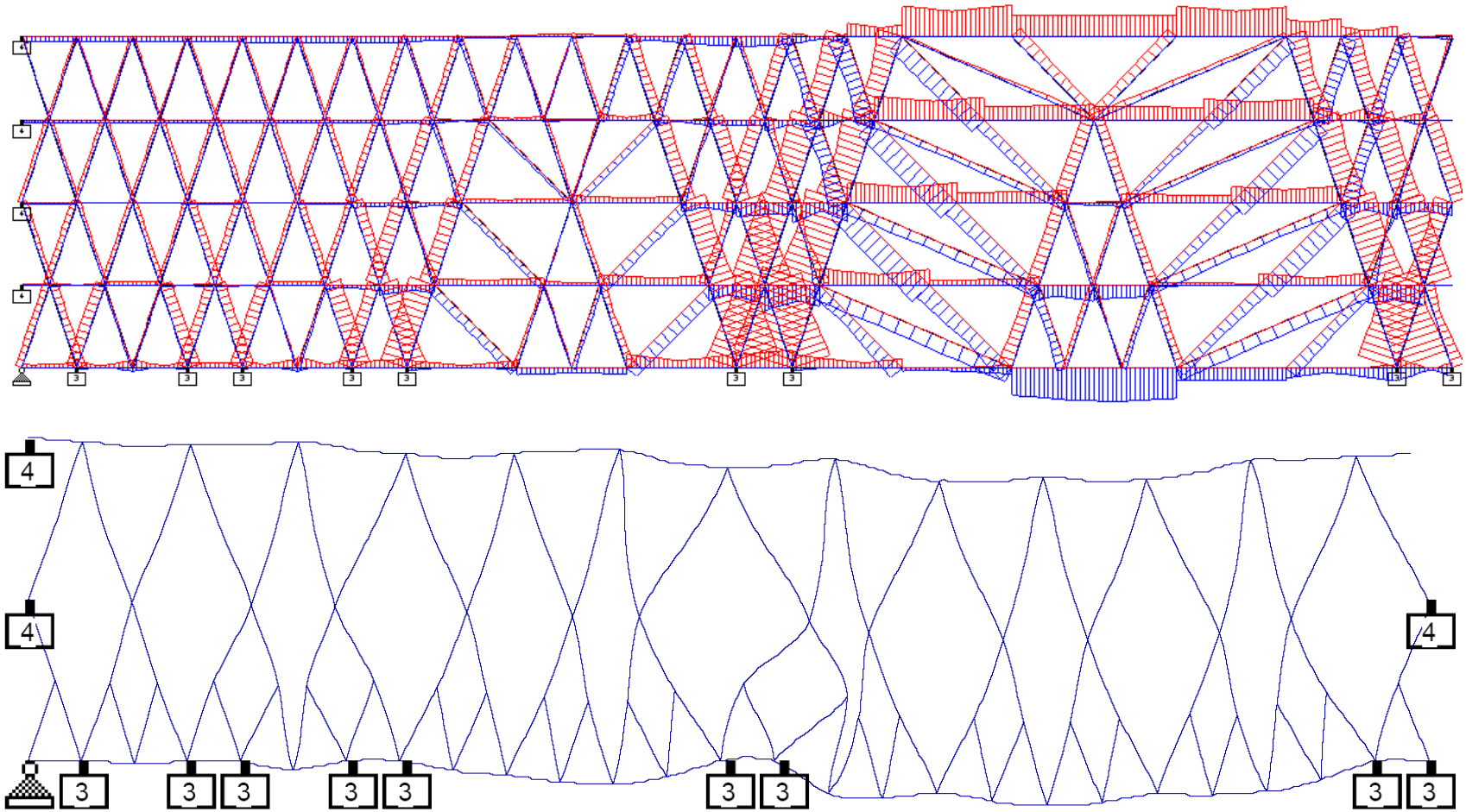
Structural Redesign

Considerations

- Structural Efficiency
- Structural Stability
- Architectural Impact
- Floor Framing Impact
- Material Cost
- Complexity

Structural Redesign

2D STAAD Model



Structural Redesign

Tabular Results

	Str. Eff.		Redundancy		Deflection		Architecture		Flr. Framing		Mat. Cost		Complexity	
Case	**Weight**	**Score**	**%**	**Score**	**in.**	**Score**	**Index**	**Score**	**Index**	**Score**	**Index**	**Score**	**Index**	**Score**
0	42170	0.79	71.6	1.00	0.029	1.00	100	1.00	100	1.00	100	0.70	100	0.50
1	36192	0.92	54.4	0.76	0.059	0.49	90	0.90	80	0.80	80	0.88	75	0.67
2	51648	0.64	42.5	0.59	0.079	0.37	75	0.75	70	0.70	70	1.00	50	1.00
3	33417	0.99	53.4	0.75	0.044	0.66	90	0.90	80	0.80	80	0.88	75	0.67
4	65833	0.50	46.0	0.64	0.095	0.31	75	0.75	70	0.70	70	1.00	50	1.00
5a	40845	0.81	64.3	0.90	0.037	0.78	95	0.95	90	0.90	90	0.78	85	0.59
5b	45110	0.74	58.8	0.82	0.057	0.51	95	0.95	80	0.80	85	0.82	80	0.63
5c	68016	0.49	66.3	0.93	0.074	0.39	95	0.95	70	0.70	80	0.88	75	0.67
6	33176	1.00	69.0	0.96	0.029	1.00	90	0.90	100	1.00	95	0.74	100	0.50
Weight		1.0		0.8		0.8		0.7		0.3		0.5		0.4

