

# The Millennium Science Complex

University Park, PA

Penn State  
Integrated Project Delivery /  
Building Information Modeling  
Senior Capstone Thesis





## Project Team Members



**Jason Brognano**  
Lighting/Electrical Designer



**Michael Gilroy**  
Mechanical Designer



**David Maser**  
Construction Manager



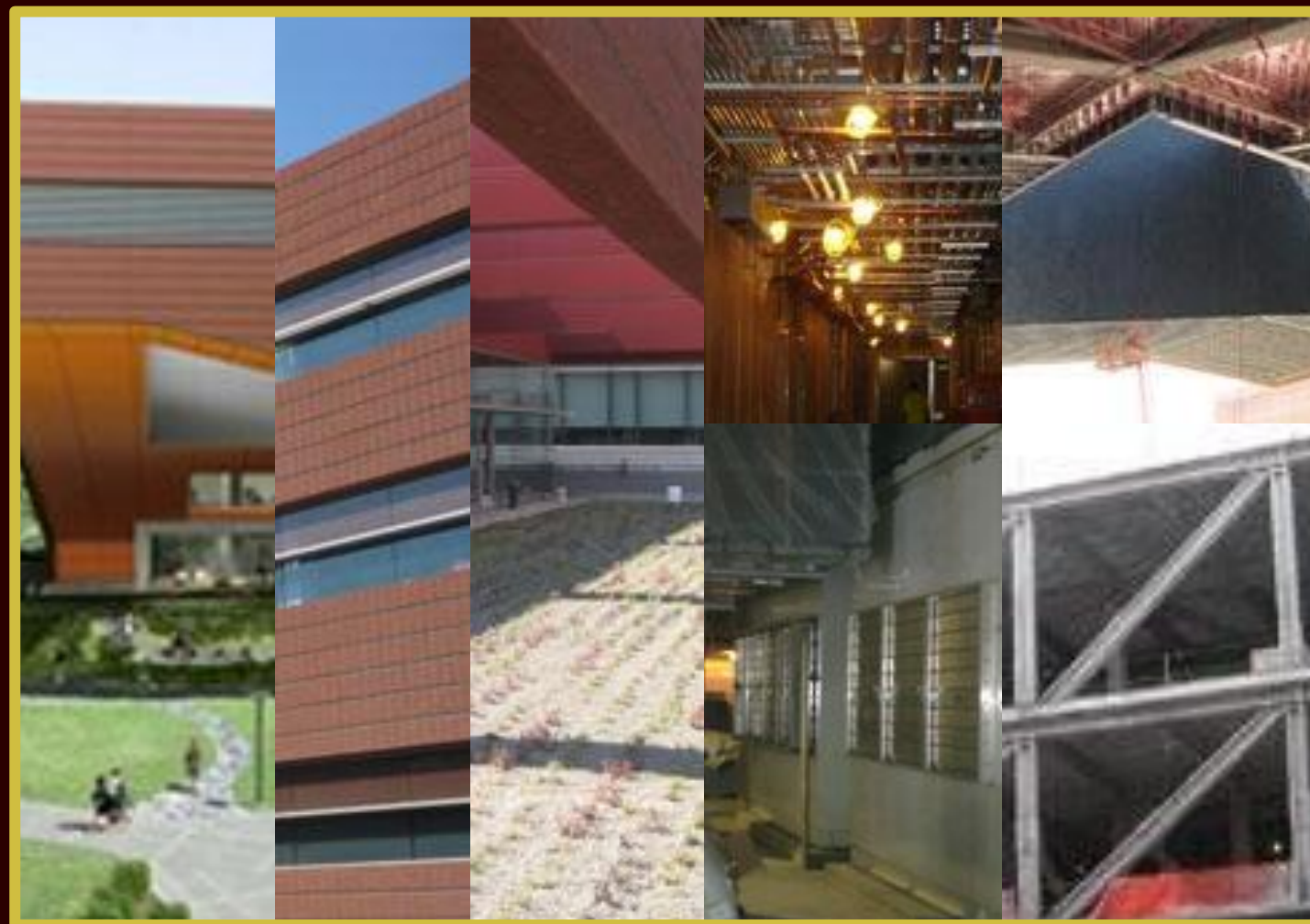
**Stephen Kijak**  
Structural Designer

## Location, Size, and Use



- Science Research complex
- 275,600 sq. ft.
- Three above grade floors, penthouse, mezzanine, and basement

## Project Overview



## Time and Cost

- Design-Bid-Build Delivery
- June 2008 — July 2011 Construction
- \$230,000,000 budgeted overall cost
- \$175,000,000 building cost

## Sustainability Features

- LEED Gold Certification
- Green roofs on both wings
- Low VOC materials on interior
- Daylight integration in perimeter spaces
- CO<sub>2</sub> occupancy density sensors

## Construction

CONSTRUCTION PHASE	DURATION (DAYS)	START	FINISH
Notice to Proceed	1	8-12-08	8-12-08
Foundation	270	2-16-09	2-26-10
Superstructure	274	7-7-09	7-23-10
Enclosure	303	11-9-09	1-5-11
Building Systems & Finishes	345	12-14-09	4-8-11
Construction Duration	758	8-12-08	7-7-11
Substantial Completion	1	7-7-11	7-7-11

## Project Overview



## Lighting and Power

- All **lighting on 480Y/277V** supply
- **Receptacle** and small loads **on 208Y/120V**
- Lutron Ecosystem in public perimeter spaces
- Occupancy and daylight sensor control
- Lighting control panels for exterior spaces
- Campus tied, 12.47kV supply voltage
- Dual 5000A main-tie-main switchgear
- Rigid conduit and aluminum cladding in electrical rooms to mitigate EMF interference



## Mechanical

- **VAV Reheat Air Distribution**

- (5) 50,000 CFM AHUs deliver 100% OA to General Lab Areas
- (3) 40,000 CFM AHUs serve Office & Common Areas
- Animal Care, Quiet Lab, and Clean Room AHUs

- **High pressure steam** from PSU central plant

- Reduced to medium and low pressure for use

- PSU campus **chilled water** used for cooling coils AHUs

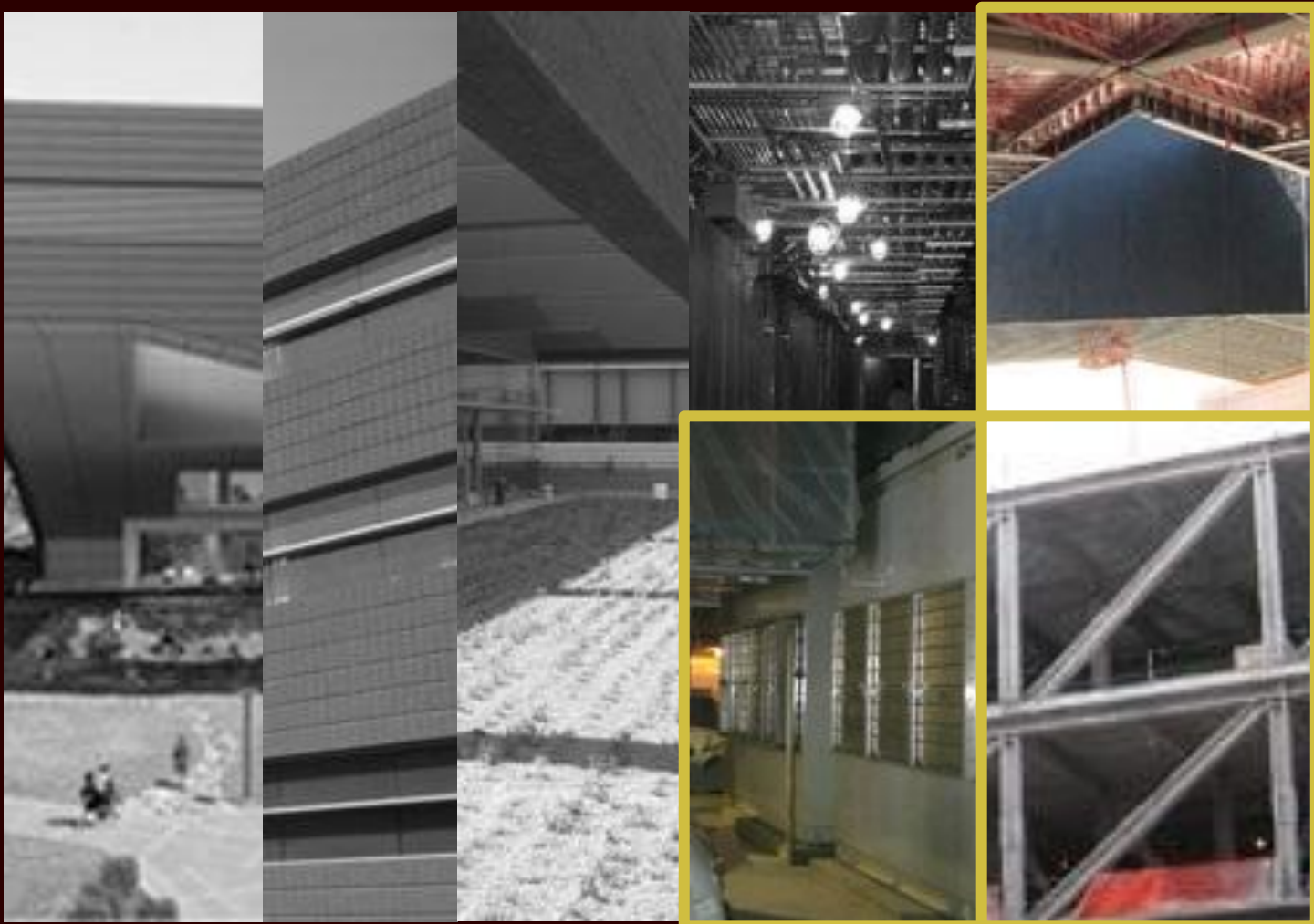
- Dedicated exhaust system for fume hoods, biosafety cabinets

- CO<sub>2</sub> Sensors throughout to maintain air quality

- 4<sup>th</sup> floor penthouse and basement mechanical rooms



## Project Overview



## Structural

- **Steel Structure**

- LWT Concrete on 3inch Metal Deck
- Wide Flange Beams and Girders, 21 and 24 inches deep

- **22ft. X 22ft. Bays**

- **154ft. Cantilever** at the North-West corner of the Building

- 4 Main Supporting Trusses
- Web Members Oriented for Axial Compression
- Moment Connected Members for Stiffness
- Controlled by Deflection - 2 inch Allowance

- Lateral System

- Shear Walls, Braced Frames, Moment Frames
- 90% of Lateral Forces Received by Shear Walls
- Seismic Forces Control

- Foundation

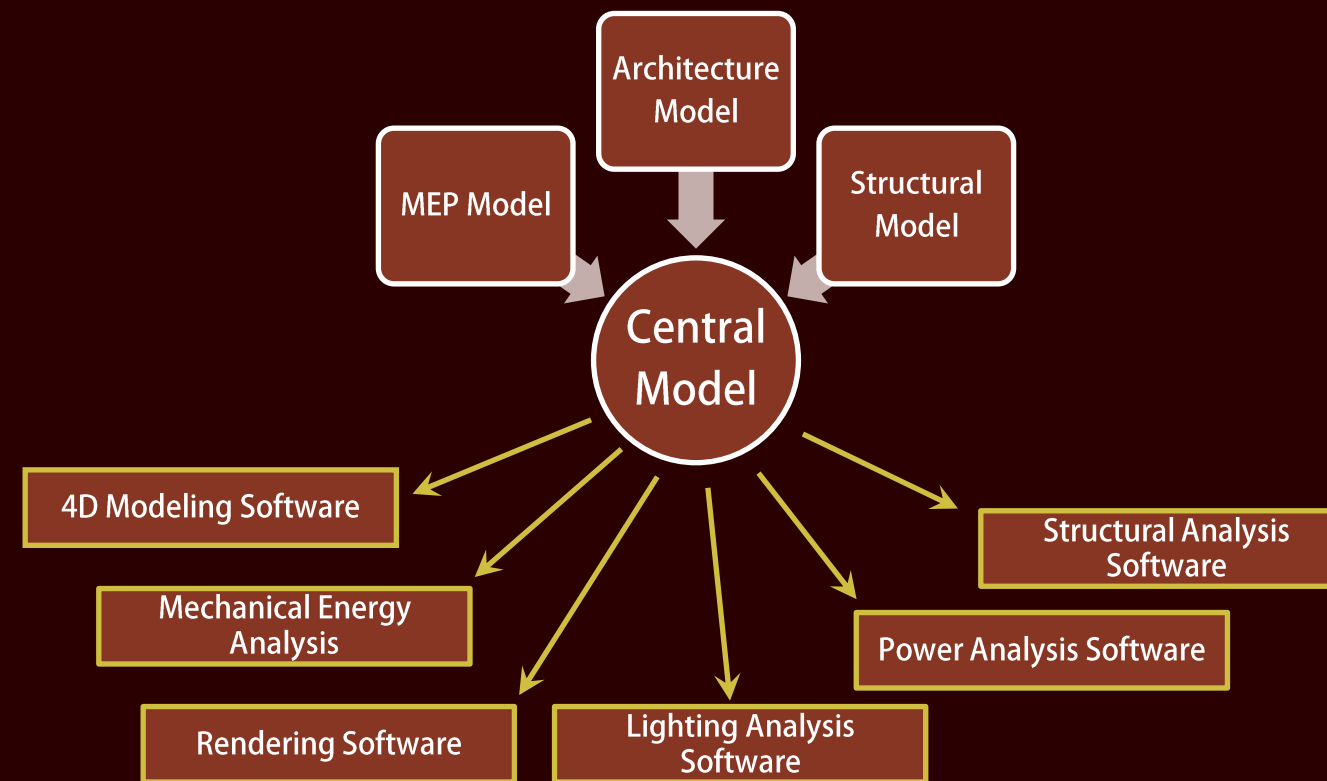
- Micropiles Beneath Pile Caps
- Grid of Foundation Beams



## IPD/BIM Goals

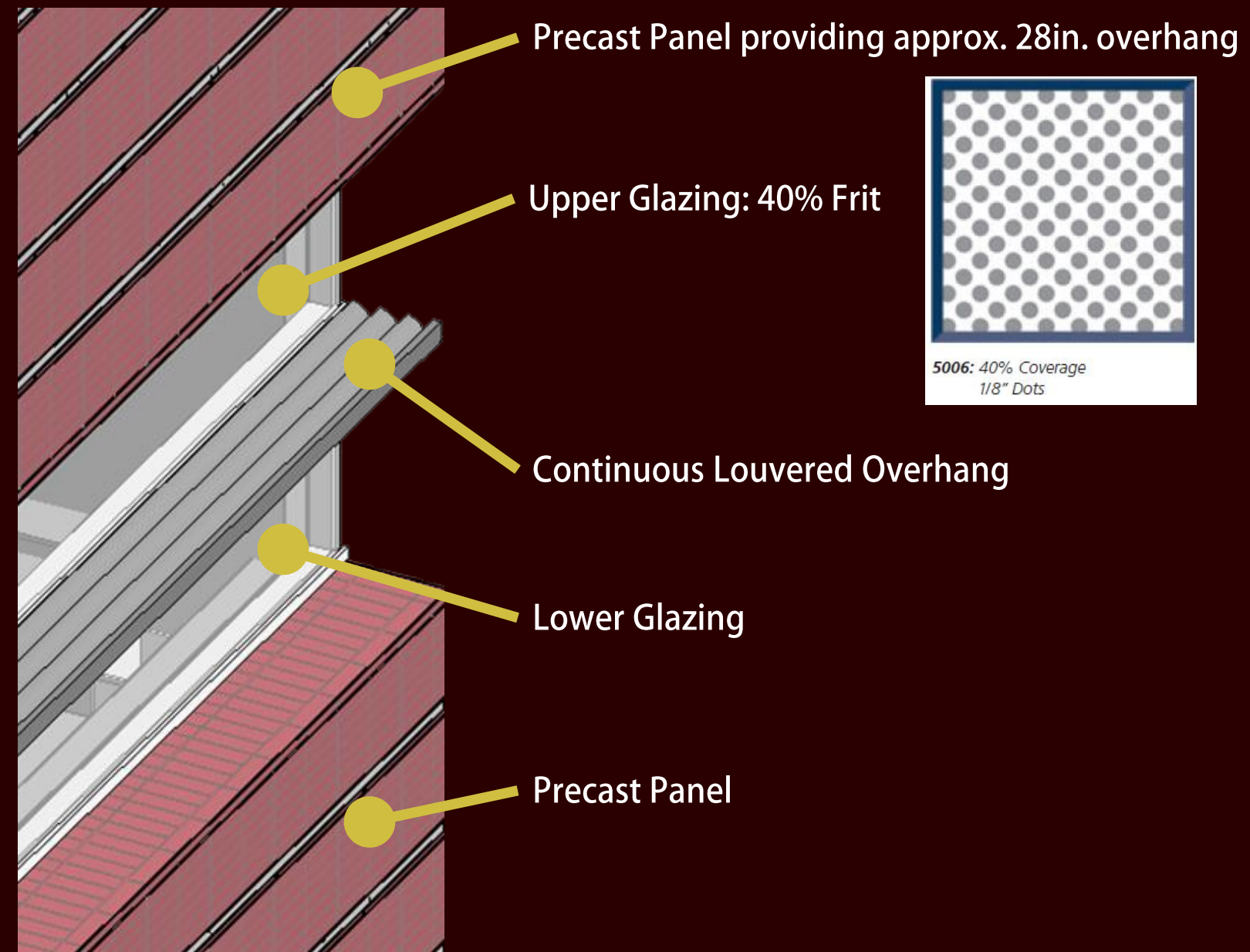
- Update option-specific designs within the appropriate **BIM models**
- Perform analyses using the **central model** as a base
- Document **model sharing processes** to achieve design goals
- Work collaboratively to assess repercussions of design changes on **all disciplines**

## KGB Maser Goals of Analysis



## Engineering Goals

- Decrease energy consumption by **10%**
- **Reduce size** and **cost** of structural system
- Modify façade to accommodate **multiple disciplines**: daylight delivery, structural efficiency, mechanical system sizing, and constructability



## Existing vs. Proposed Façade

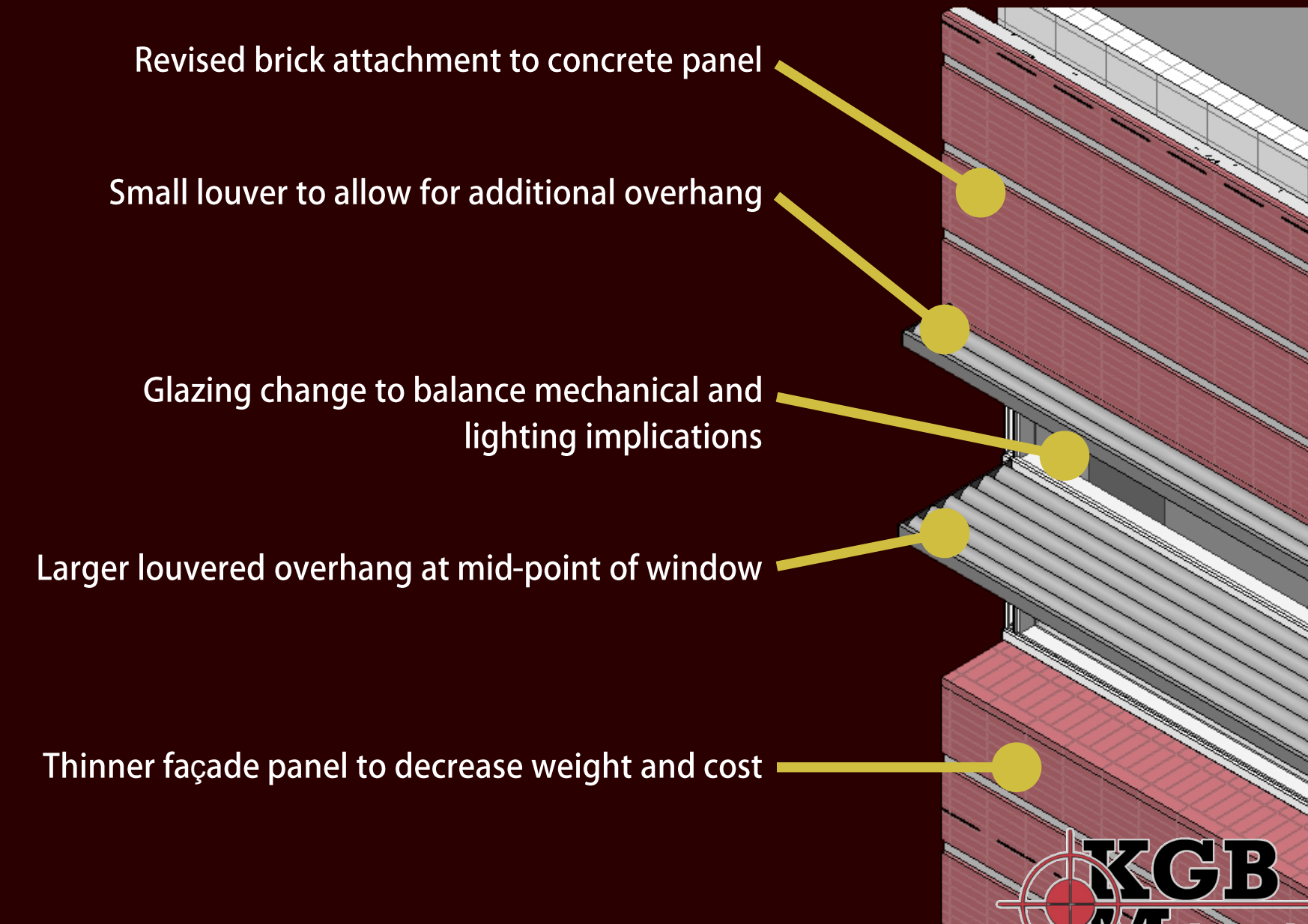
### Key Design Issues

How does overhang depth affect **mechanical load**?