Observations

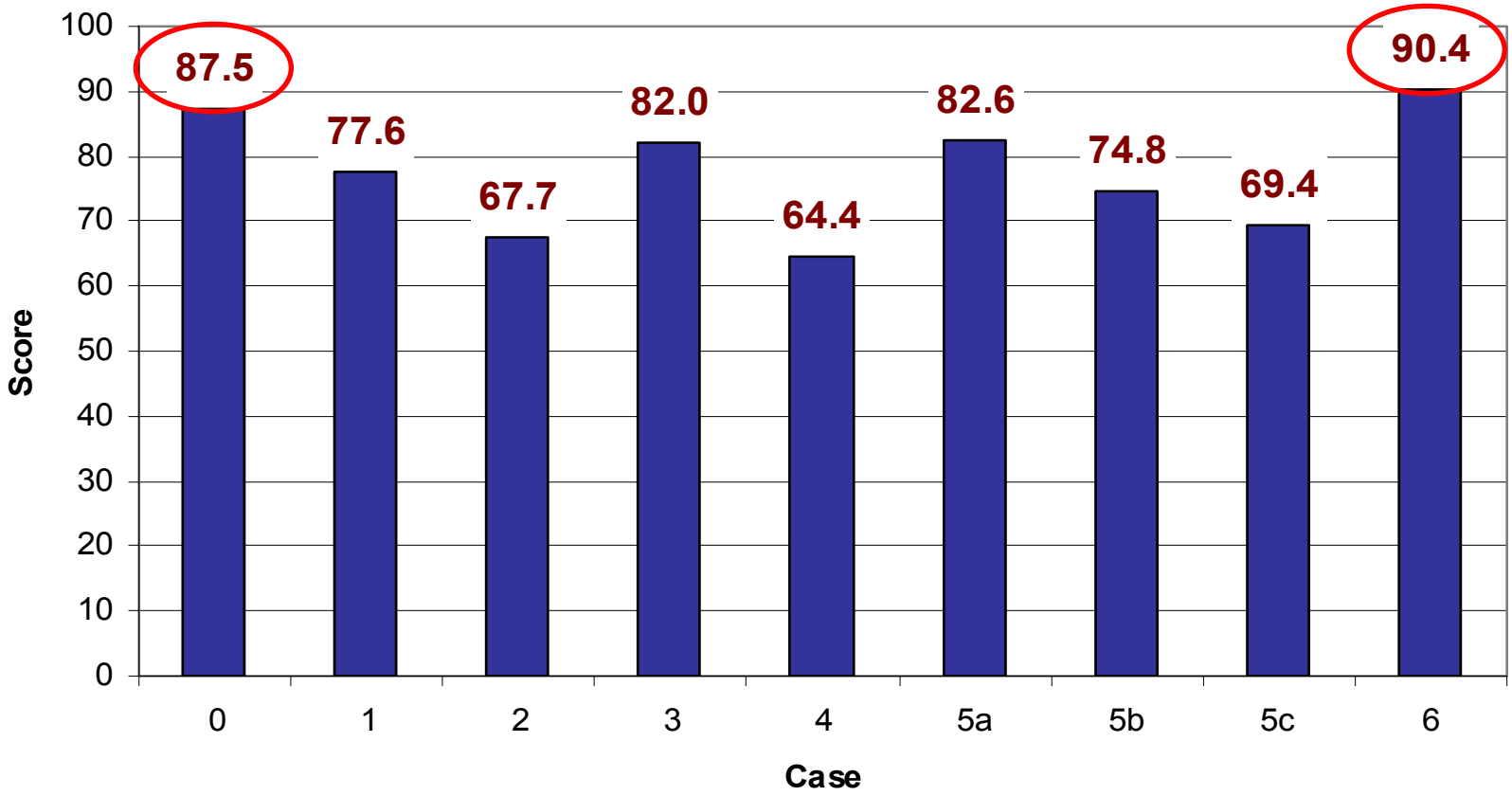
Varying member length has a substantial impact on structural efficiency.

In general, there is a noticeable tradeoff between architectural impact and cost.

High system redundancy helps control deflection.

Structural Redesign

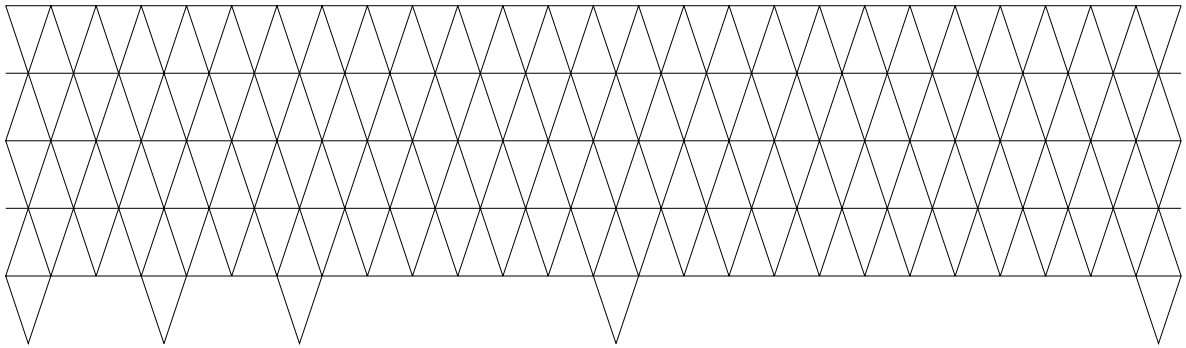
Overall Results



Structural Redesign

Conclusion

Original



Stick with the original diagrid configuration!

Structural Redesign

A whole new approach

- Diagrid is eliminated
- Move lateral system within the building
- Curtain wall becomes new building enclosure