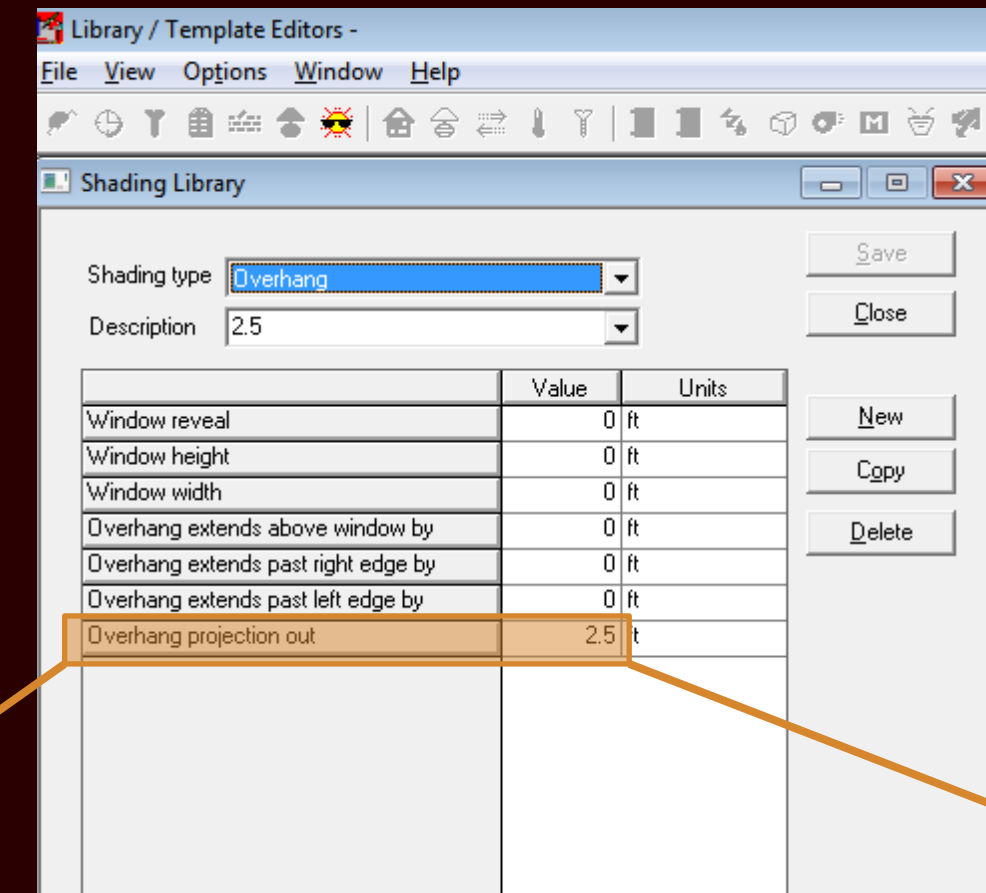
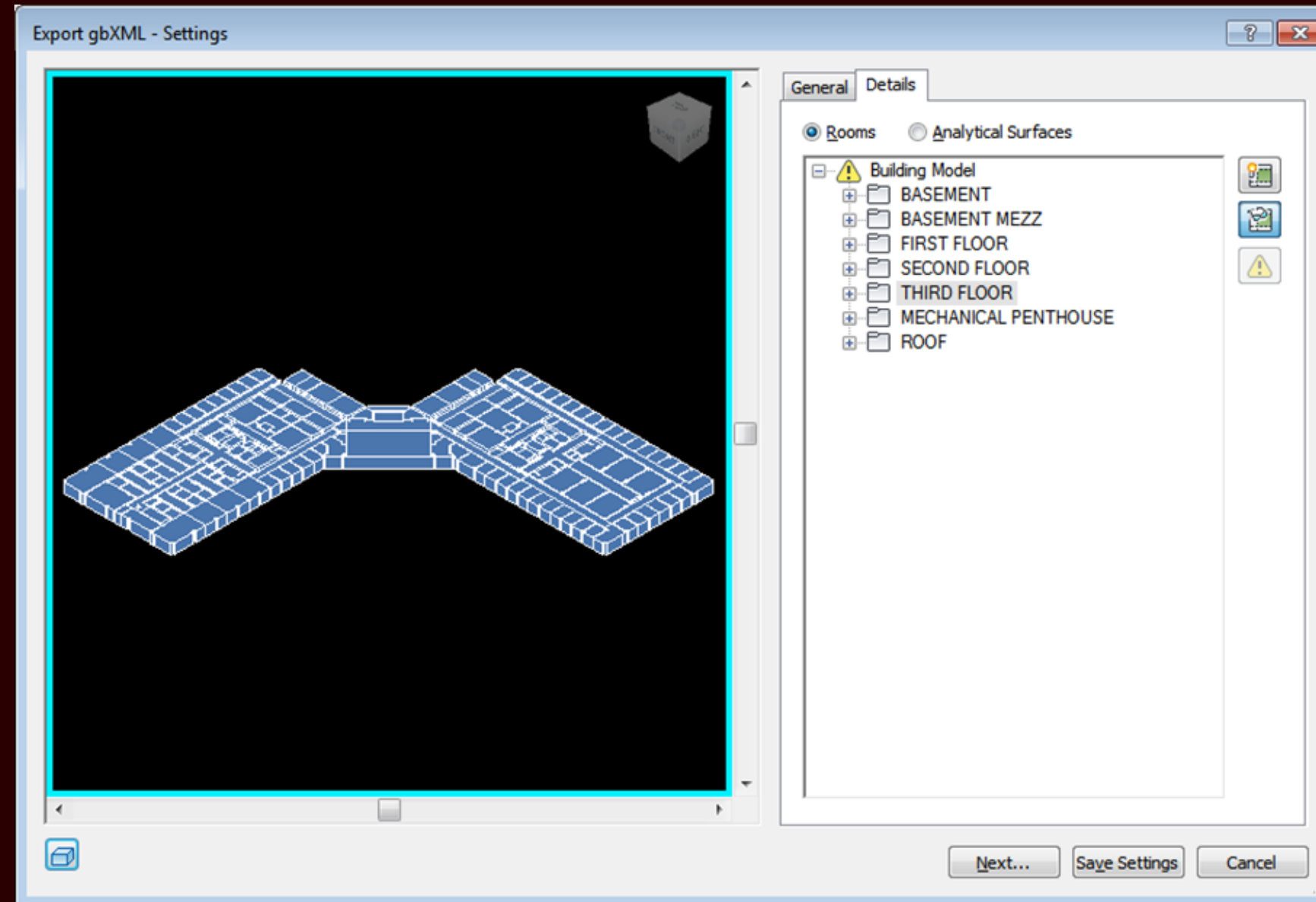
How does overhang depth affect **daylight delivery**?

Is it possible to **reduce the weight** of panels?

Can all options come to a conclusion that is **beneficial** and **cost effective**?



# Overhang Investigation: Trane TRACE



Overhang projection out 2.5 ft

External Shading

Overhang - 2.5

	Opening - 1	Opening - 1	Opening - 1	Opening - 1	Opening - 1
Opening Description	Opening - 1	Opening - 1	Opening - 1	Opening - 1	Opening - 1
Wall Description	Wall - 1w	Wall - 1w	Wall - 1w	Wall - 1w	Wall - 2-s
Room / Door	sp-W-321-Neurophys_Invitro	sp-W-322-Neurophys_Invitro	sp-W-325-Neurophys_Invitro	sp-W-326-Neurophys_Invitro	sp-W-326-Neurophys_Invitro
Window / Door	Window	Window	Window	Window	Window
Opening Dimension Type	% Wall Area	% Wall Area	% Wall Area	% Wall Area	% Wall Area
% Area	45.8	45.8	45.8	45.8	100
Opening Length (ft)	0	0	0	0	0
Opening Height (ft)	0	0	0	0	0
Quantity	0	0	0	0	0
Opening Type	6mm Dbl Ref D Clear 13mm Argon	6mm Dbl Ref D Clear 13mm Argon	6mm Dbl Ref D Clear 13mm Argon	6mm Dbl Ref D Clear 13mm Argon	6mm Dbl Ref D Clear 13mm Argon
Opening U-factor (Btu/h ft <sup>2</sup> °F)	0.47	0.47	0.47	0.47	0.47
Shading Coef	0.44	0.44	0.44	0.44	0.44
% Solar Load to RA	0	0	0	0	0
Internal Shading	None	None	None	None	None
External Shading	Overhang - 2.5	Overhang - 2.5	Overhang - 2.5	Overhang - 2.5	Overhang - 2.5

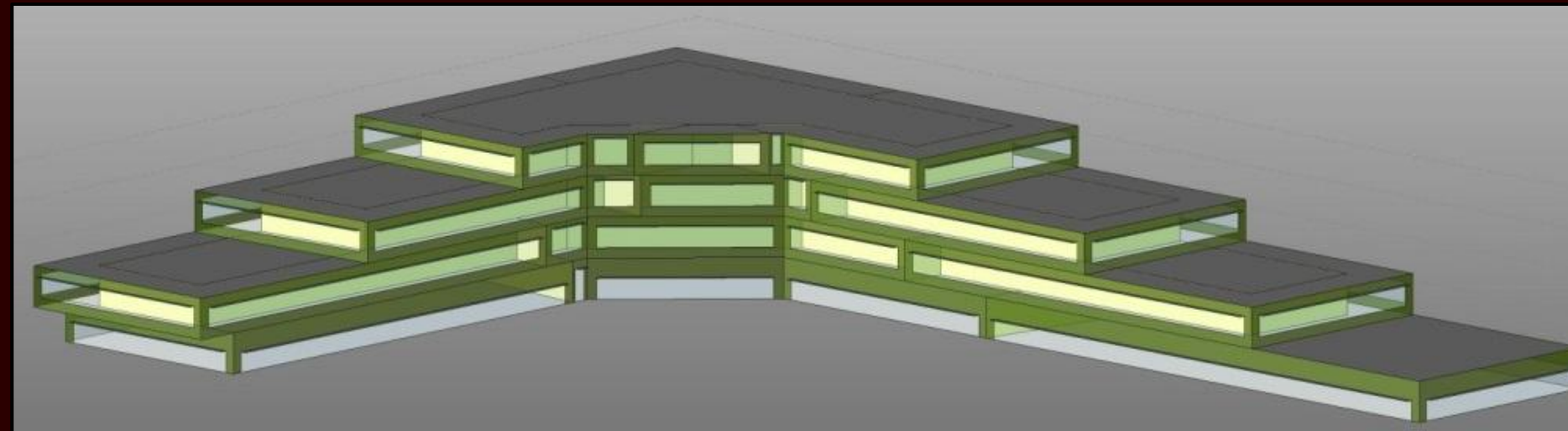


# Overhang Investigation: Project Vasari

Parameter	Value
<b>Common</b>	
Building Type	School or University
Ground Plane	Level 1
Location	40.8015937805176, -77.85958862304
<b>Detailed Model</b>	
Project Phase	New Construction
Sliver Space Tolerance	1' 0"
Export Complexity	Complex with Shading Surfa
<b>Energy Model</b>	
Create Energy Model	<input checked="" type="checkbox"/>
Core Offset	22' 0"
Divide Perimeter Zones	<input checked="" type="checkbox"/>
Conceptual Constructions	Edit...
Target Percentage Glazing	48%
Target Sill Height	5' 0"
Glazing is Shaded	<input checked="" type="checkbox"/>
Shade Depth	3' 0"
Target Percentage Skylights	0%
Skylight Width & Depth	3' 0"
<b>Energy Model - Building Services</b>	
Building Operating Schedule	12/6 Facility
HVAC System	Central VAV, HW Heat, Chiller 5.96
Outdoor Air Information	Edit...

Shade Depth

3' 0"



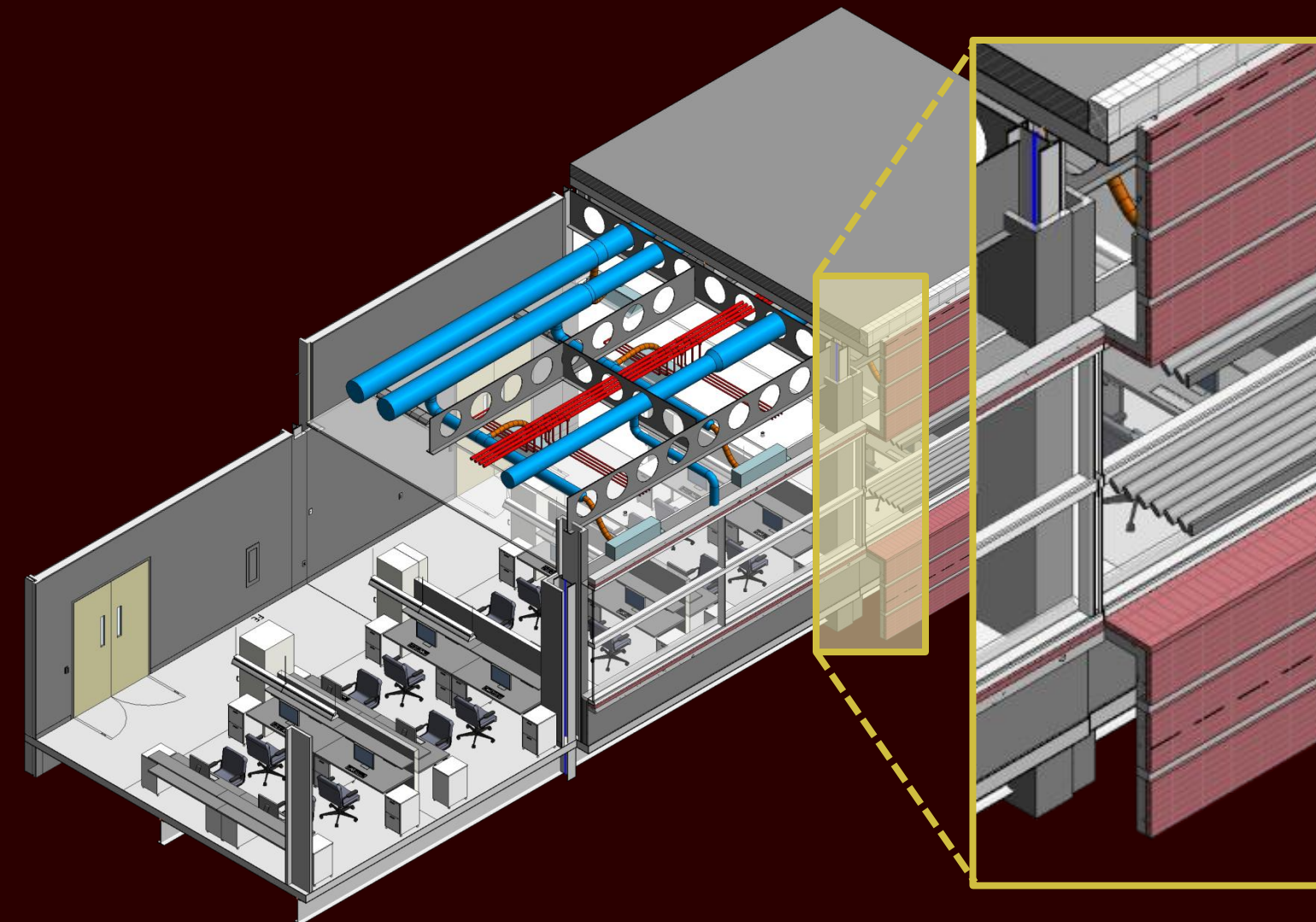
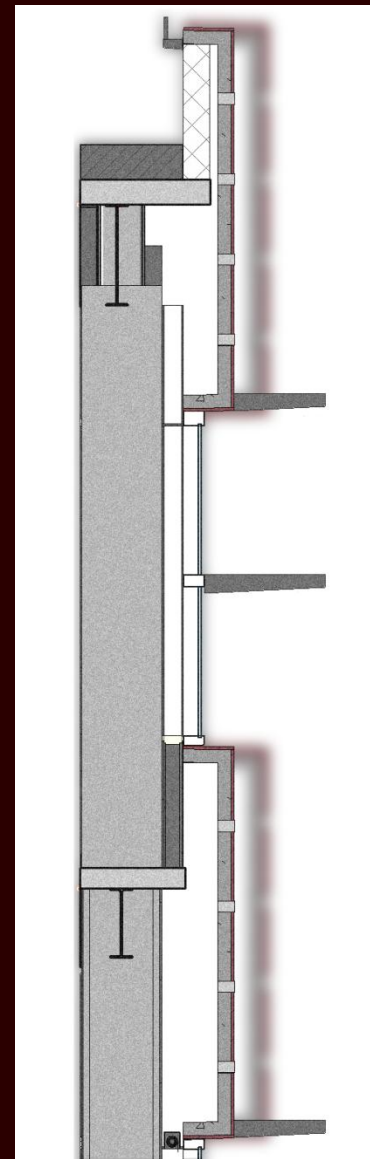
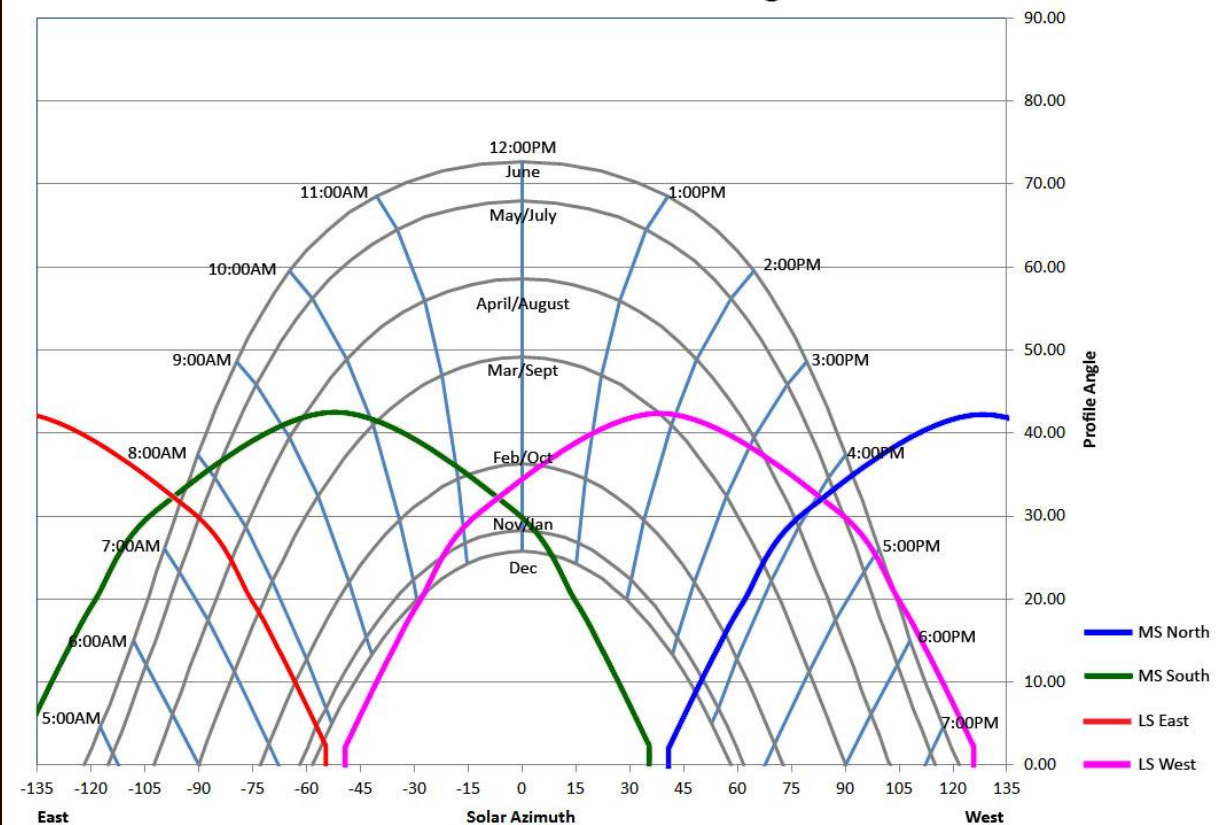
Mass Glazing