Solution Area III

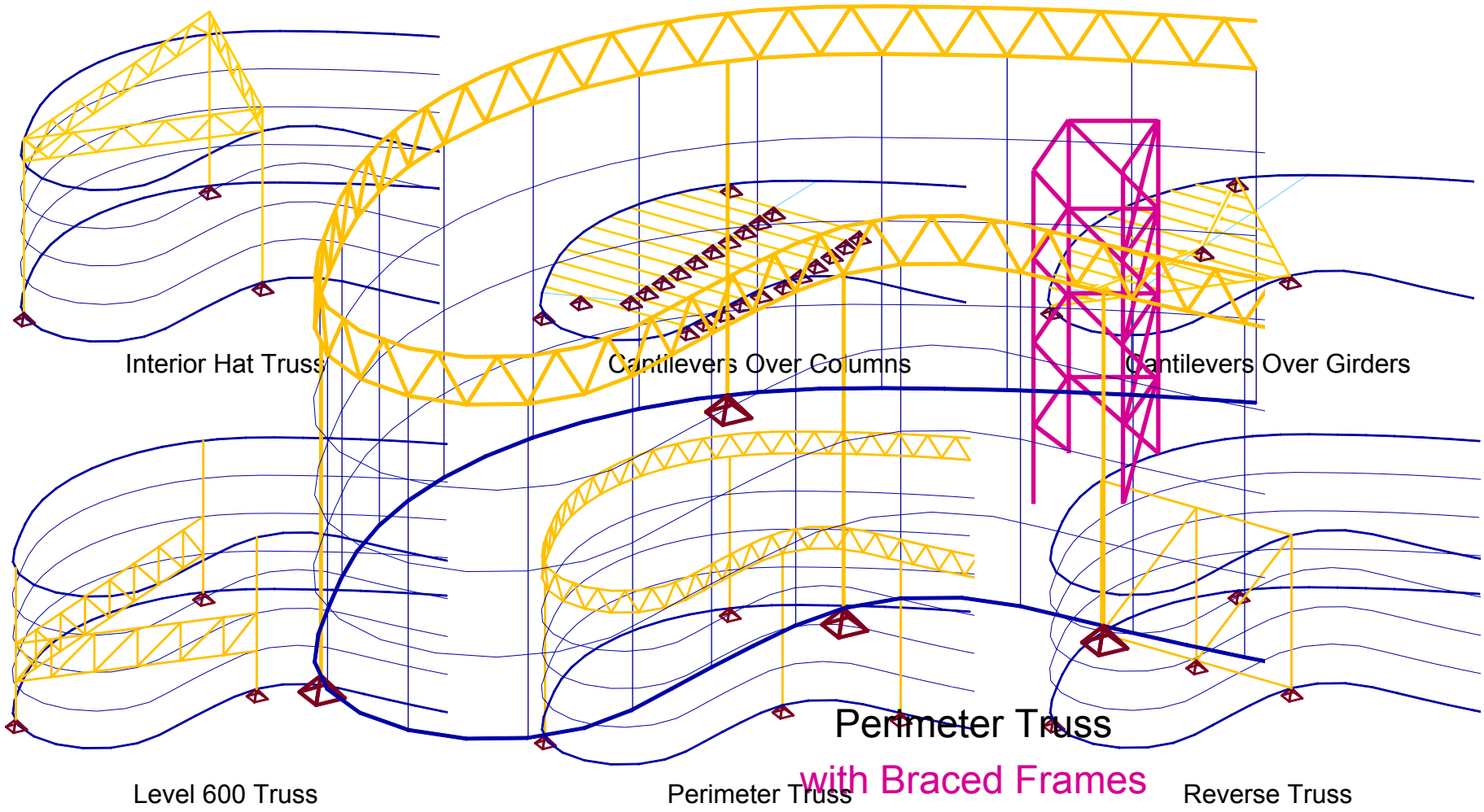
Removing the Diagrid

Development phases

- Conceptual Design
- Schematic Design
- Design Development
- Construction Documents