Triple Pane Clear - LowE Hot or Cold Climate

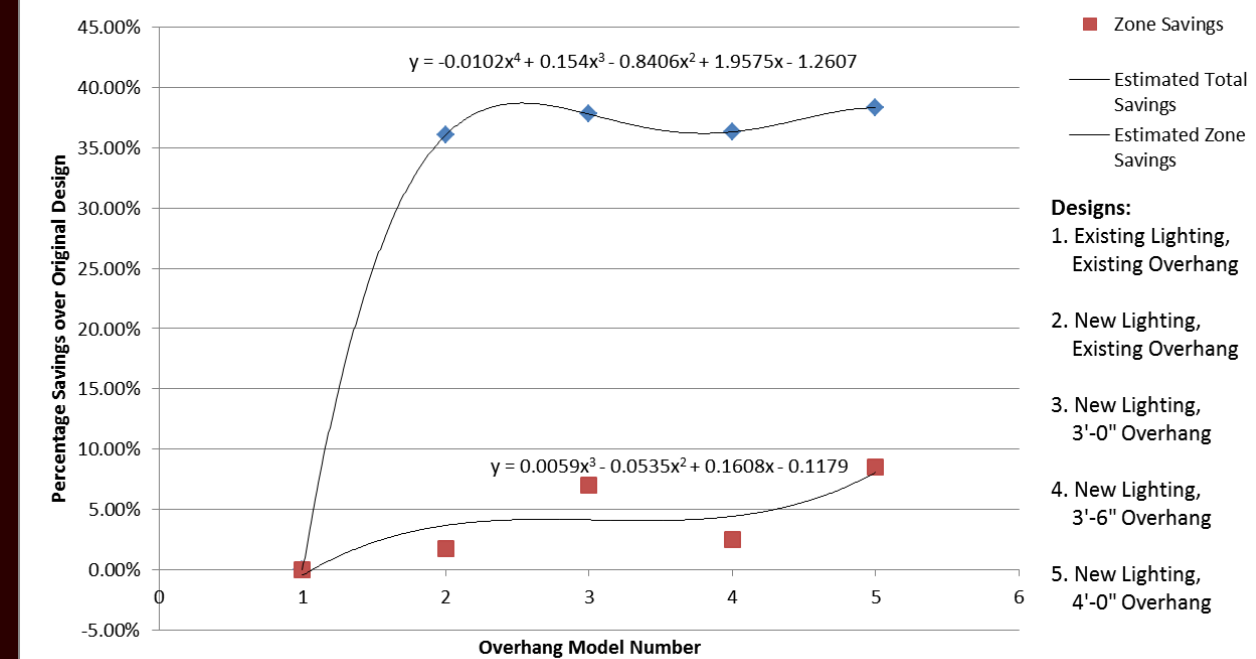
Mass Model	Constructions
Mass Exterior Wall	Lightweight Construction - Typical Mild Climate Insulati
Mass Interior Wall	Lightweight Construction - No Insulation
Mass Exterior Wall - Underground	High Mass Construction - Typical Mild Climate Insulatio
Mass Roof	Typical Insulation - Cool Roof
Mass Floor	Lightweight Construction - No Insulation
Mass Slab	High Mass Construction - No Insulation
Mass Glazing	Triple Pane Clear - LowE Hot or Cold Climate
Mass Skylight	Double Pane Clear - No Coating
Mass Shade	Basic Shade
Mass Opening	Air

# Overhang Investigation: Daysim

1'-0" Panel, 3'-0" Tot Overhang Profiles



Dimming System kWh Savings by Design



At 3'-0" the zone savings density is as follows:

Existing System 0.5905 kWh/SF applied to 14115 SF of perimeter area

3'-0" Overhang 0.5494 kWh/SF applied to 14115 SF of perimeter area

Total operating cost savings at \$0.08/kWh is **\$46.48** for Existing System the third floor perimeter spaces  
 Existing System 8335.34 kWh energy usage  
 3'-0" Overhang 7754.36 kWh energy usage

Net Difference 580.98 kWh energy usage  
 Applied building wide, the overhang saves mechanical operating costs by **\$23,088**

# Overhang Investigation: Operating Cost Findings

## Overhang and Glazing Analysis: Summary of Effect on HVAC Operating Cost

	Existing Glazing			Proposed Glazing			
	2.5	3	3.5	0	2.5	3	3.5
Overhang Depth							
TRACE Results	\$1,501,728	\$1,494,852	\$1,490,400	\$1,512,576	\$1,481,418	\$1,478,640	\$1,478,268
Decrease	-	0.45%	0.75%	-0.7%	1.35%	<b>1.53%</b>	1.56%
Vasari Results	\$953,470	\$952,430	\$951,956	\$888,241	\$884,272	\$883,823	\$883,286
Decrease	-	0.11%	0.16%	6.84%	7.26%	<b>7.30%</b>	7.36%

Design Overhang	Energy Savings (kWh)													% Savings
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
Actual Grand	135.01	112.46	118.70	107.26	123.12	117.71	117.71	123.17	113.72	127.98	128.93	125.25	1451.08	0.00%
New Grand	100.58	78.23	73.52	61.91	70.60	63.21	63.13	69.44	70.10	83.76	93.91	99.26	927.72	36.07%
3' Grand	97.35	75.36	70.71	60.18	68.73	62.67	62.82	67.96	67.78	81.56	91.47	96.10	902.75	37.79%
3.5' Grand	100.16	77.80	73.03	61.65	70.54	63.10	63.02	69.23	69.73	83.36	93.51	98.95	924.12	36.32%
4' Grand	96.29	74.55	70.08	59.68	68.31	62.60	62.78	67.51	67.09	80.87	90.47	95.06	895.33	38.30%
Actual Zone	49.61	38.20	37.02	33.01	37.73	36.03	36.03	37.78	35.75	42.59	47.24	47.28	478.33	0.00%
New Zone	60.40	43.29	35.08	26.96	30.42	24.77	24.69	29.25	33.41	43.58	55.47	62.57	469.95	1.75%
3' Zone	57.17	40.42	32.27	25.24	28.55	24.23	24.38	27.77	31.09	41.38	53.04	59.41	444.99	<b>6.97%</b>
3.5' Zone	59.97	42.86	34.59	26.70	30.35	24.66	24.58	29.05	33.04	43.17	55.07	62.26	466.36	2.50%
4' Zone	56.11	39.61	31.64	24.74	28.12	24.16	24.34	27.32	30.40	40.68	52.03	58.36	437.57	8.52%

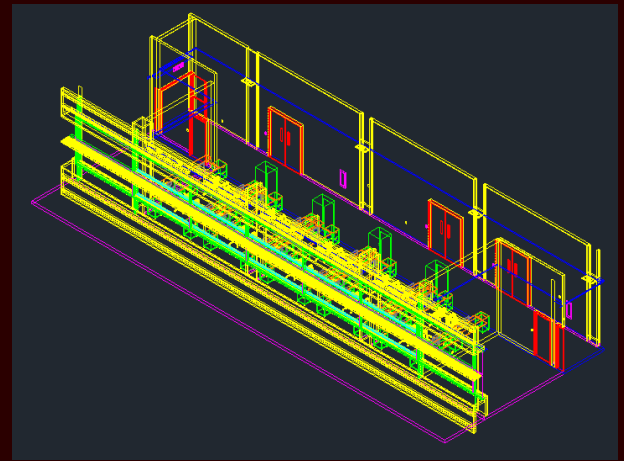
Design Overhang	Orientation Change Summary						
	MS South kWh from Table X	Mat. Science North		Life Science East		Life Science West	
	Total kWh	% of MS South	Total kWh	% of MS South	Total kWh	% of MS South	
Actual Grand Total	1451.08	1446.46	99.68%	1457.40	100.44%	1447.28	99.74%
Actual Zone Total	478.33	473.70	99.03%	484.65	101.32%	474.53	99.21%

# Impact on Lighting Design



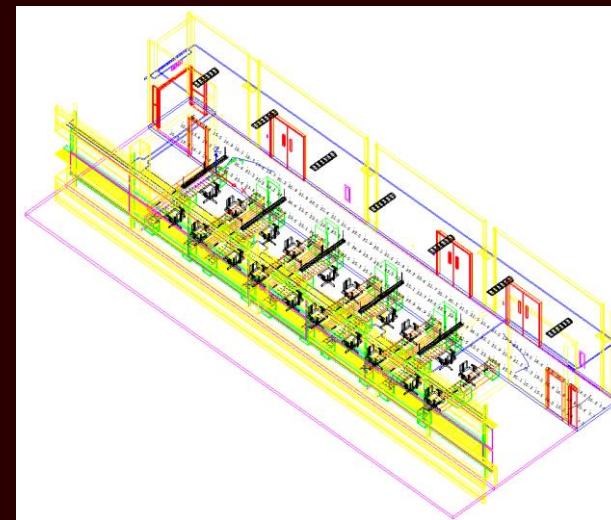
StudentExport.rvt

Export parameter change to "ACIS Solids"

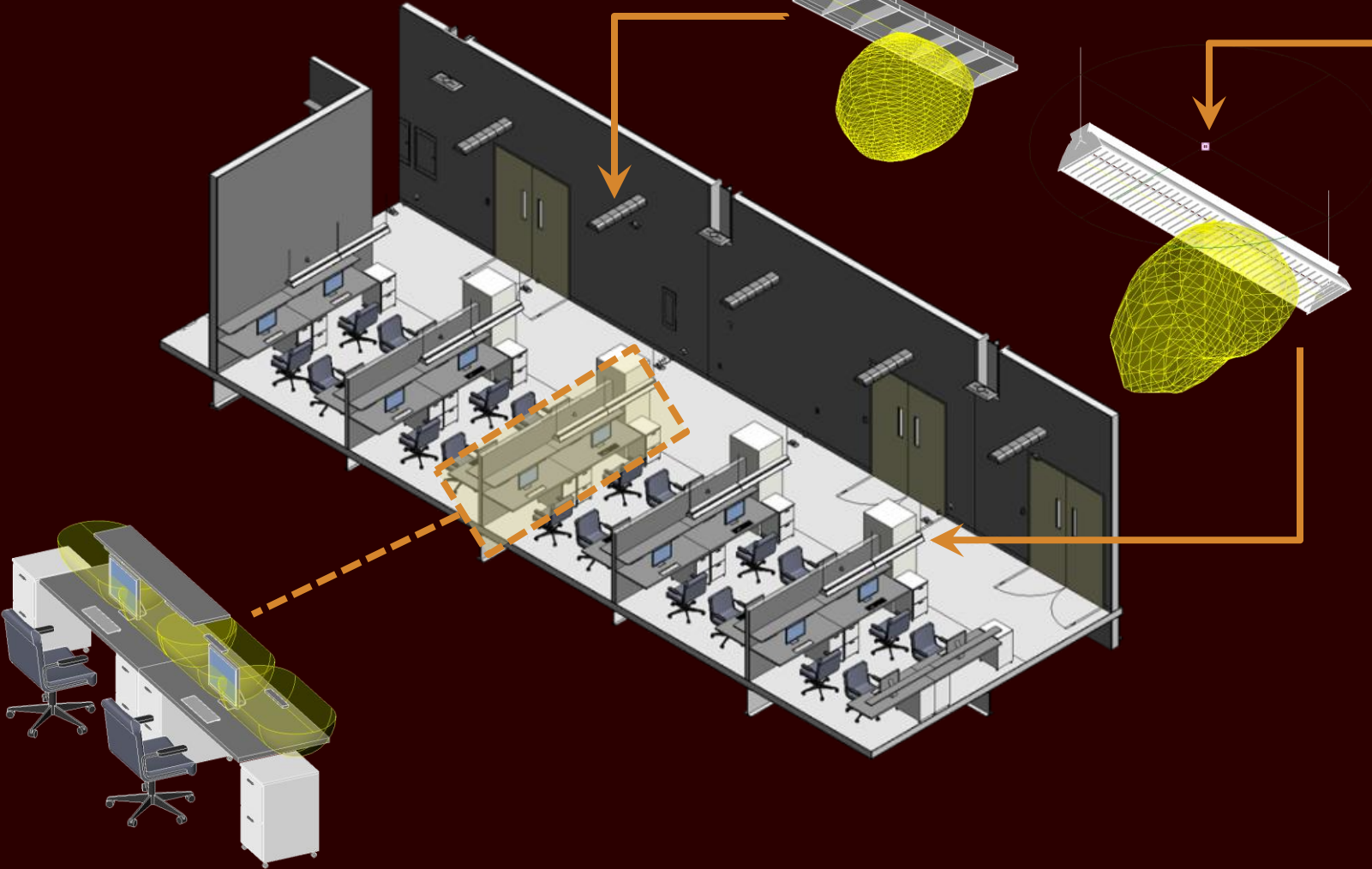


StudentExport.dwg

Import to AGI32 where material properties are assigned



StudentExport.AGI



Family Types

Parameter	Value	Formula	Lock
<b>Electrical - Loads</b>			
Apparent Lo	32.65 VA	=	
<b>Dimensions</b>			
Width	8.000	=	<input checked="" type="checkbox"/>
Length	48.000	=	<input checked="" type="checkbox"/>
Height	5.000	=	<input checked="" type="checkbox"/>
<b>Photometrics</b>			
Tilt Angle	-90.000°	=	<input checked="" type="checkbox"/>
Photometric	12-SDx-2x	=	
Light Loss Fa	0.88	=	
Initial Intensi	64.00 W @ 9	=	
Initial Color	4100 K	=	

Family Types: New..., Rename..., Delete

Parameters: Add..., Modify..., Remove

Buttons: OK, Cancel, Apply, Help

Fluorescent Dimming Ballasts EcoSystem® H-Series Architectural Dimming

**EcoSystem® H-Series Overview**

EcoSystem H-Series digitally addressable ballasts provide a low-cost, flexible solution for any space in any application. Industry leading dimming to less than 1% meets the needs of the most demanding applications. Individual control with the EcoSystem Digital Link eliminates the need to rewire, reduces design time, and provides a scalable solution from a small area to an entire building.

**Features**

- Continuous, flicker-free dimming from 100% to <1% for T8, and 1% for T5 and T5HO lamps
- Compatible with EcoSystem Energy Savr Node®, GRAFIK Eye® QS, and Quantum®, allowing for integration into an existing/planned EcoSystem lighting control solution
- Design preheats lamp cathodes by applying full arc voltage to ensure full-rated lamp life during starting and cycling
- Lamps turn on in many dimmed levels without flashing to full brightness
- Low harmonic distortion throughout the entire dimming range maintains power quality
- Frequency of operation ensures that ballast does not interfere with infrared devices operating between 38 and 42 KHz
- Ballasts maintain consistent light output for different lamp lengths, ensuring fixture-to-fixture uniformity
- Ultra-quiet operation
- Protected from miswiring of any input power to control lead or from lamp leads to each other and/or ground

**EcoSystem H-Series, case type C**  
1.18 in. W (30 mm) x 1.00 in. H (25 mm) x 18.00 in. L (457 mm)

**LITECONTROL** Fixture Type: S-1  
Project Name: Penn State MSC

**SDX™**  
P-S/D-1800, S-S/D-1800  
Recessed Mounted Semi-Direct  
Surface Mounted Semi-Direct

**Product Description**  
Estimated aluminum semi-direct fixture with tapered end-ground plate. This fixture is CULIE to CULIE Certified™ by UL.

**Ordering Guide**

Ordering	Product	Length	Mounting	Options
Recessed	SDX	1800	Surface	Standard
Surface	SDX	1800	Surface	Standard

**Options**

Option	Description	Code
Ballast	Ballast	Ballast
Dimming	Dimming	Dimming
Color	Color	Color
Other	Other	Other

**Notes**

1. See notes on page 18 for fixture details and options.

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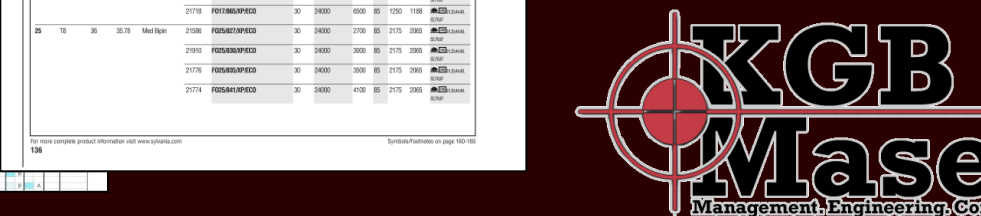
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# Impact on Lighting Design

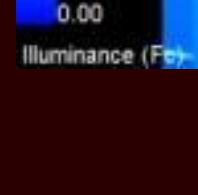
Study Area Illuminance Summary						
Space	Illuminance (fc)			Max./Min.	Coeff. Of Variation	Uniformity Gradient
	Min.	Avg.	Max.			
Study Area Only	9.0	36.5	106.0*	11.73	0.47	2.47
Corridor Only	4.5	9.36	10.8	2.40	0.15	1.31
Student Area Combined	15.0	34.3	55.0	3.67	0.27	1.42
Corridor Combined	7.3	20.0	25.3	3.47	0.23	1.38



2



2



1



1

## Existing Conditions

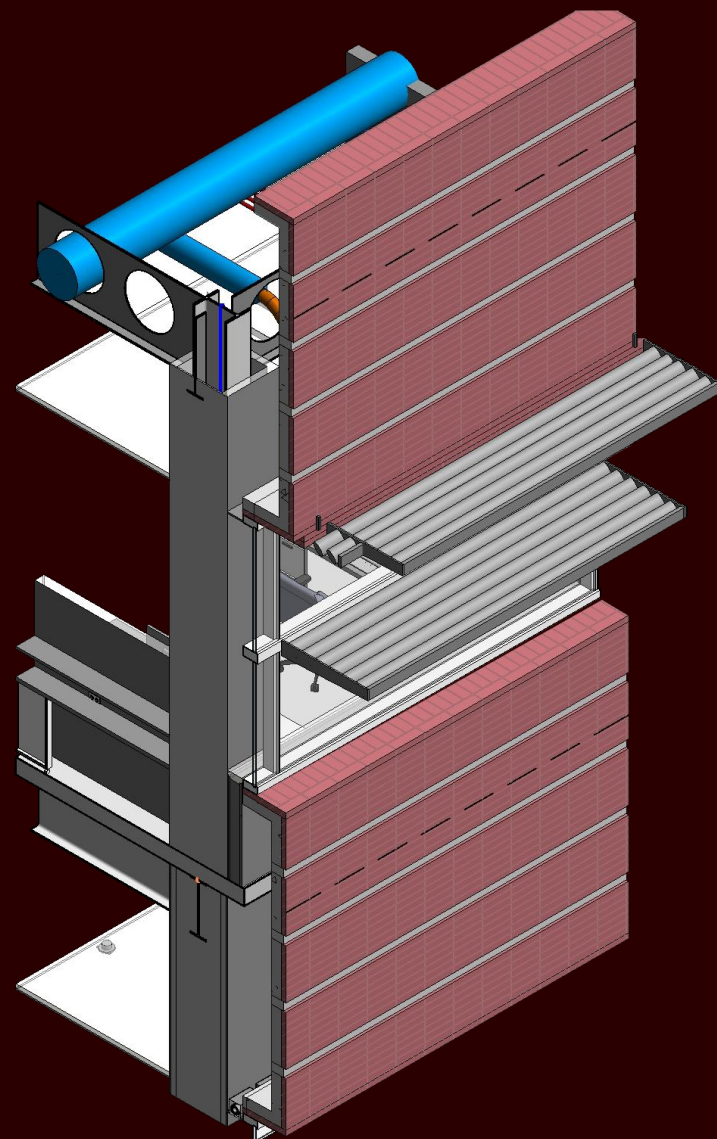
- **27.6" Deep**
- 6" Thick Concrete at Face
- **2" Facebrick**
- Largest Panel 21ft. Wide by 11ft. Tall

**Gravity Controlled** Design

- Prone Position Causes Greatest Stress
- 2 Bearing Connections at Either End
- 2 Lateral Connections at Either End

Cracking Stress			
(factored)	477.2971	psi	
Self Weight Check Prone			
Weight/in.	8.53125	lb./in.	(factored)
Inertia of Strip	76.765625	in.4	
Moment	16695.94	lb.in.	
Stress	462.17134	psi.	OK

## Panel Depth Assessment



## Existing Conditions

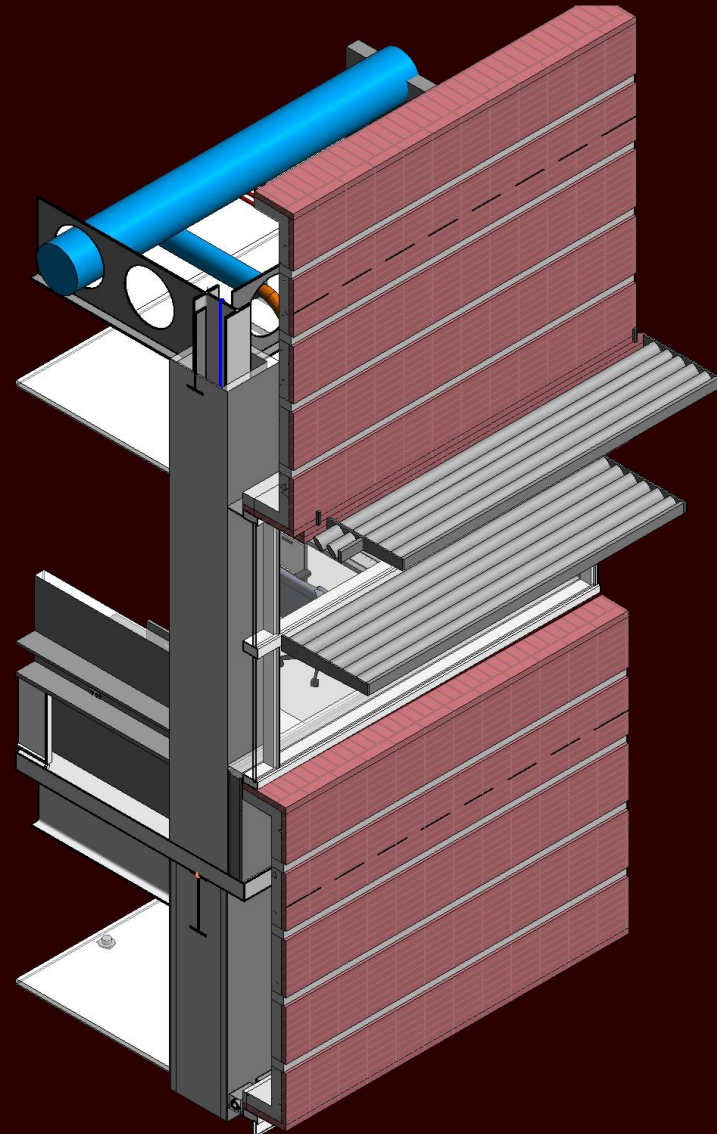
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- Prone Position Causes Greatest Stress
- 2 Bearing Connections at Either End
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Cracking Stress			
(factored)	477.2971	psi	
Self Weight Check Prone			
Weight/in.	8.53125	lb./in.	(factored)
Inertia of Strip	76.765625	in.4	
Moment	16695.94	lb.in.	
Stress	462.17134	psi.	OK

## Panel Depth Assessment



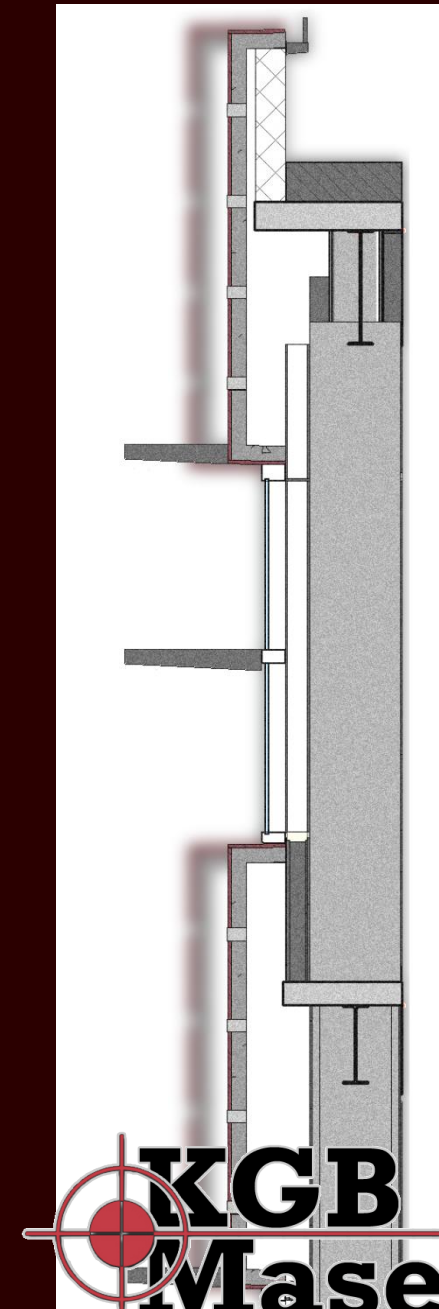
## Redesign

- **15.75" Deep**
- 5" Thick Concrete at Face
- **1/2" Facebrick**
- Largest Panel 21ft. Wide by 11ft. Tall

**Wind Controlled** Design

- Prone Position Causes Greatest Stress
- 2 Corbel Connections at Either End
- 2 Lateral Connections at Either End

Required Steel	
Vu.max=	189 k.
As.req=	0.44 in.2
$\mu_e$ =	3.4
As.req=	0.32 in.2
As.min=	0.77 in.2
As=	0.77 in.2
Ah=	0.30 in.2
Ldh=	8.91 in.



# Cost Assessment

Properties

Stacked Wall  
Exterior - Brick Over Precast Return 1

Stacked Walls (1) Edit Type

Constraints	
Location Line	Wall Centerline
Base Constraint	SECOND FLOOR
Base Offset	-8' 8 5/8"
Base is Attached	<input type="checkbox"/>
Base Extension Distance	0' 0"
Top Constraint	Up to level: SECOND FLOOR
Unconnected Height	11' 8 5/8"
Top Offset	3' 0"
Top is Attached	<input type="checkbox"/>
Top Extension Distance	0' 0"
Related to Mass	<input type="checkbox"/>

Existing Pre-Cast							
Total (SF)	Material	Labor	Equipment	Total	Cost	Time	O & P
72319.11	27.3	1.74	1.63	30.67	\$2,218,027	\$2,816,894	\$3,295,766
				<b>TOTAL COST = \$3,295,766.47</b>			
Redesign Pre-Cast							
Total (SF)	Material	Labor	Equipment	Total	Cost	Time	O & P
72319.11	25.03	1.74	1.63	28.4	\$2,053,862	\$2,608,405	\$3,051,834
				<b>TOTAL COST = \$3,051,834.62</b>			

**Cost Savings = \$240,000**

Dimensions	
Length	363' 0"
Area	4253.91 SF
Volume	

Phase Demolished	None
Analytical Model	
Enable Analytical Model	<input checked="" type="checkbox"/>
Horizontal Projection	Auto-detect
Top Vertical Projection	Auto-detect
Bottom Vertical Projection	Auto-detect

Properties help Apply



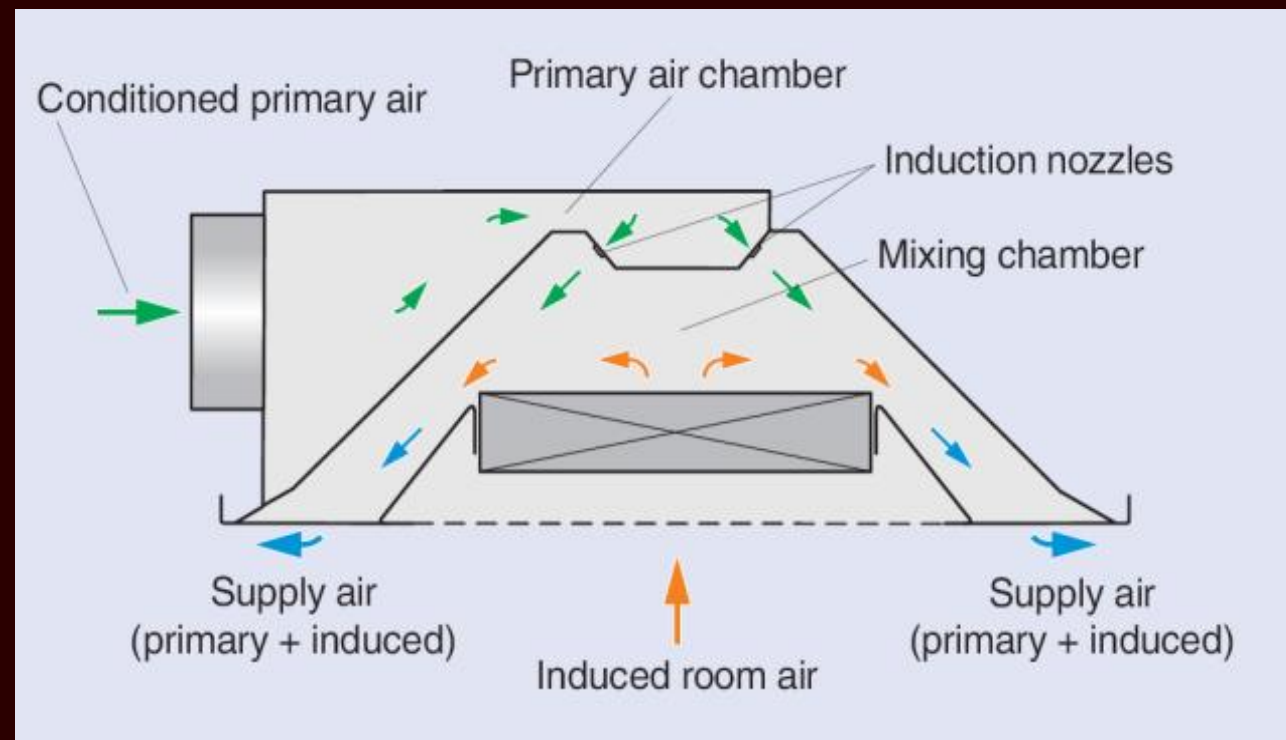
## Existing VAV Distribution System

Energy efficient design that can be **easily controlled** to space airflow needs

**Familiar system** for designers and contractors

**Less pumping energy** required

## Existing vs. Proposed Distribution



## Proposed Active Chilled Beam Distribution System

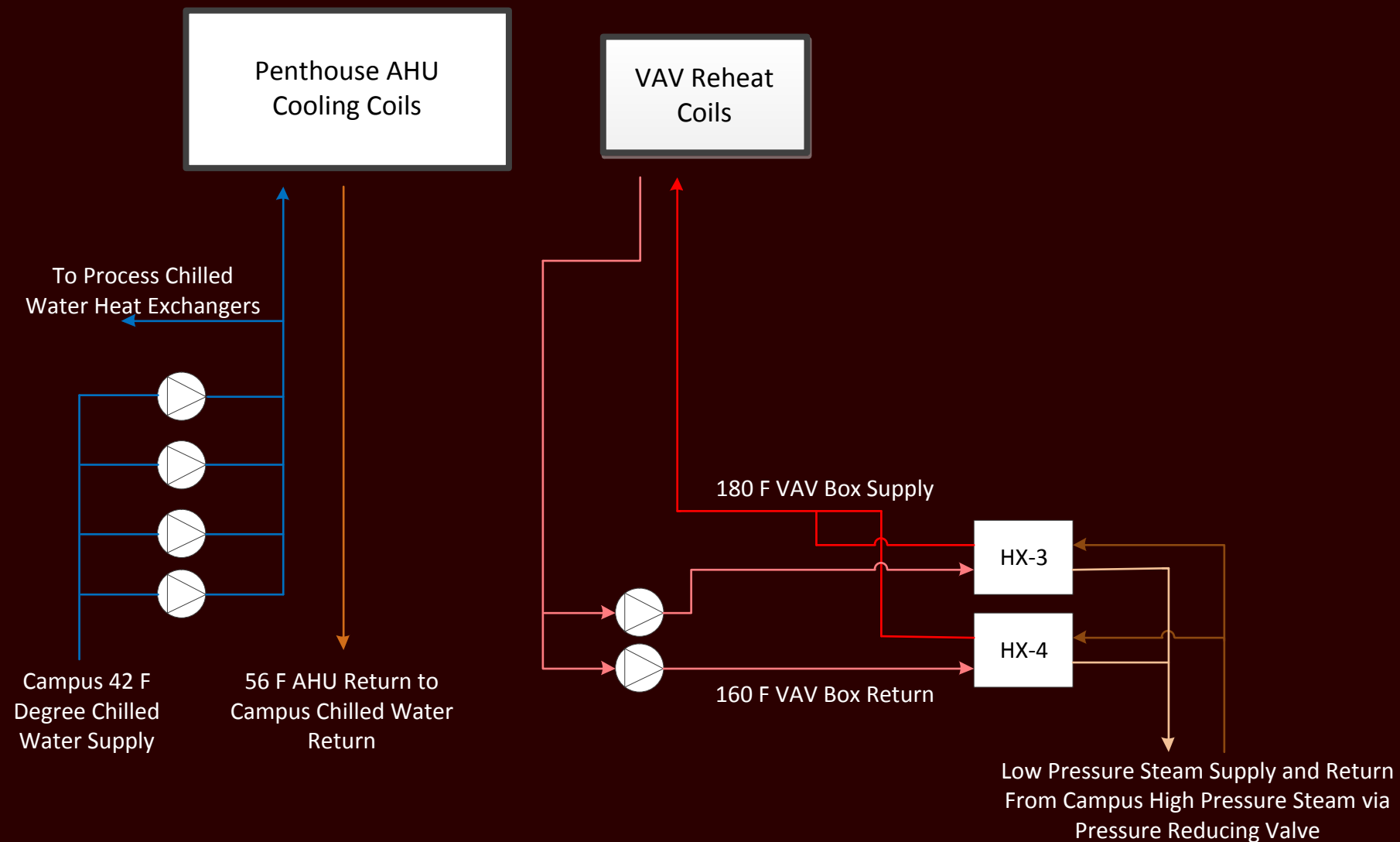
Takes advantage of the higher **specific heat capacity of water**

**More concern** for handling **latent** loads

Higher **initial cost**

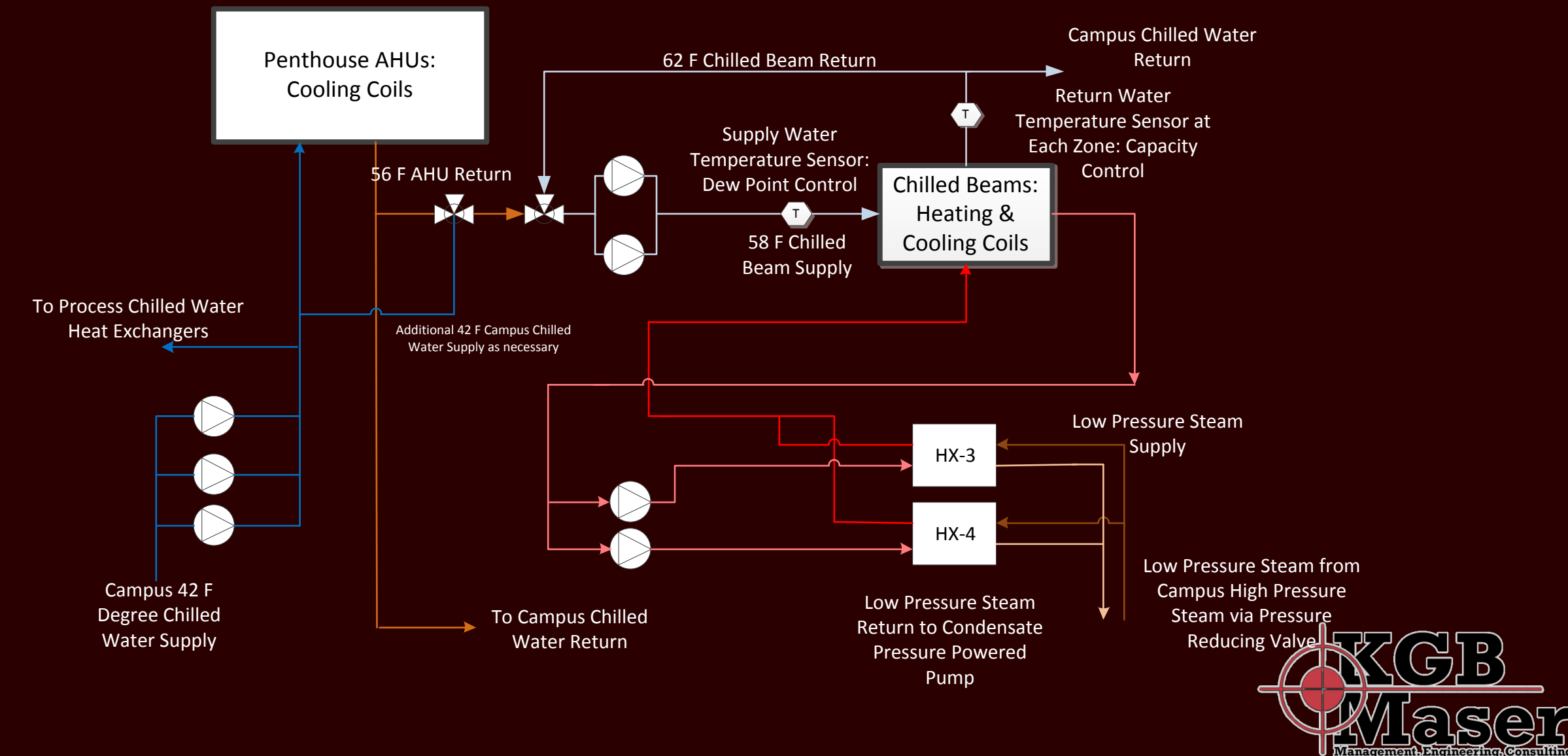
**Fan energy saved**, pumping energy increased

## Existing VAV Water Flow Diagram



## Existing vs. Proposed Distribution

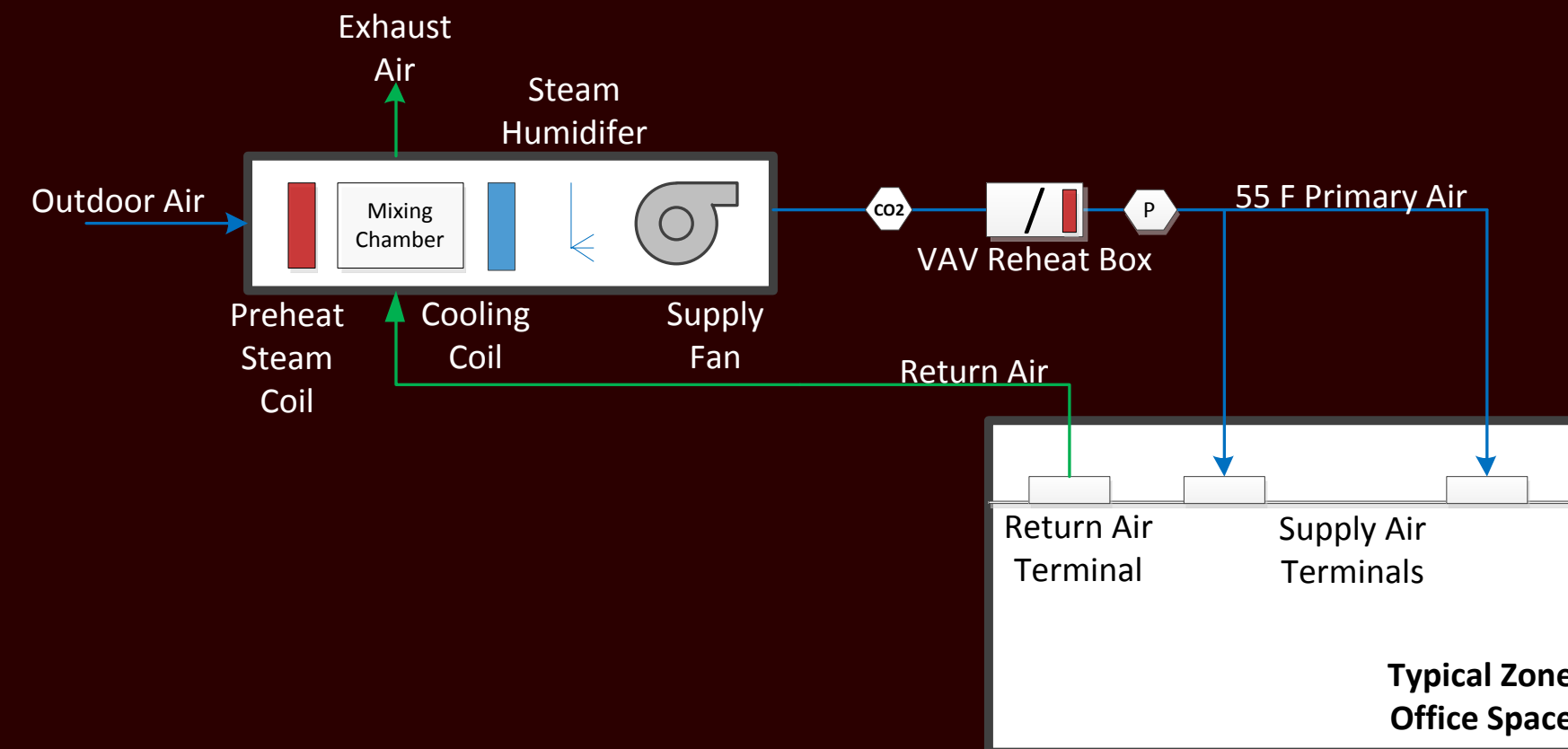
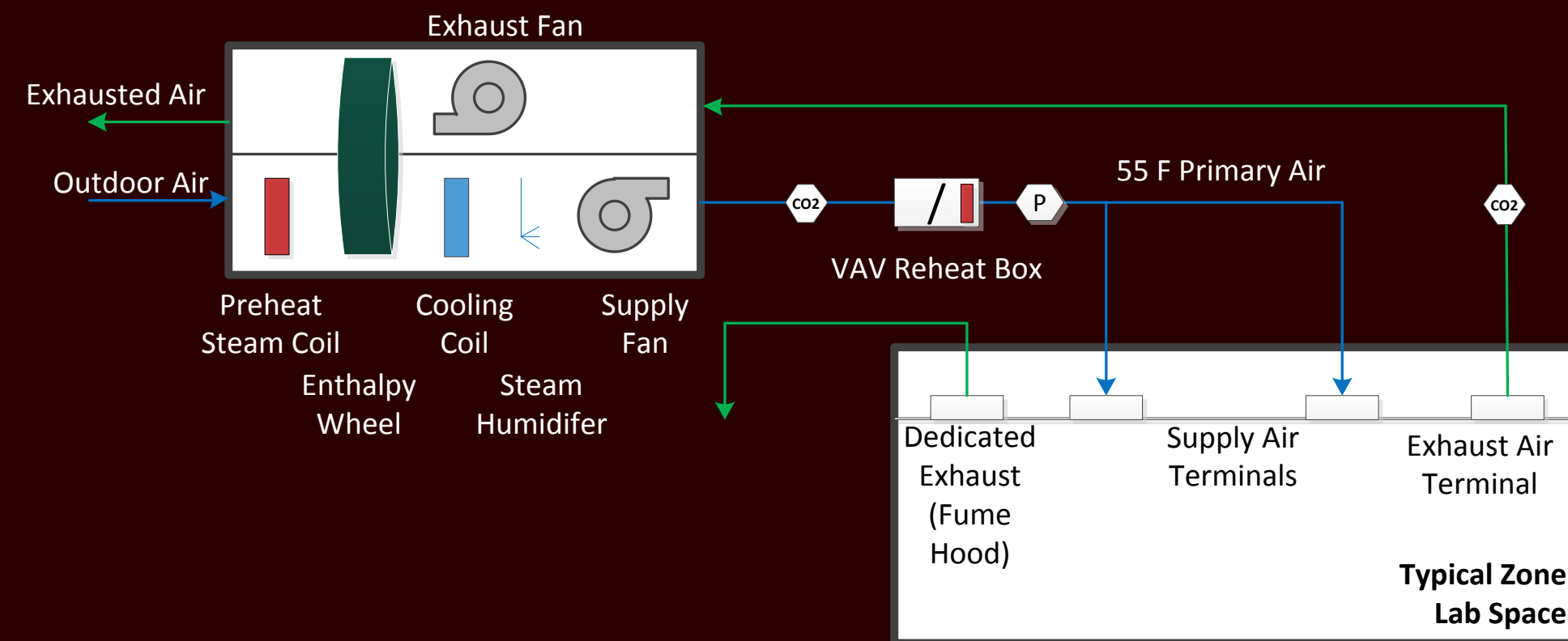
## Proposed Chilled Beam Water Flow Diagram