Structural Redesign

Conceptual Design

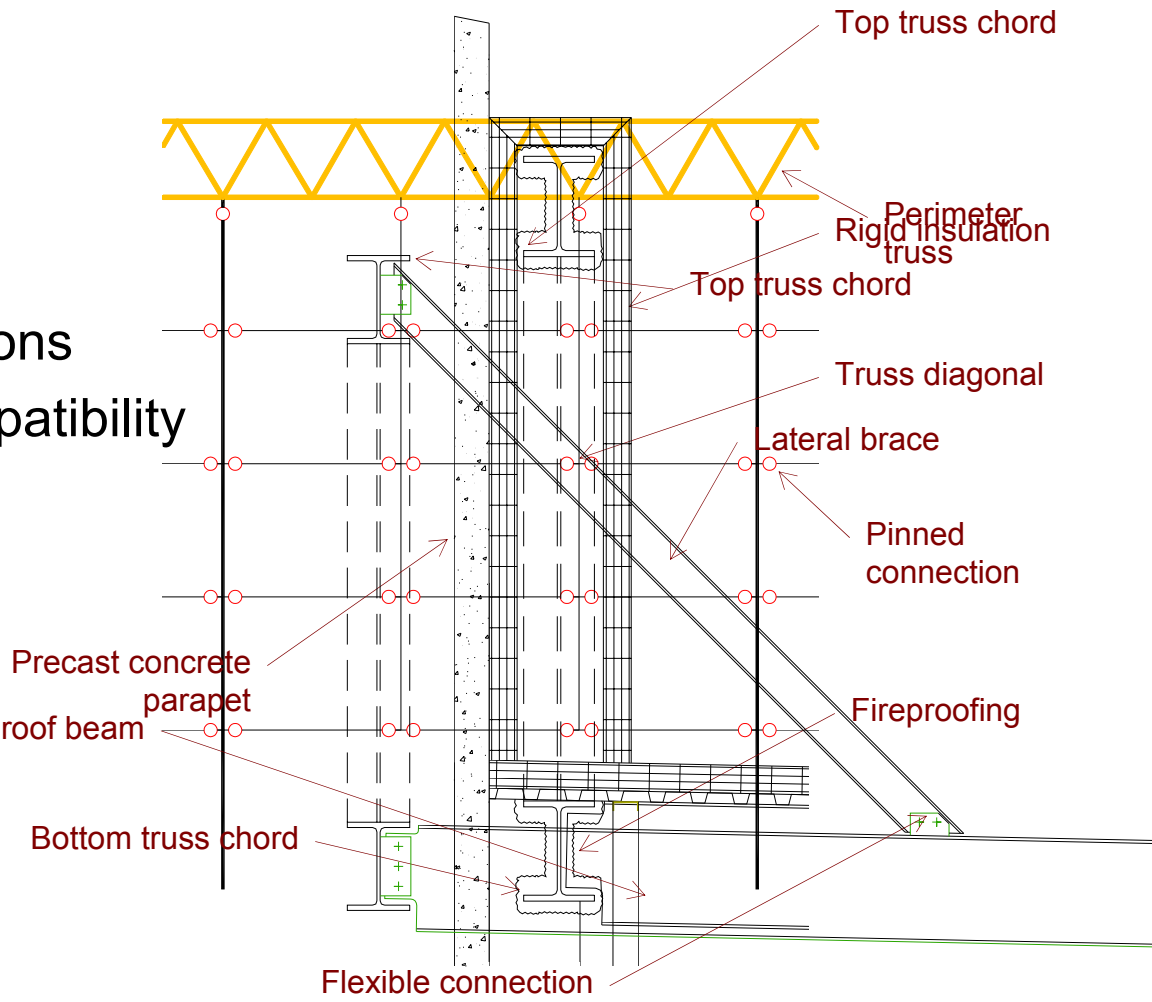


Structural Redesign

Schematic Design

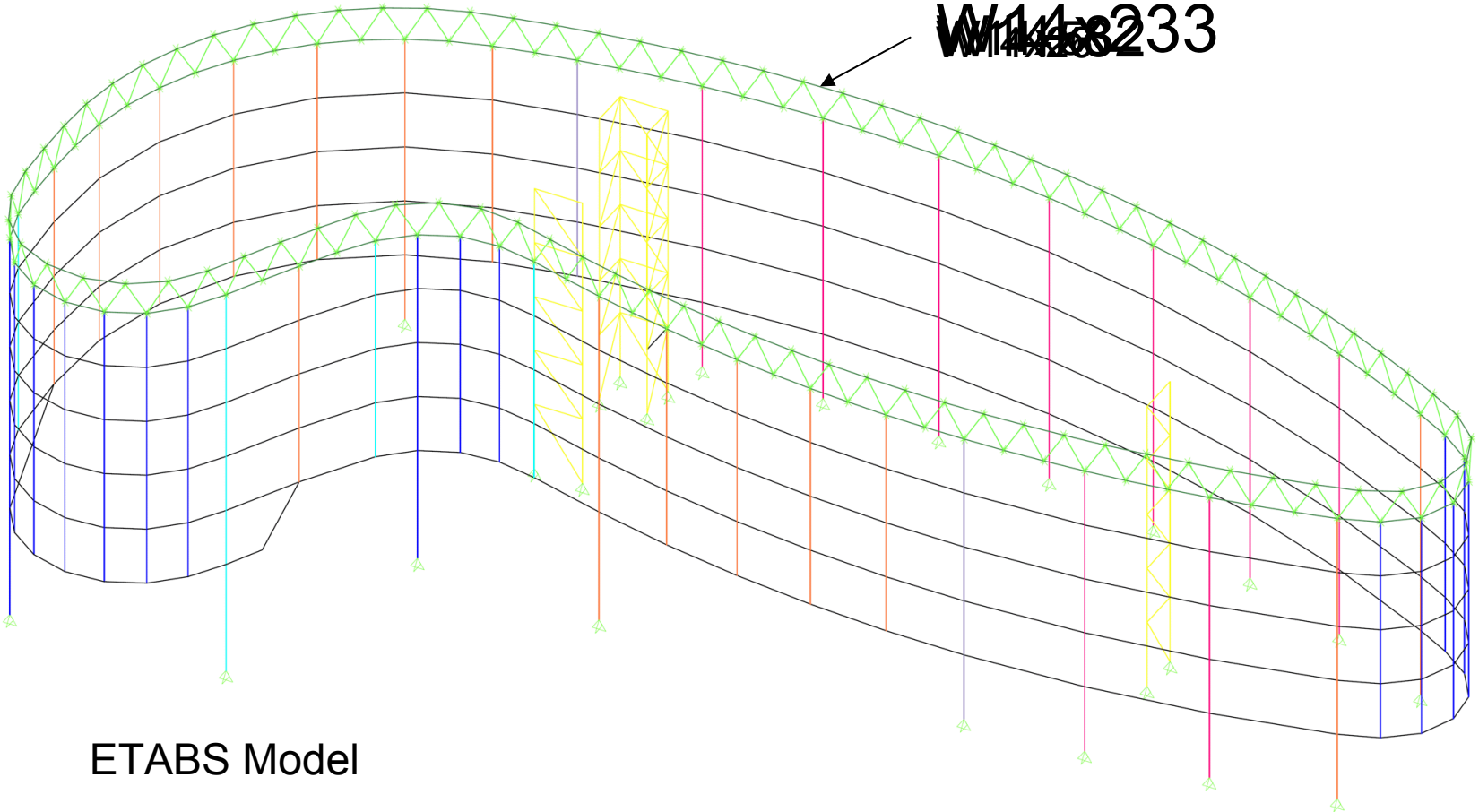
10 Considerations

1) Floor beam sweep
2) Column spacing
3) Pinned vs. fixed connections
4) Column deformation compatibility
5) Fire resistance
6) Thermal movement
7) Truss height
8) Truss lateral bracing
9) Corrosion
10) Braced frame placement



Structural Redesign

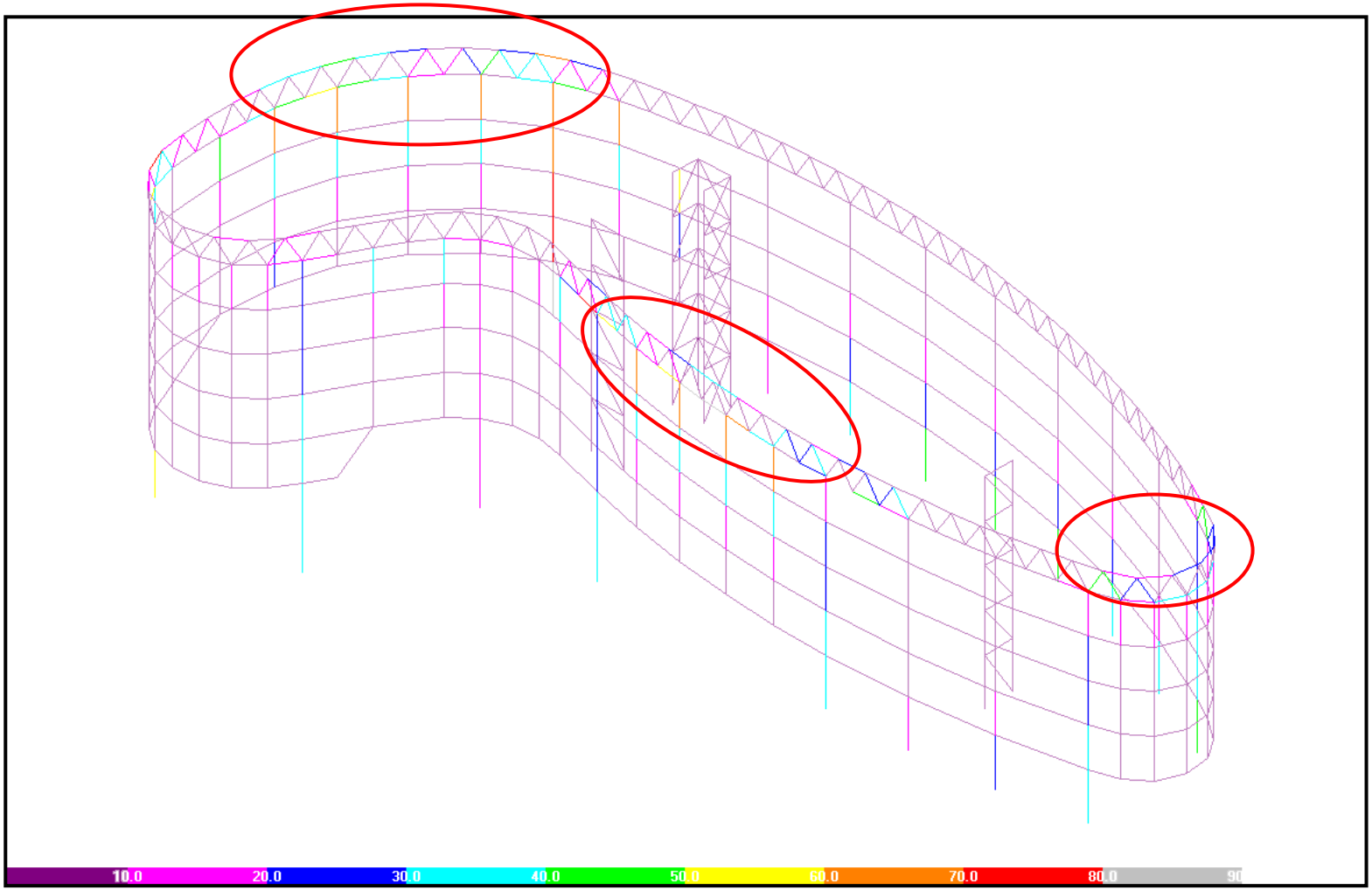
Design Development



ETABS Model

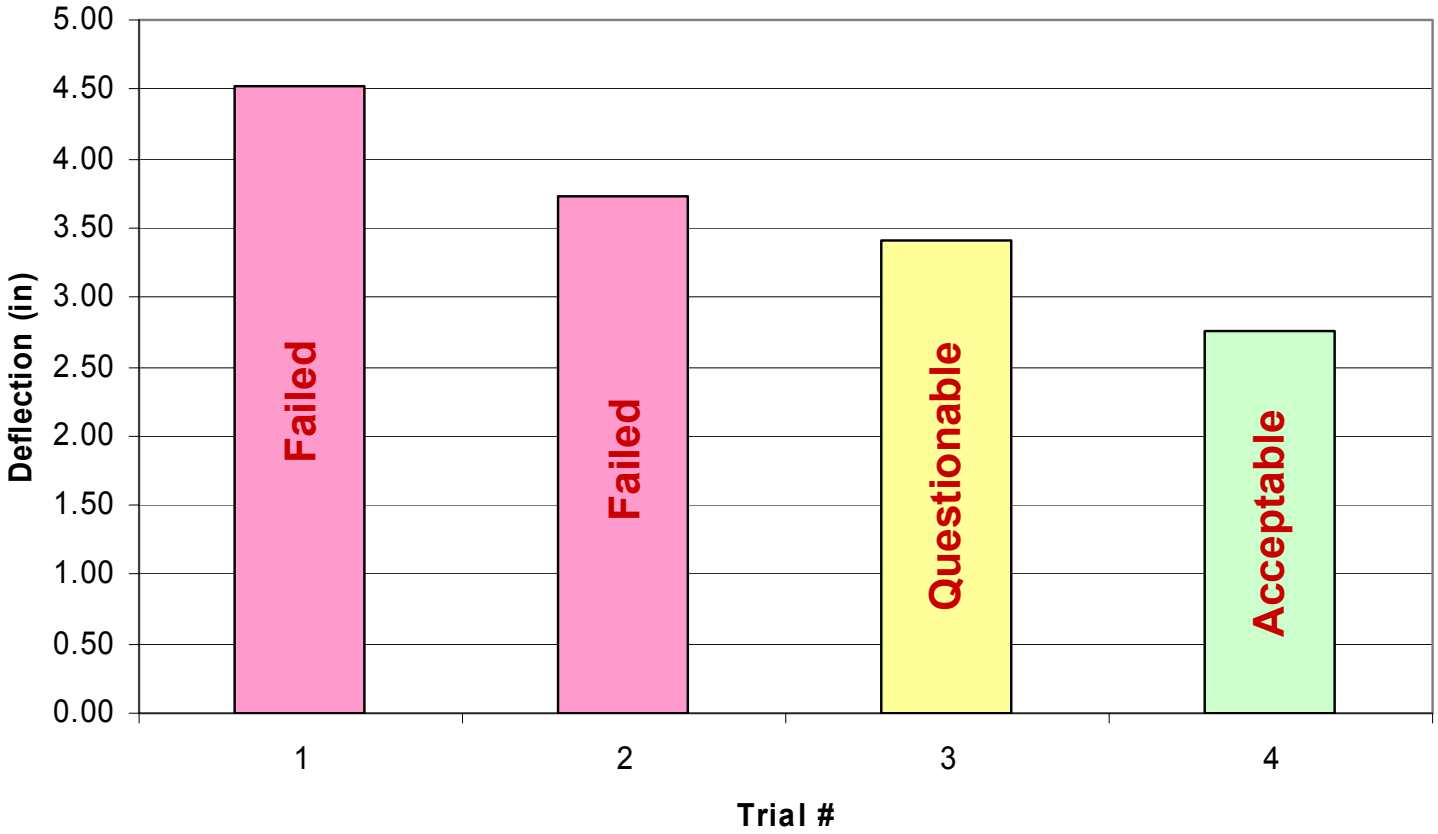
Structural Redesign

Virtual Work



Structural Redesign

Deflections

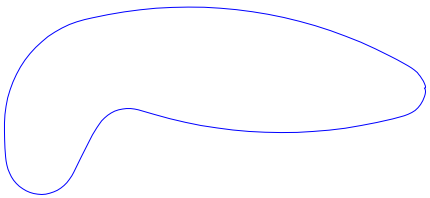


Construction Documents

	Weight (tons)						
Member Group	**Trial #1**	**Trial #2**	**Trial #3**	**Trial #4**	**Trial #5**	**Trial #6**	**Trial #7**
Truss Horizontals	39.1	47.6	57.2	59.9	79.9	85.2	85.2
Truss Diagonals	28.8	33.4	38.2	49.8	49.8	54.5	54.5
Truss Columns	75.2	69.5	69.5	80.3	80.3	83.9	83.9
Sum =	143.0	150.6	164.9	189.9	209.9	223.7	223.7

	Weight (tons)				
Member Group	**Trial #1**	**Trial #2**	**Trial #3**	**Trial #4**	**Trial #5**
Above Grade Braces	8.1	10.6	11.6	13.0	12.1
Above Grade Columns	87.1	87.1	92.6	63.5	59.4
Below Grade Braces*	4.1	5.3	5.8	6.5	6.1
Below Grade Columns*	43.5	43.5	46.3	31.8	29.7
Sum =	142.8	146.4	156.3	114.7	107.3

*Assumed at 50% of above grade sum