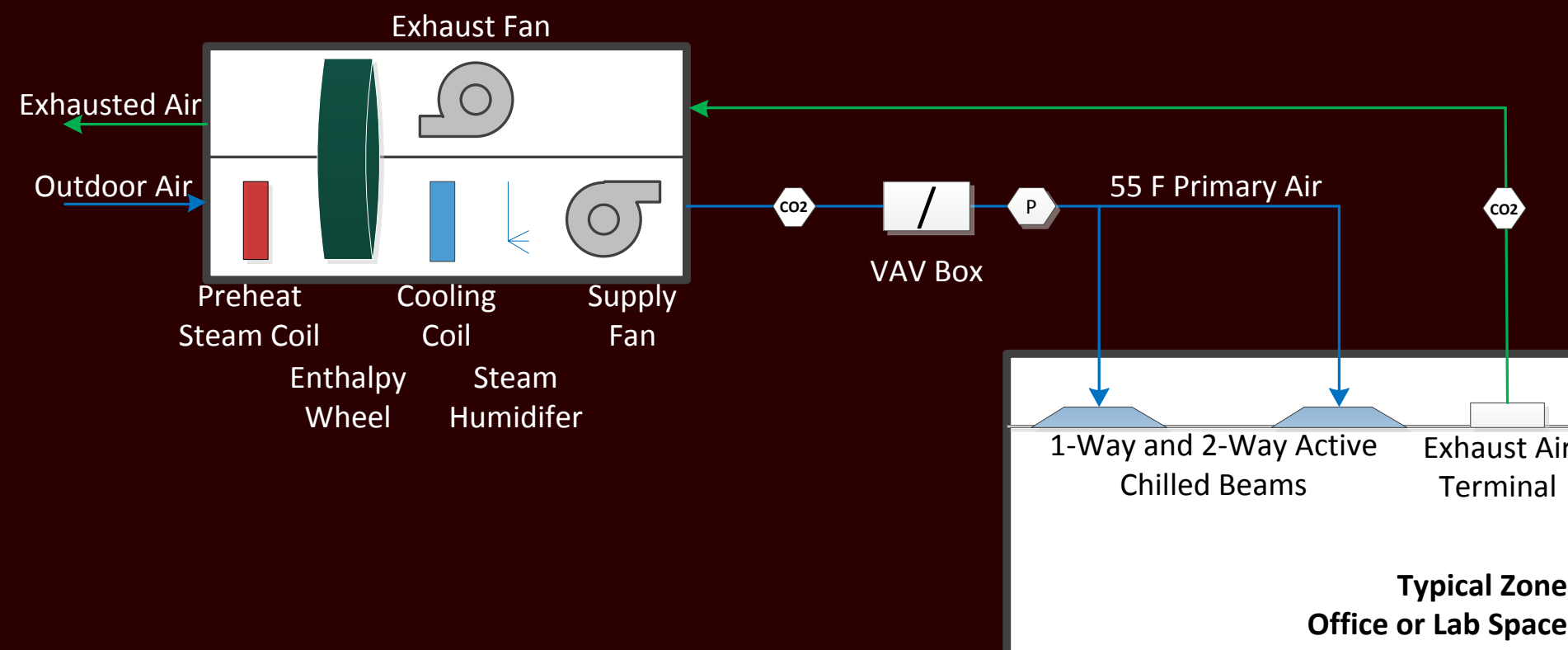
## Existing Lab VAV Air Flow Diagram

## Existing vs. Proposed Distribution

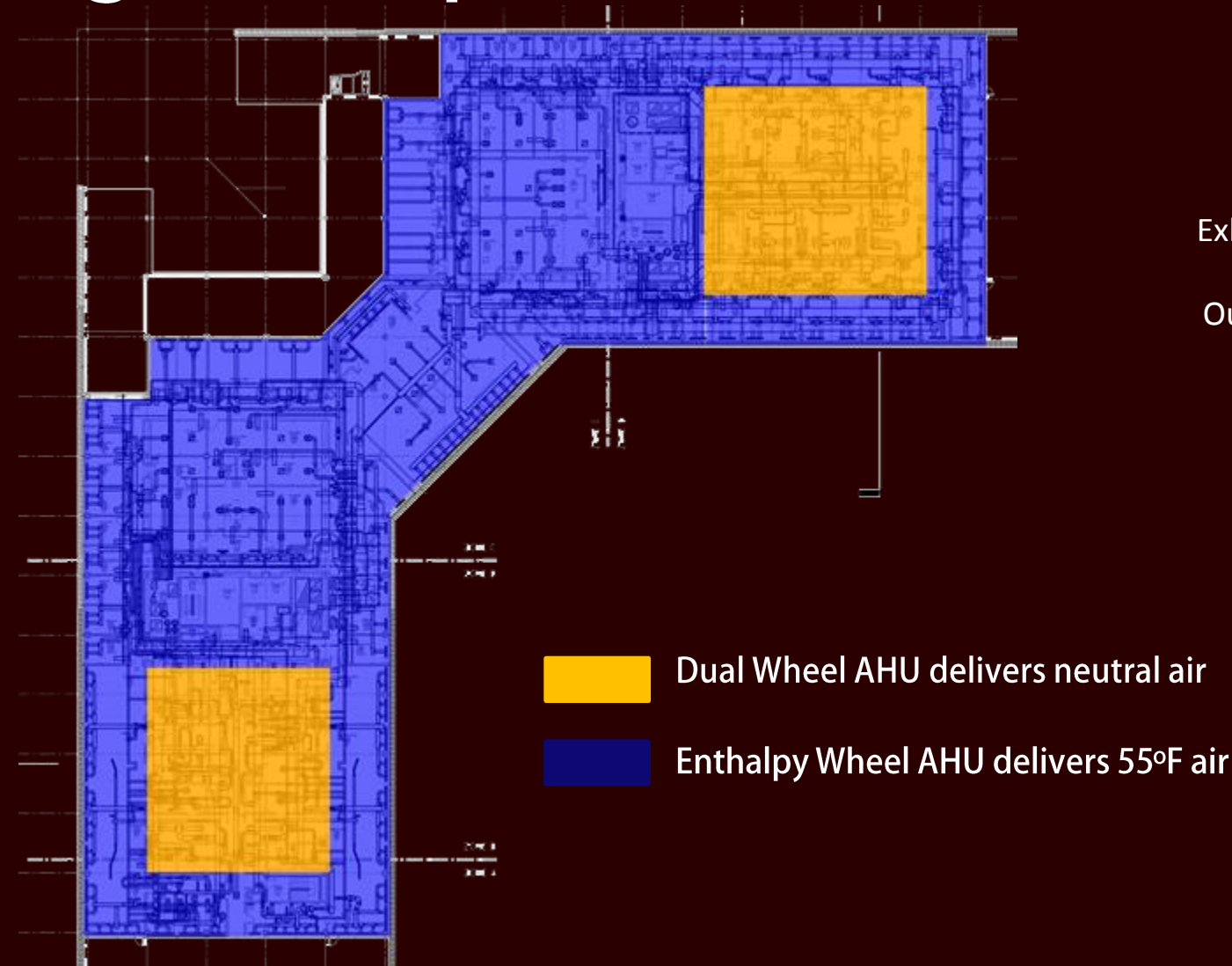
## Existing Office VAV Air Flow Diagram



## Perimeter Zone Chilled Beam Air Flow Diagram



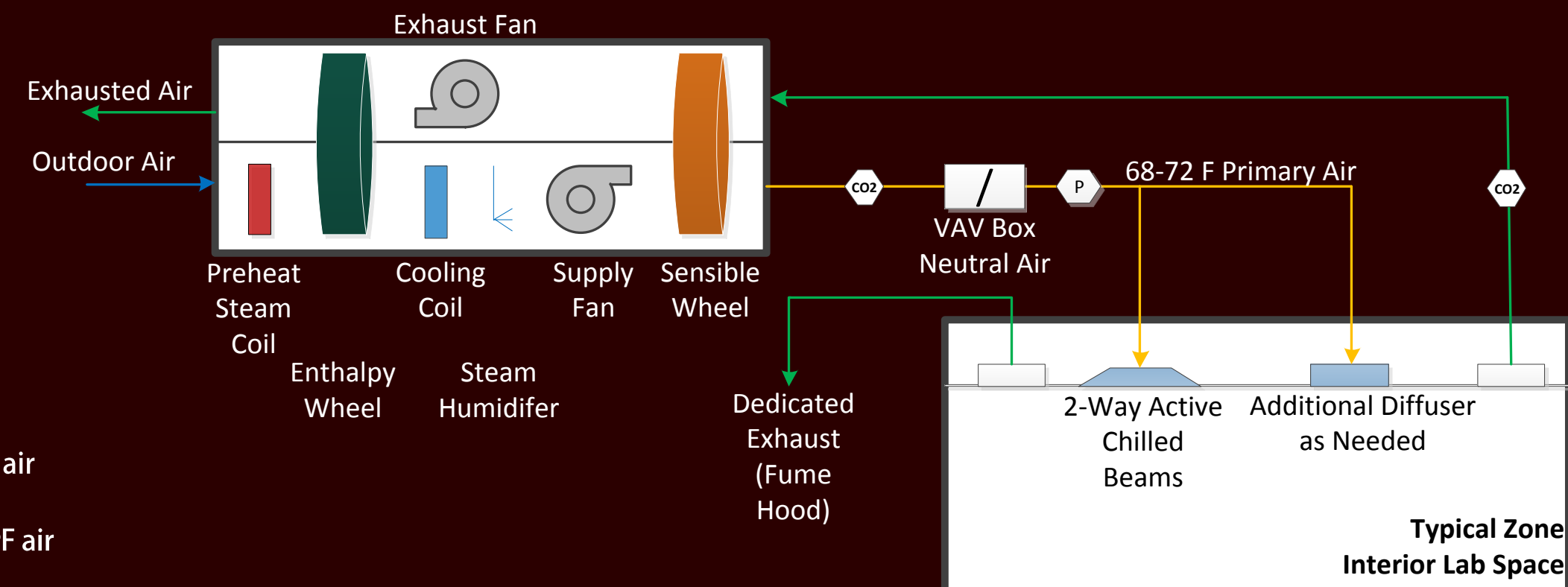
## Existing vs. Proposed Distribution



■ Dual Wheel AHU delivers neutral air

■ Enthalpy Wheel AHU delivers 55°F air

## Interior Lab Chilled Beam Air Flow Diagram



# Active Chilled Beam Design Process

1. Obtain room loads from Trane TRACE updated model

2. Compare ventilation needs: ASHRAE 62.1, Latent, Air Changes

3. Select Chilled Beam Manufacturer

Room Checksums  
By ACADEMIC

sp-N-337-Faculty

COOLING COIL PEAK				CLG SPACE PEAK				HEATING COIL PEAK				TEMPERATURES			
Peaked at Time: Mo/Hr: 7/8				Mo/Hr: 8/9				Mo/Hr: Heating Design				Cooling			
Outside Air: OADB/WBHR: 78/69/92				OADB: 73				OADB: 11				SADB: 55.0			
												Heating: 74.0			
												Ra Plenum: 75.3			
												Return: 75.3			
												65.5			
												65.5			
Envelope Loads	Space	Plenum	Net	Percent	Space	Percent	Space	Percent	Space	Percent	Space	Percent	Space	Percent	
Skylite Solar	Sens	Sens	Total	Of Total	Sens	Of Total	Sens	Of Total	Sens	Of Total	Sens	Of Total	Sens	Of Total	
Skylite Cond	Lat	Lat	Btu/h	(%)	Btu/h	(%)	Btu/h	(%)	Btu/h	(%)	Btu/h	(%)	Btu/h	(%)	
Roof Cond	0	0	0	0	0	0	0	0	0	0	0	0	0		
Glass Solar	6,970	-23	6,970	85	7,415	85	7,415	85	7,415	85	7,415	85	7,415	85	
Glass/Door Cond	202	0	202	2	-155	2	-155	2	-155	2	-155	2	-155	2	
Wall Cond	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Partition/Door	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Adjacent Floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Infiltration	131	0	131	1	-8	1	-8	1	-8	1	-8	1	-8	1	
Sub Total ==>	7,303	-23	7,280	58	7,252	58	7,252	58	7,252	58	7,252	58	7,252	58	
Internal Loads	Space	Plenum	Net	Percent	Space	Percent	Space	Percent	Space	Percent	Space	Percent	Space	Percent	
Lights	472	118	590	5	472	5	472	5	472	5	472	5	472	5	
People	8,835	0	8,835	70	4,508	70	4,508	70	4,508	70	4,508	70	4,508	70	
Misc	258	0	258	2	258	2	258	2	258	2	258	2	258	2	
Sub Total ==>	9,575	118	9,693	77	5,648	77	5,648	77	5,648	77	5,648	77	5,648	77	
Ceiling Load	Space	Plenum	Net	Percent	Space	Percent	Space	Percent	Space	Percent	Space	Percent	Space	Percent	
Ventilation Load	67	-67	0	0	49	0	49	0	49	0	49	0	49	0	
Adj Air Trans Heat	0	0	-5,288	-42	0	0	0	0	0	0	0	0	0	0	
Dehumid. Ov Sizing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ov/Undr Sizing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Exhaust Heat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sup. Fan Heat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ret. Fan Heat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Duct Heat Pkup	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Underfir Sup Ht Pkup	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Supply Air Leakage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Grand Total ==>	16,945	-296	12,610	100.00	12,950	100.00	12,950	100.00	12,950	100.00	12,950	100.00	12,950	100.00	

Export gbXML - Settings

General Details

Rooms Analytical Surfaces

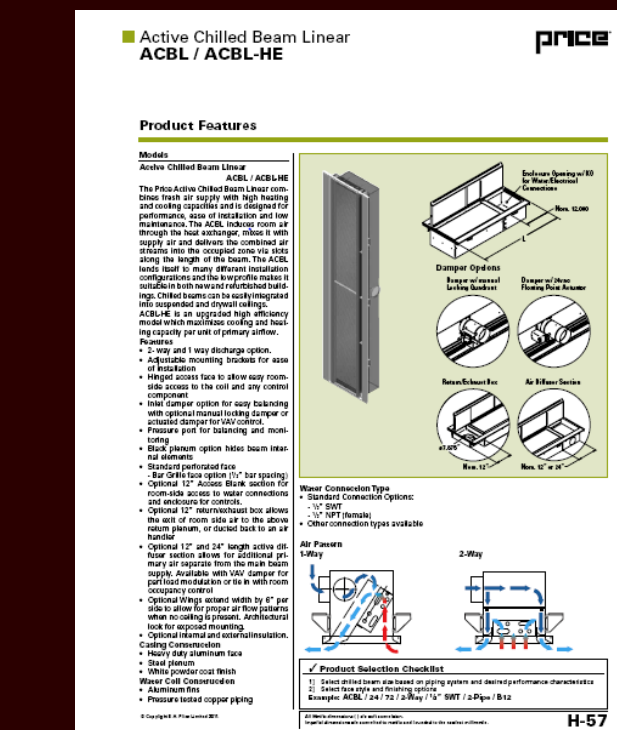
- Building Model
  - BASEMENT
  - BASEMENT MEZZ
  - FIRST FLOOR
  - SECOND FLOOR
  - THIRD FLOOR
  - MECHANICAL PENTHOUSE
  - ROOF

Next... Save Settings Cancel

Office:  $0.06 * SF + 5 * People$   
 Labs:  $0.18 * SF + 10 * People$

$$Q_{Latent\ CFM} = \frac{q_{latent}}{(0.68 \times (W_{room} - W_{Primary}))}$$

6 Air Change Minimum for Lab Spaces

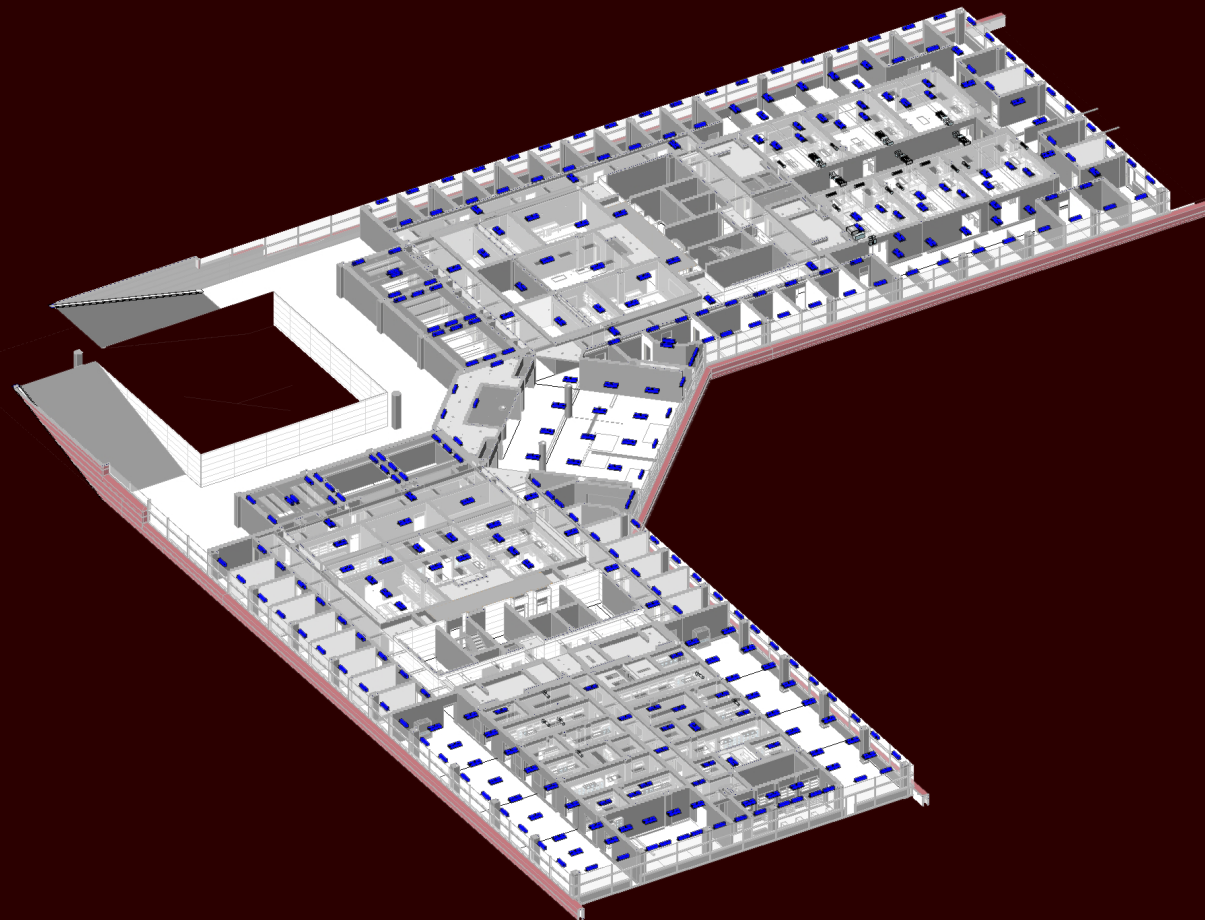


# Active Chilled Beam Design Process

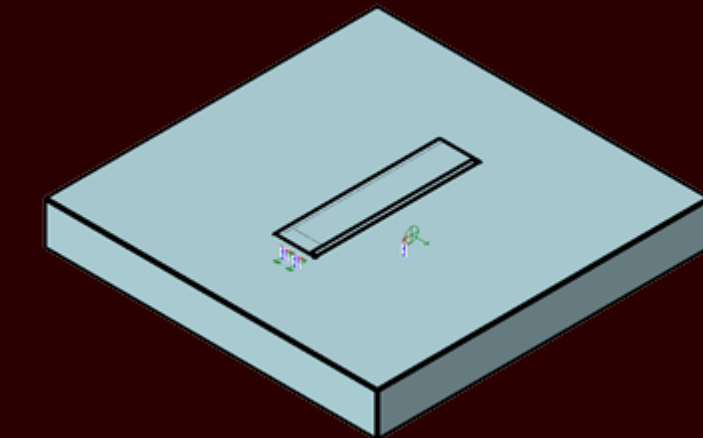
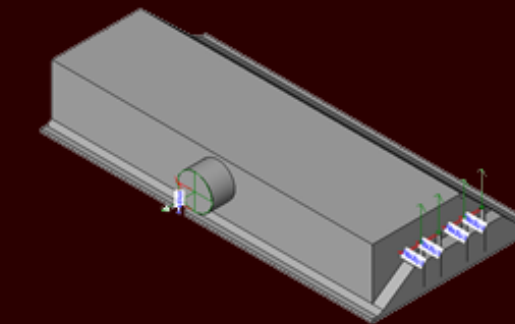
## 4. Reference RCP & Manufacturer Selection Spacing Program

DID 632 Two Way Active Chilled Beam Selection Program								
Input DID	4 pipe coil		2 pipe coil		Project	Room-No.	Comment	
	cooling	heating	cooling	heating				
Vwater DID	1.25 GPM	1.25 GPM	1.00 GPM	0.80 GPM				
Unit length	4.0 ft							
Nozzle-type	U							
Vair-primary DID	140.0 CFM							
Connection-diameter / primary air	6 in							
Input Temperatures		cooling		heating		Input Room Dimensions		
Tair-primary	55.0 °F		55.0 °F		Room Height (H)	11.0 ft		
Troom / rel. Humidity	75.0 °F	53.0 %	70.0 °F	50.0 %	A	12.0 ft		
Twater-flow	58.0 °F		95.0 °F		X	10.0 ft		
					Occupied Zone Height	6.0 ft		
<b>TROX® TECHNIK</b> The art of handling air								
Results		4 pipe coil		2 pipe coil				
	cooling	heating	cooling	heating				
Δtwater	-4.9 °F	5.9 °F	-6.7 °F	14.8 °F				
Twater-return	62.9 °F	89.1 °F	64.7 °F	80.2 °F				
ΔT room - water flow	-17.0 °F	25.0 °F	-17.0 °F	25.0 °F				
ΔT Room water average	-14.5 °F	22.0 °F	-13.7 °F	17.6 °F				
Qwater DID	-3085 BTUH	3694 BTUH	-3332 BTUH	3705 BTUH				
Qair DID	-3048 BTUH	-2297 BTUH	-3048 BTUH	-2297 BTUH				
Q DID	-6133 BTUH	1398 BTUH	-6380 BTUH	1408 BTUH				
ΔP water	1.7 ft WG	2.0 ft WG	4.8 ft WG	1.4 ft WG				
ΔP air	0.68 inch WG							
NC (incl. 10 dB room absorption)	30							
<b>NOTE: This calculation program is only applicable to DID632 beams manufactured by TROX USA.</b>								
Terminal Velocities and Temperatures				Support Values		TROX USA, Inc 4305 Settlebottom Circle Cumming, GA 30028 Phone: (770) 569-1433 Fax: (770) 569-1435 www.TROXUSA.com Version 1.8 1/21/2011		
ΔL2 (measured 2" from wall)	91 FPM	64 FPM	91 FPM	64 FPM	N-nozzles total			90
ΔL6 (measured 6" from wall)	55 FPM	38 FPM	54 FPM	38 FPM	Aeff			0.046295 ft²
ΔH1	53 FPM		53 FPM		v <sub>eff</sub>			3024 FPM
ΔTL	-1.7 °F	0.1 °F	-1.6 °F	0.1 °F	H1			5.0 ft
ΔTH1	-0.8 °F		-0.7 °F		L			15.0 ft
ΔTsupply	-15.8 °F	2.8 °F	-15.1 °F	2.8 °F	room air dew point-cooling			56.7 °F
Connection-diameter / primary air	DID632-HC		DID632-US					
Text in red represents a value that is not generally recommended (see user notes for details).								

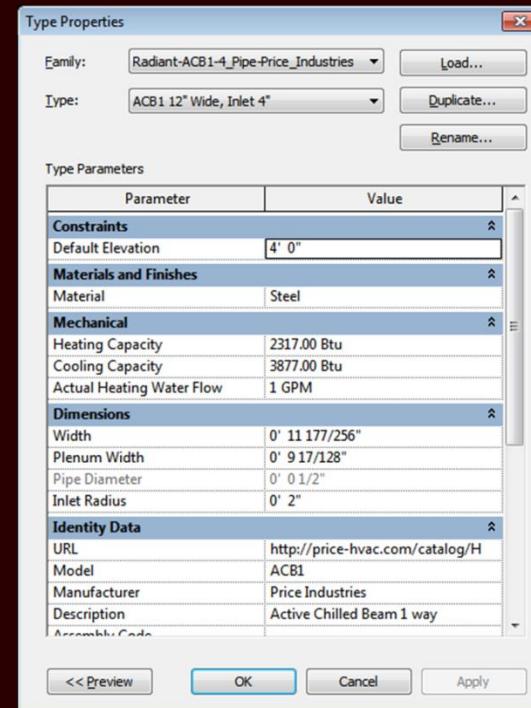
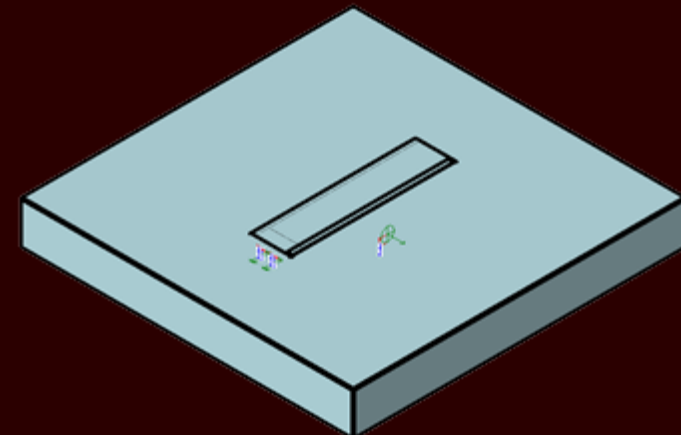
## 5. Use RCP to place beams in space in Revit MEP model



## 6. Adjust Chilled Beam Families in Revit



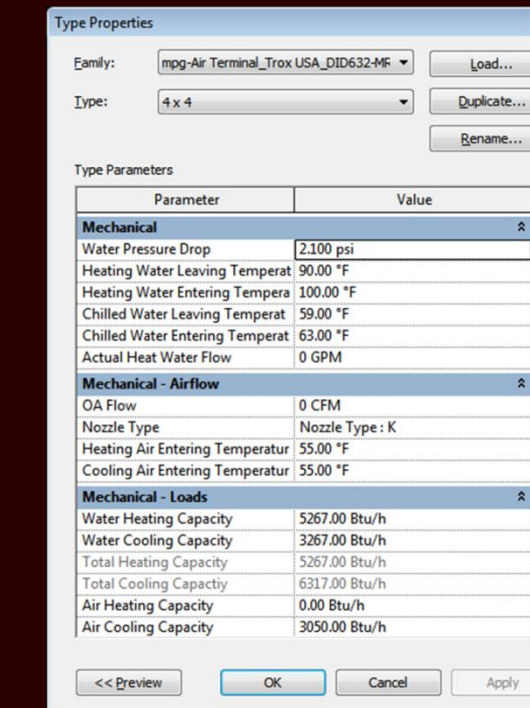
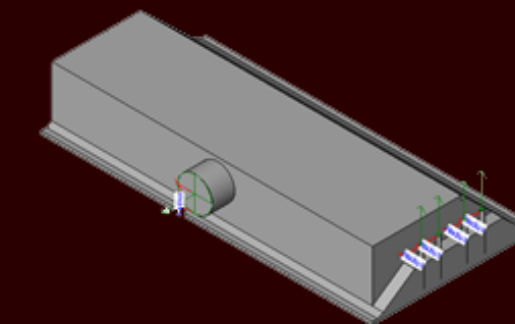
# Active Chilled Beam Design Process



## Summary of TROX Chilled Beam Adjustments

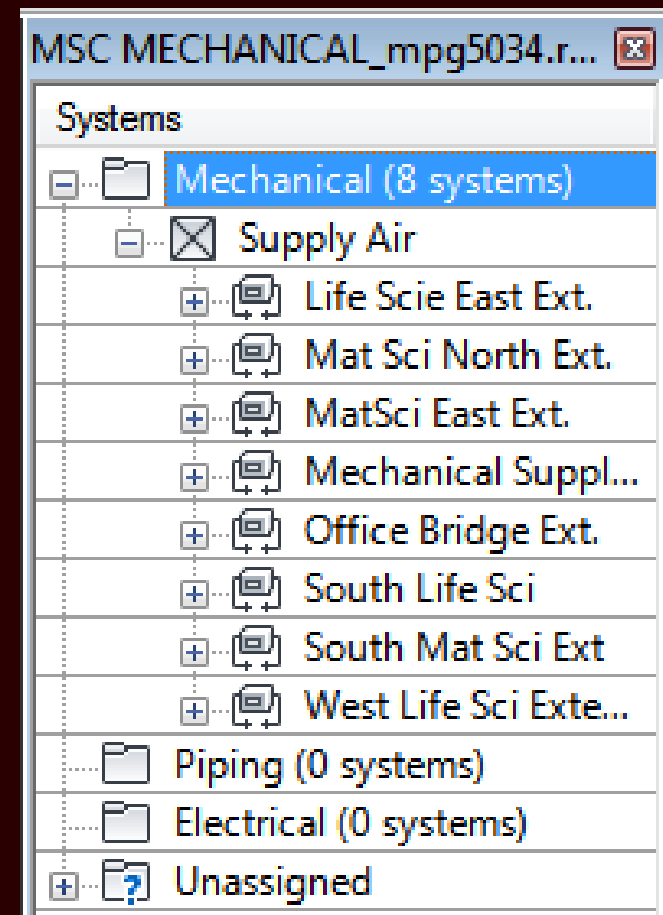
Parameter	Downloaded Setting	Adjusted Setting
Flow Configuration	Calculated	Preset
Flow Direction	In	In
Family	Air Terminal	Mechanical Equipment
Location of Inlet	Side	Top (Cost Option)
Air Flow	Instance: Keeps CFM constant for the same family	Type: Allows different CFM for same family

## 6. Adjust Chilled Beam Families in Revit

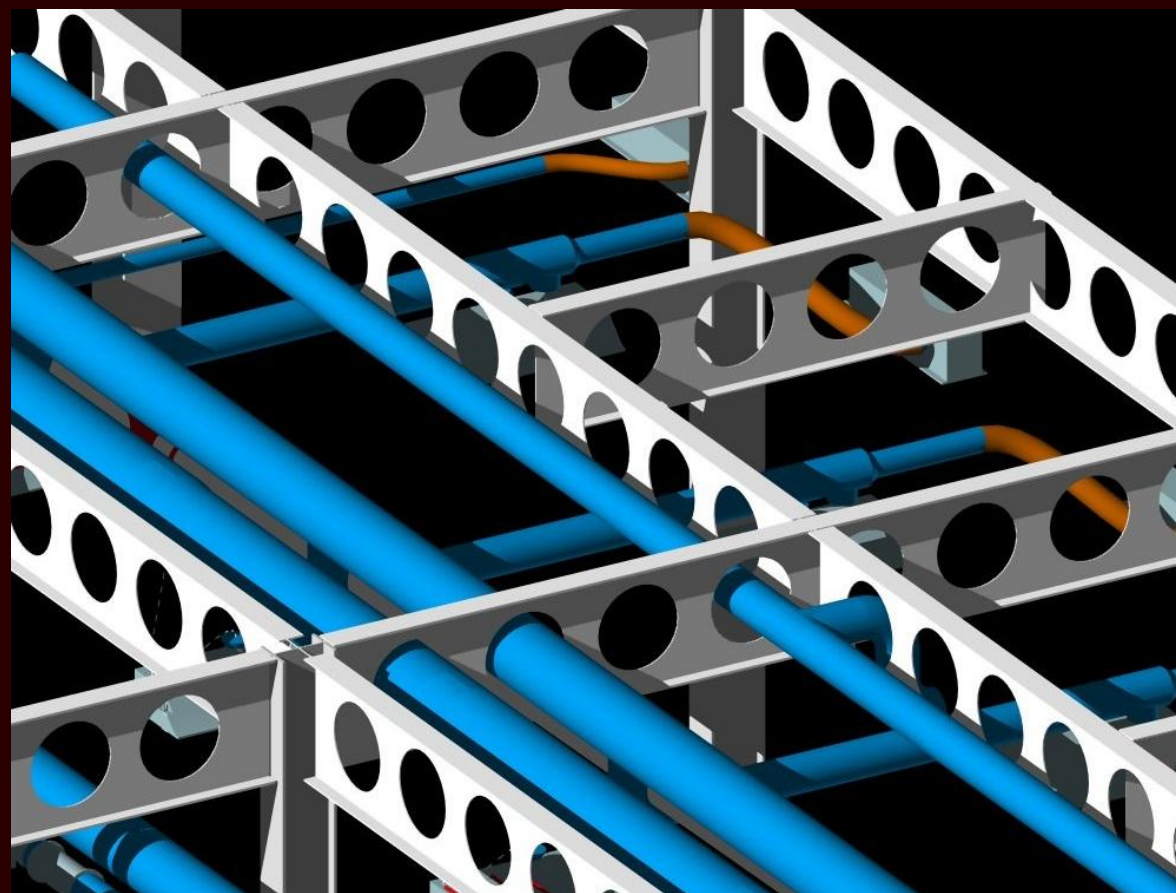


# Active Chilled Beam Design Process

## 7. Create Systems so Revit can calculate Duct, Pipe Sizes



## 8. Place main duct runs in cellular openings





# Structural Integration With Chilled Beams

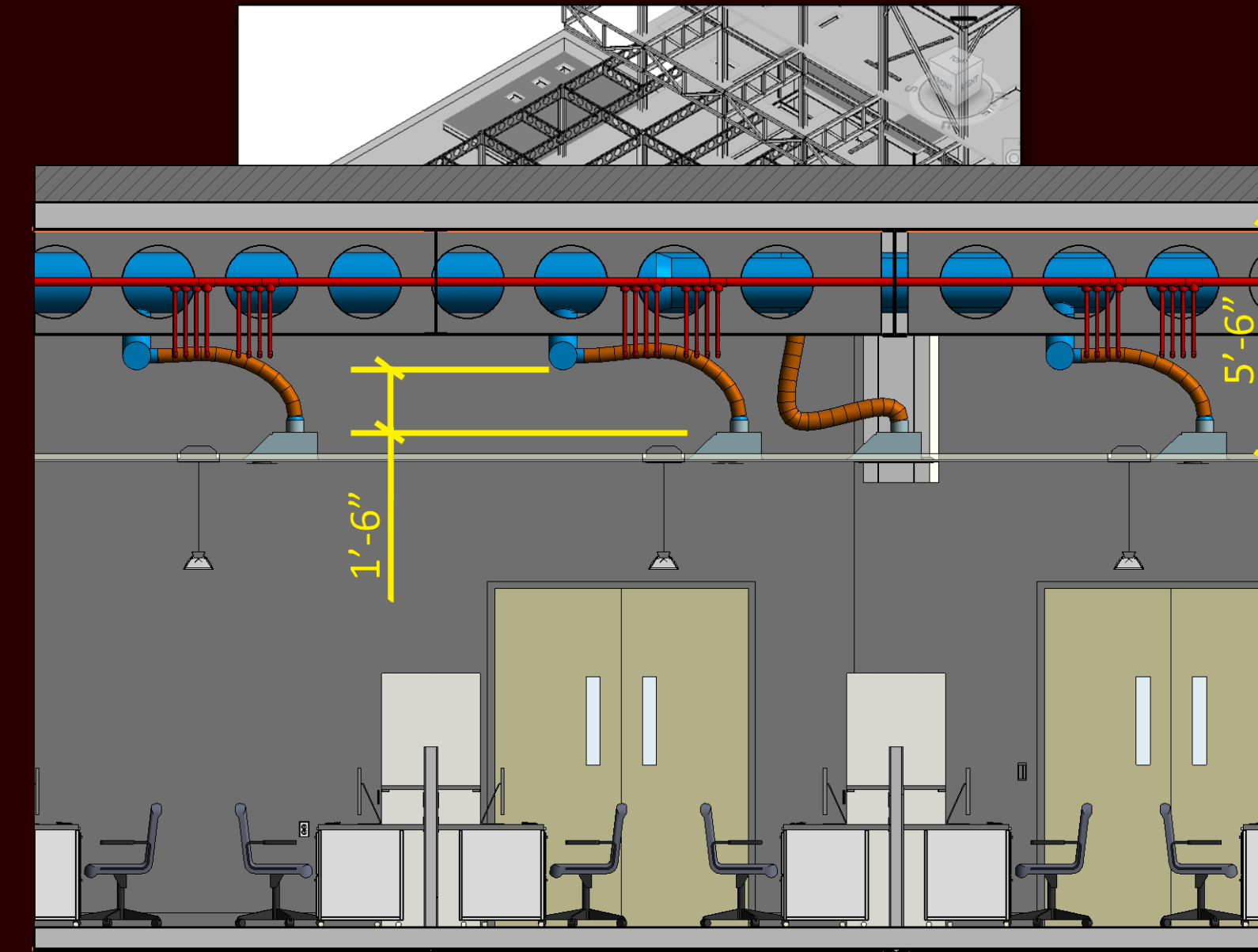
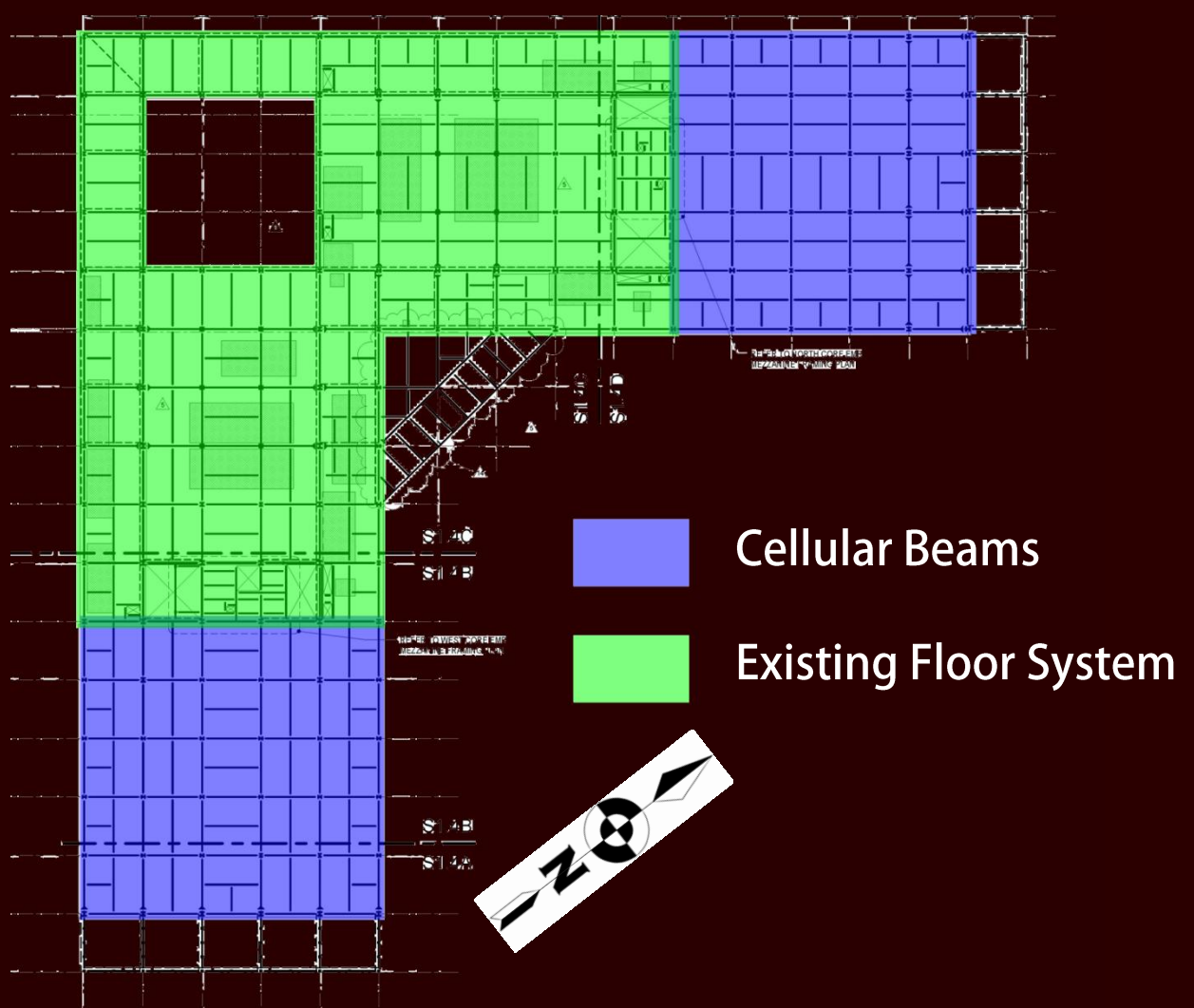
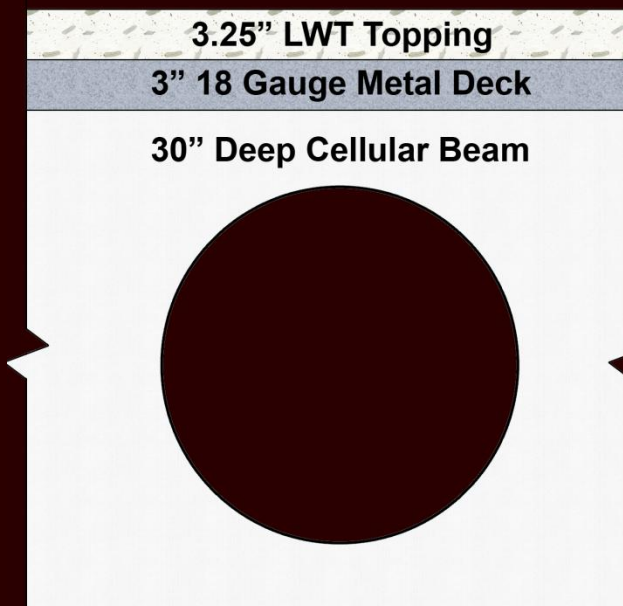
## Existing Composite Floor System