Length **ft**	**Pieces per floor**	**Total Length ft**	**Weight lb/ft**	**Total weight tons**
9	19	171	26	2.2
18	16	288	55	7.9
27	11	297	106	15.7
Per floor		756		25.9

x4 Floors	103.5

Structural Redesign

Structure weight

Perimeter Truss	Tons
Truss Horizontals	85.2
Truss Diagonals	54.5
Columns	83.9
Filler Beams	103.5
Bracing	107.3
Total Weight =	434.4

Original System	Tons
Diagrid	407.0
V columns	46.9
Bracing	62.3
Total Weight =	516.2

Perimeter Truss reduces structural steel weight by **16%**

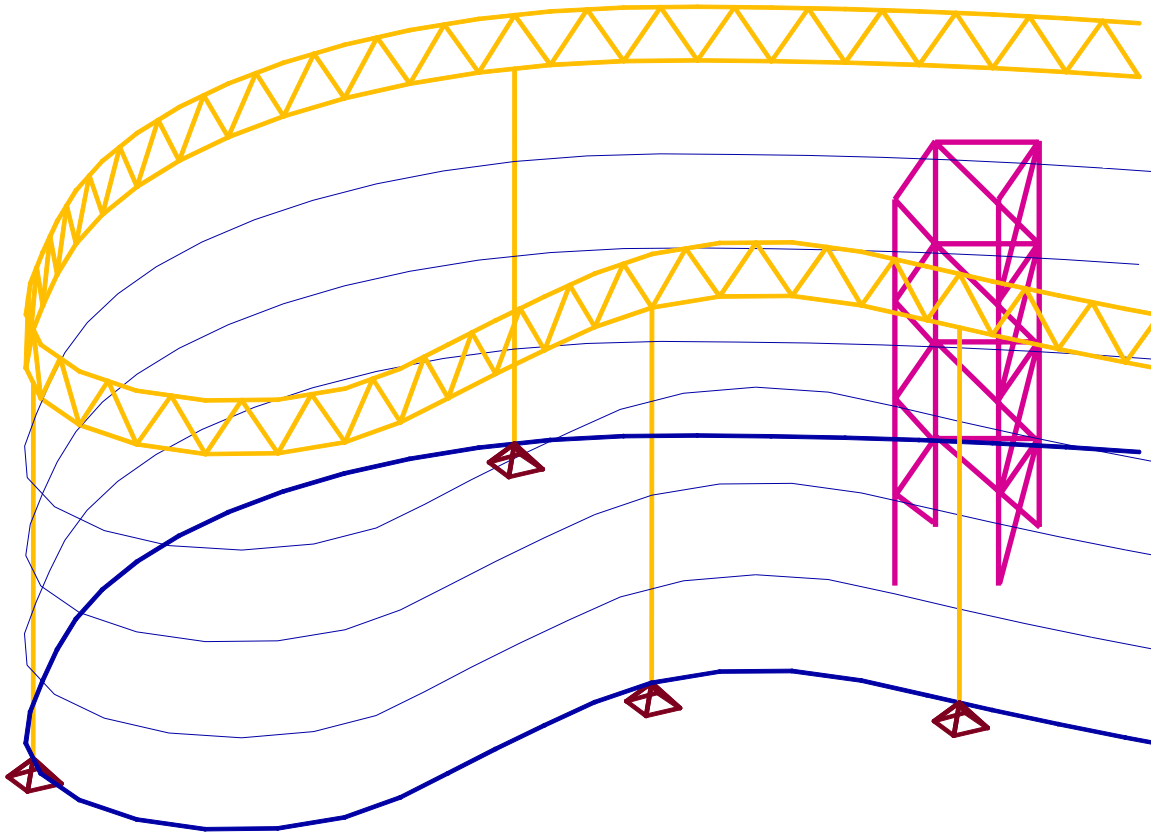
Structural Redesign

Conclusions

	Undesirable Impact	Little or no Change	Reasonable Success
Reduce structure weight			●
Reduce connection complexity			●
Increase viewable window area			●
Maintain building shape	●		
Maintain interior layout	●		
Maintain floor system		●	
Maintain floor height			●
Penetration of open spaces		●	
Placement of columns		●	

Structural Redesign

The Perimeter Truss and Braced Frame system is an acceptable alternative.