- 22ft. X 22ft. Bays
- 21in. Deep Wide Flange Beams
- 24in. Deep Wide Flange Girders
- Floor Supports Green Roof
- NWT Concrete



## Redesign

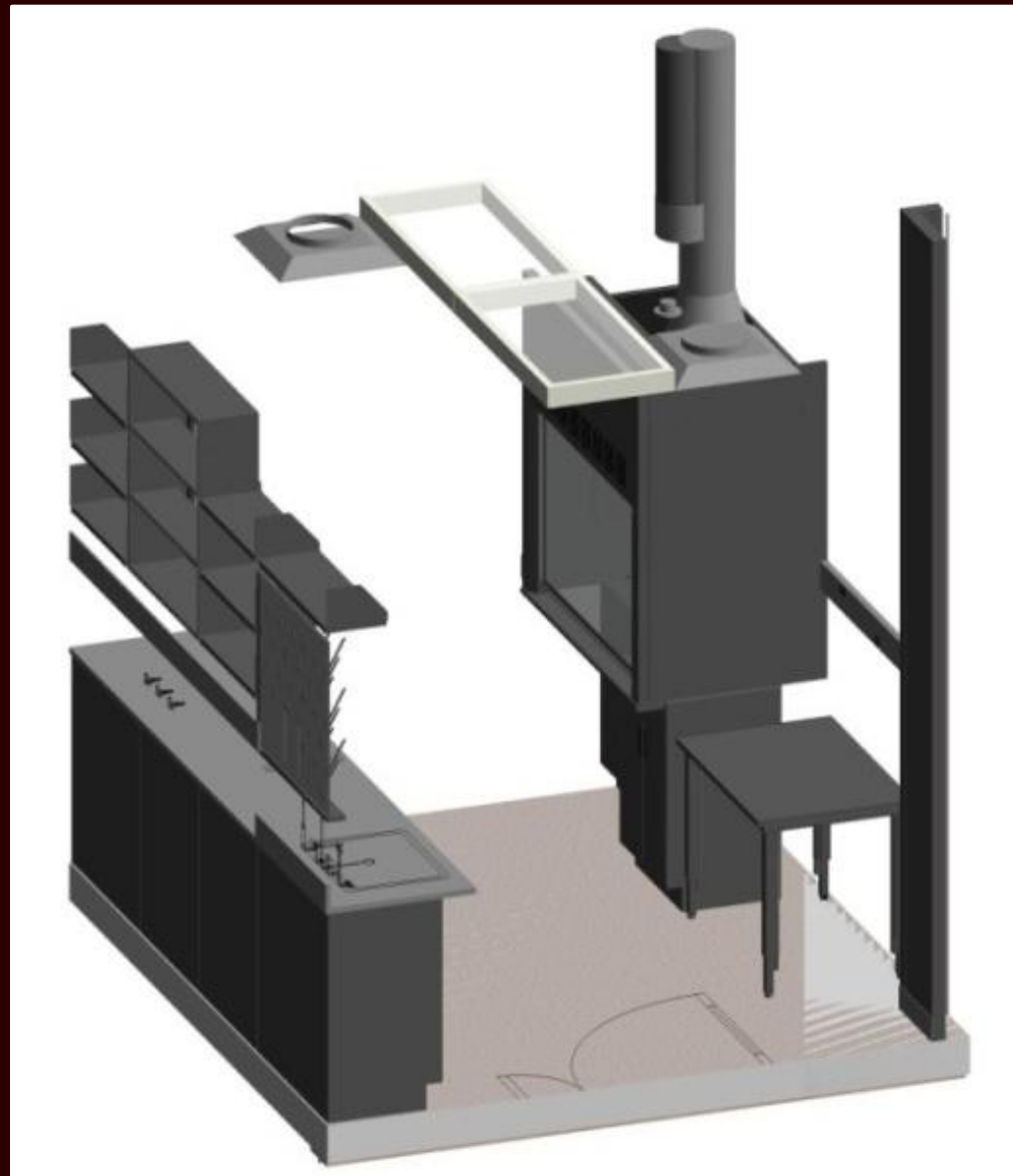
- 30in. Deep Cellular Beams
- LB30X44 Beams
- LB30X57 Girders
- Lighter Bays



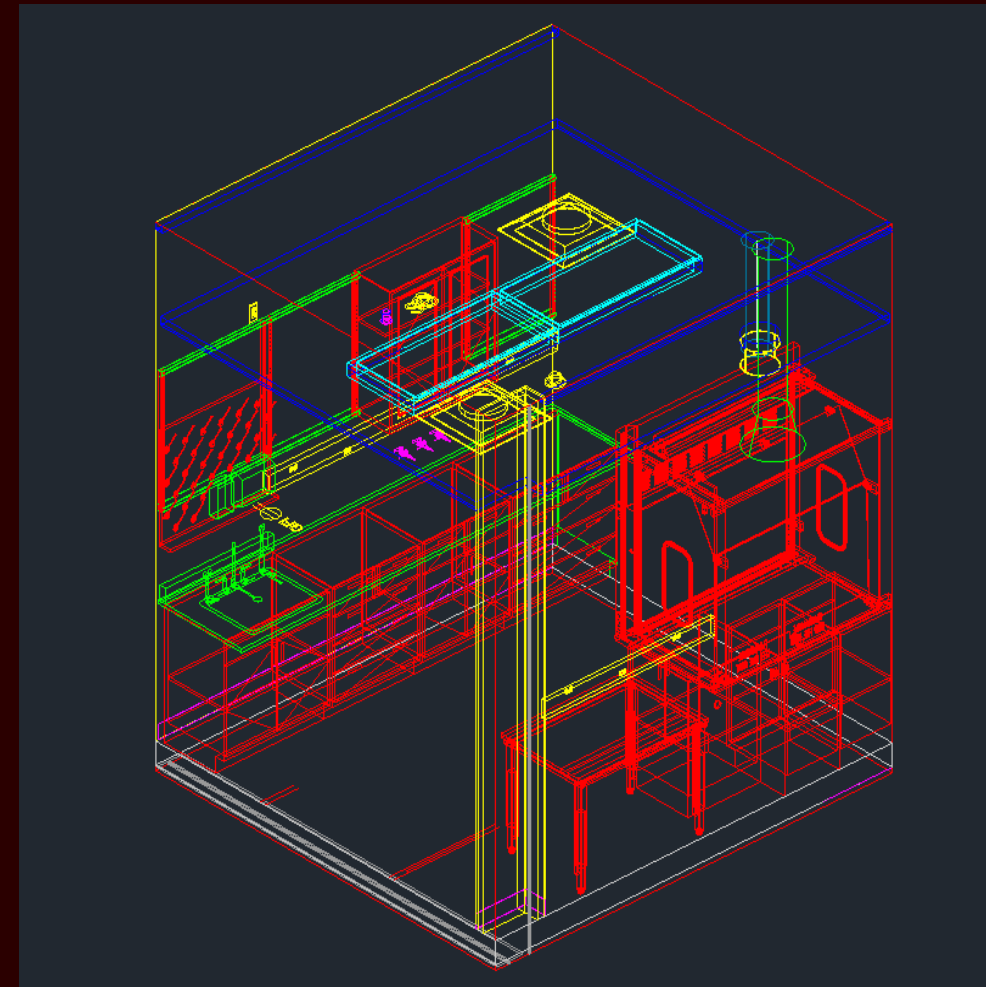


# Fume Hood Face Velocity Testing: Software Process

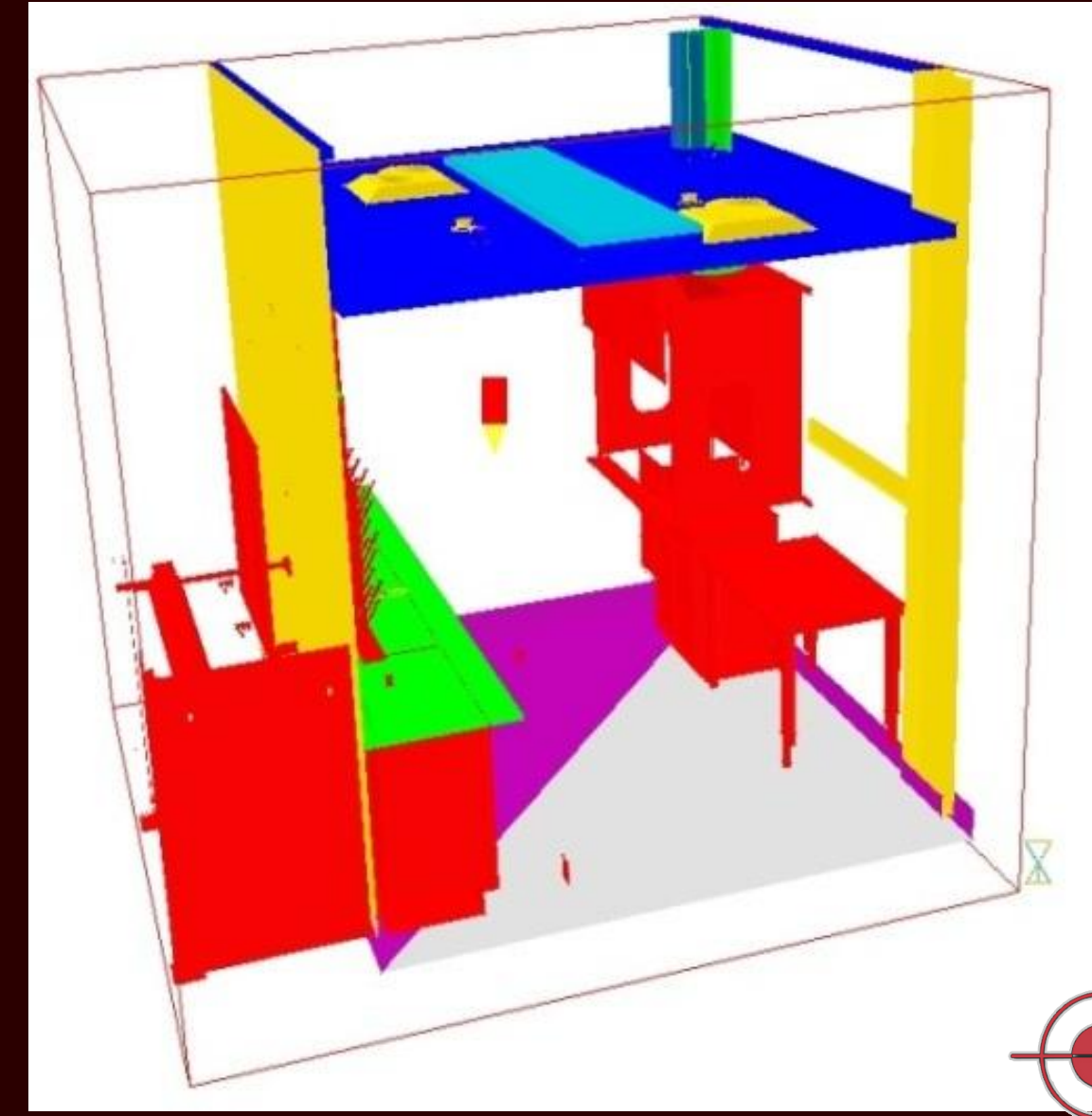
Section Box  
applied to  
W324A-Hot  
Room