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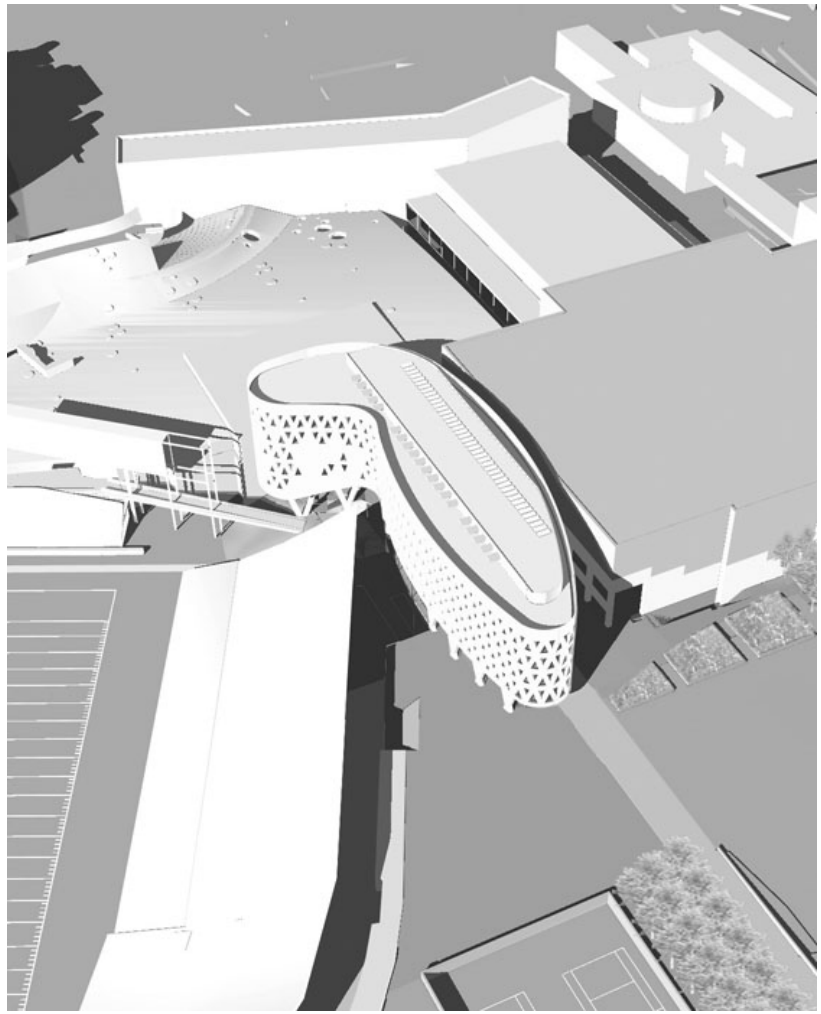
Daylighting

Benefits

- Increased worker productivity
- Potentially lower operating costs
- Environmentally sound
- Increased heat gain in winter

Challenges

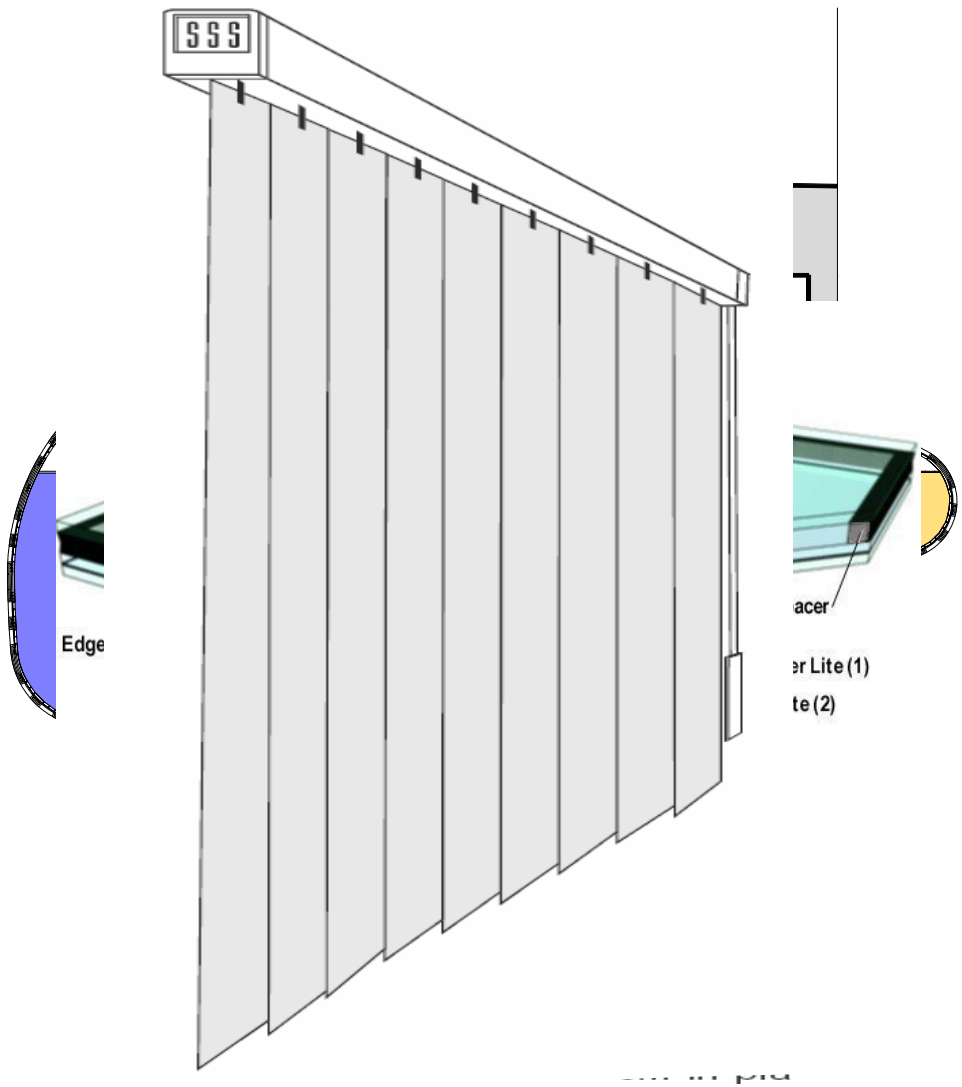
- Discipline coordination
- Increased building glare
- Thermal discomfort
- Summer heat gain



Daylighting

Considerations

- Spaces daylighted
- Window quantity
- Window geometry
- Glazing material
- Window covering
- Façade material
- Artificial lighting control
- Interior finishes



Daylighting

Conclusions

	Disadvantage	Either	Advantage
Worker productivity			●
Operating costs		●	
Initial cost			●
Environmental Impact		●	
Design coordination	●		
Glare	●		
Thermal discomfort	●		
Heat gain		●	
Views			●

Daylighting is an owner/architect decision

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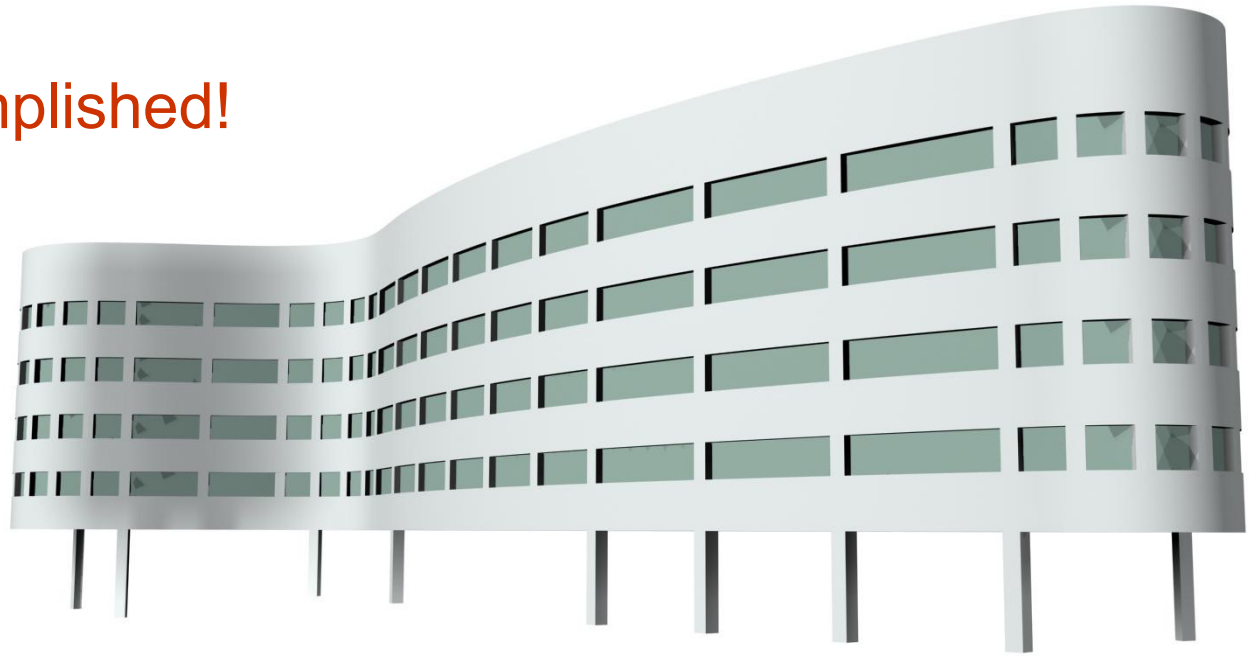
Recommendation

Perimeter Truss is an excellent alternative to the diagrid

- Lighter
- Less connections
- Better window views
- Minimal impact to existing systems

Personal goal accomplished!

- Unique yet sensible



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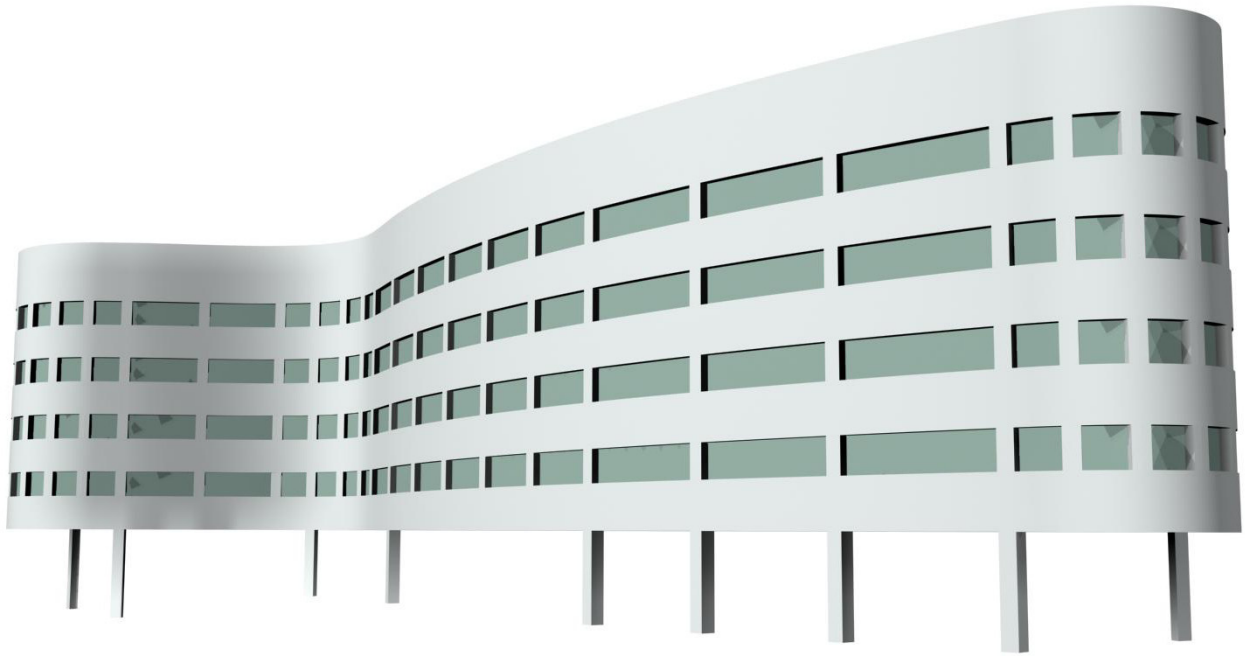
Friends
AE Professors
Dr. Linda Hanagan
Kevin Parfitt
Jonathan Dougherty
Ricardo Pittella
Michael Tavolaro
Industry consultants



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