DXF Export  
from Revit  
Architecture

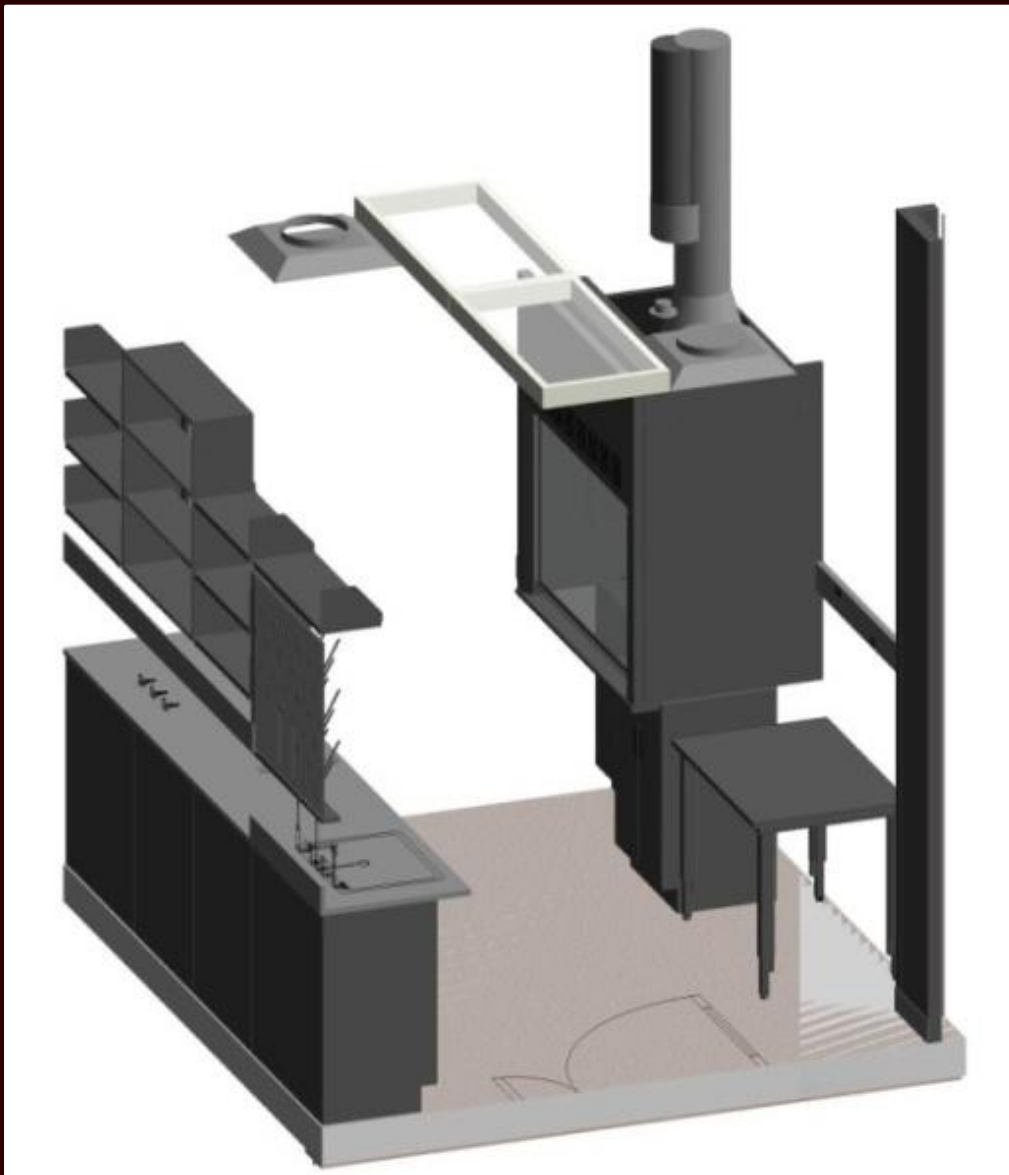


Attempted  
import as  
geometry  
into  
Phoenics  
2009

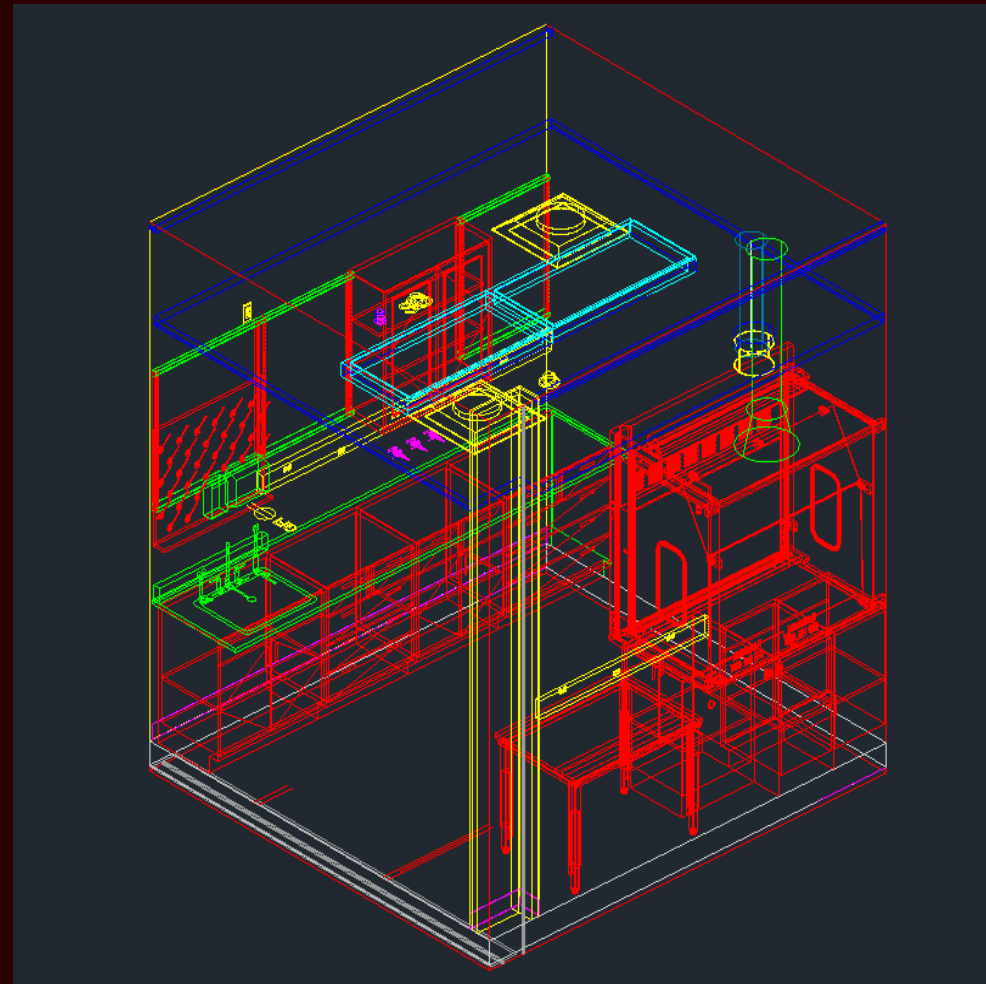


# Fume Hood Face Velocity Testing: Software Process

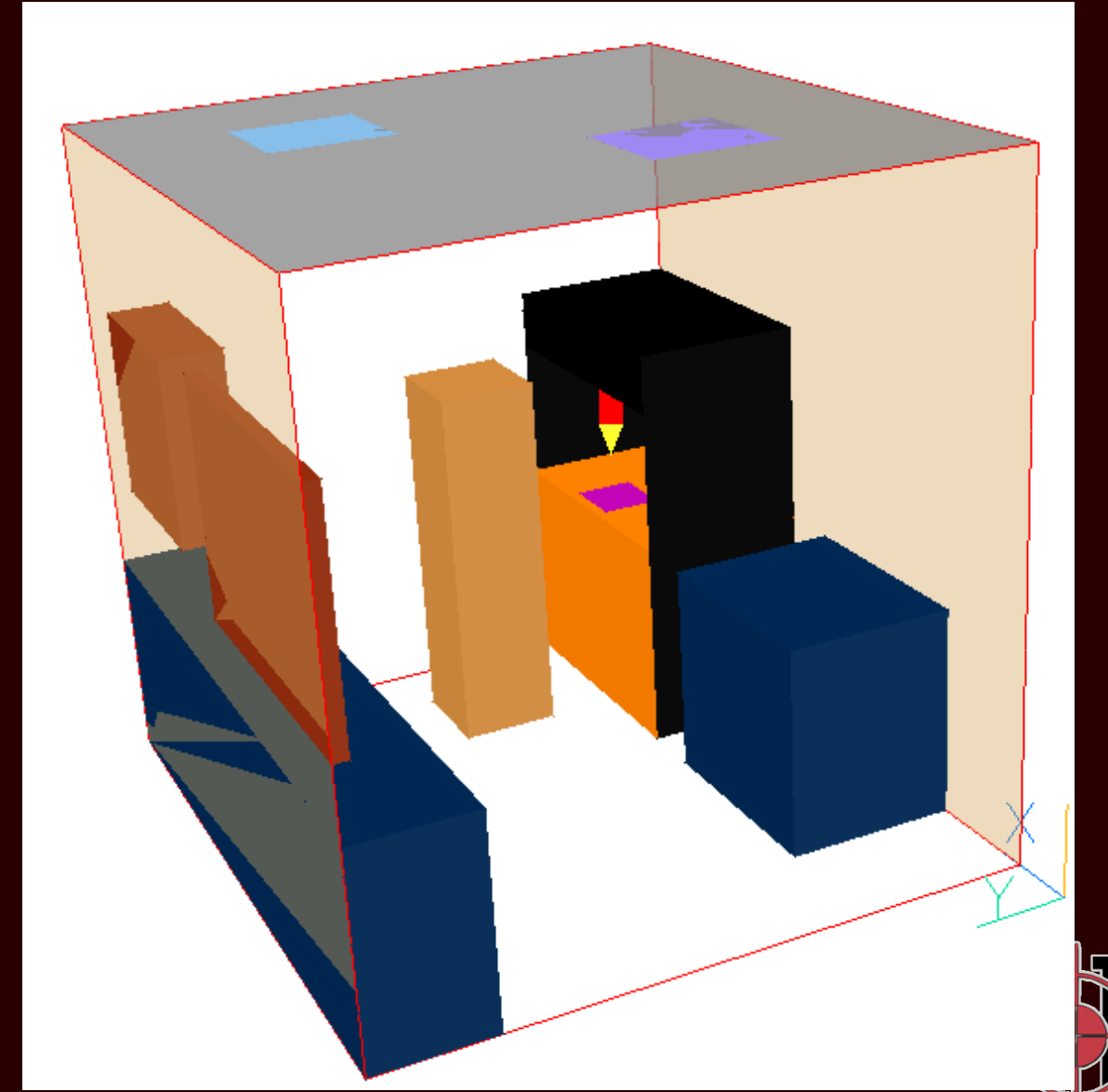
Section Box  
applied to  
W324A-Hot  
Room

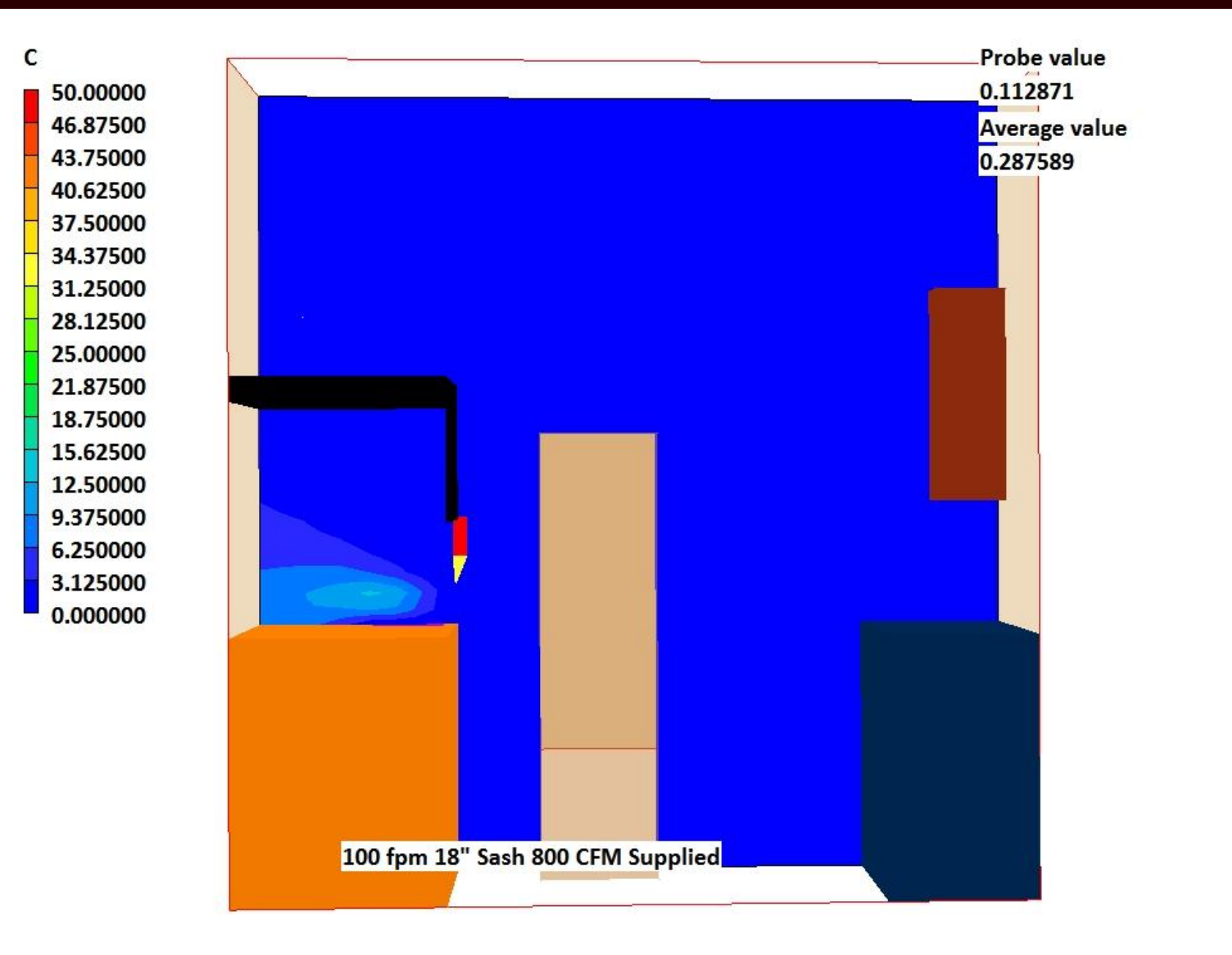


DXF Export  
from Revit  
Architecture



Final Model  
created with  
Phoenics  
elements



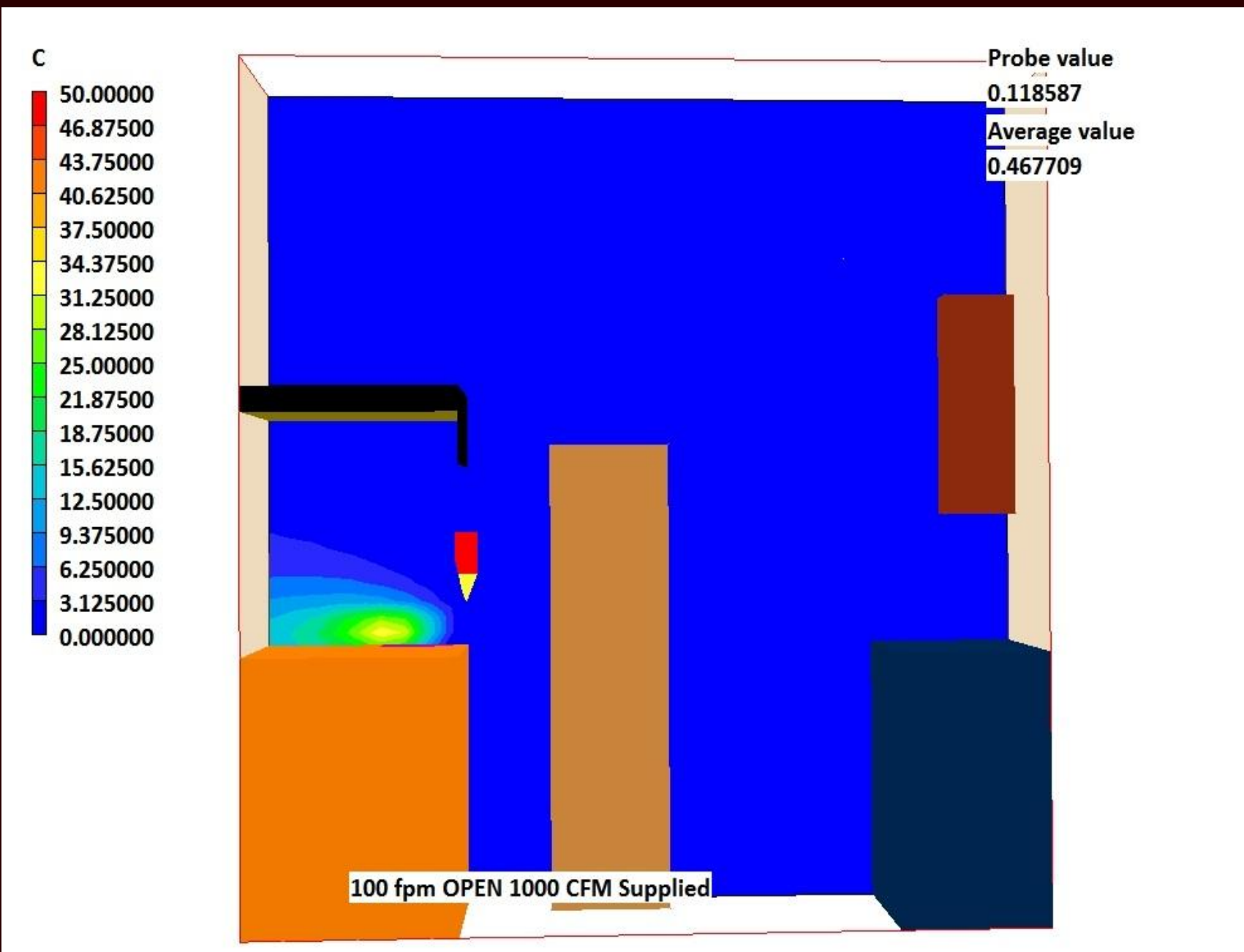


100 FPM

# CFD Contaminant Test: 18" Sash Position

80 FPM





100 FPM

## CFD Contaminant Test: 30" Sash Position

80 FPM



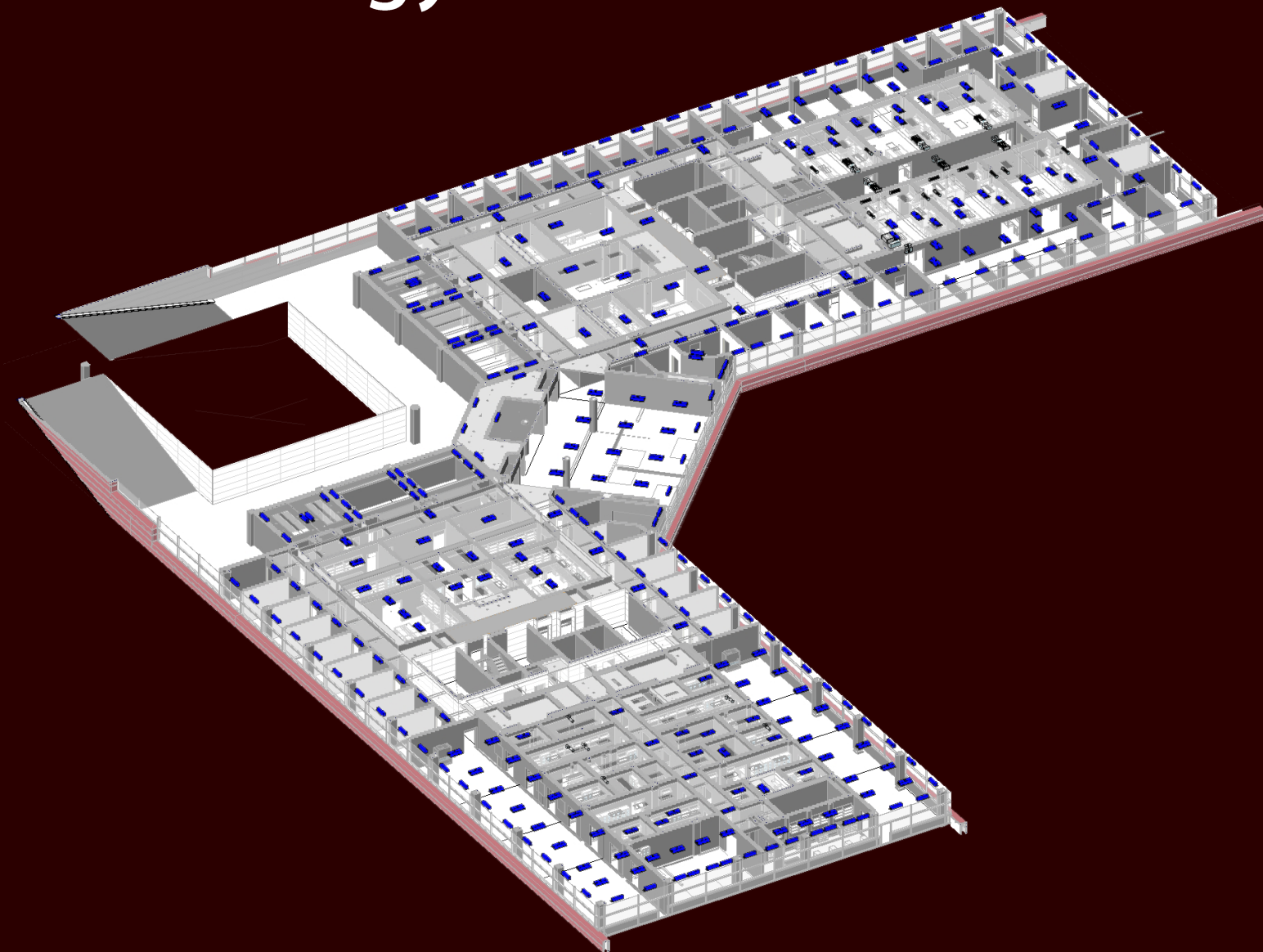
## Fume Hood Results

1. Face Velocity **achieved during 18"** simulations, **not 30"**
2. **14.2% more** contaminant present at face of fume hood in 80 fpm, 18" sash
3. **18.0% more** contaminant present at face of fume hood in 80 fpm, 30"
4. All contaminant readings **less than 0.015% of source**, drop significantly at Human
5. **31.94%** energy savings from conditioning less air

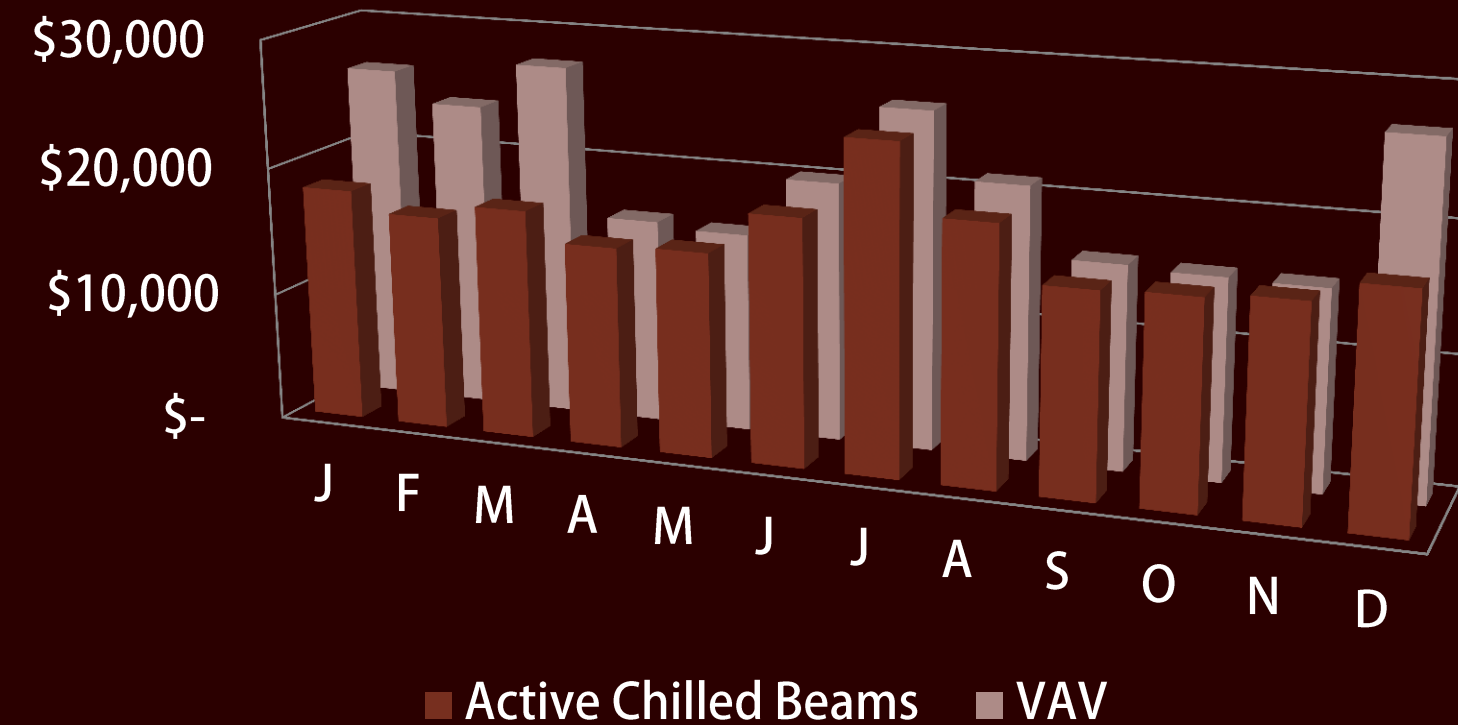
Summary of Fume Hood Makeup Air Costs and Savings		
Metric	100 fpm VAV	80 fpm ACBs
Cooling/Dehumidification	\$233,356	\$122,597
Heating	\$6,479	\$13,447
Fan	\$110,512	\$81,042
Humidification	\$17,610	\$33,343
CAV Operation Costs	\$367,958	\$250,431
VAV Multiplier for Operation	0.32	0.32
Adjusted Operation Costs	\$116,704	\$79,428.
Percent Savings		<b>31.94%</b>

# Energy Model Results

3 <sup>rd</sup> Floor and Estimated Building Operating Costs			
		3 <sup>rd</sup> Floor	Building
Existing VAV	Building Energy kBtu/yr	16,478,534	98,871,204
	Operating Costs	\$250,288	\$1,501,728
	Cost/SF	\$5.84/ft <sup>2</sup>	
Proposed ACB + Triple Pane Glazing	Building Energy kBtu/yr	13,912,786	83,476,716
	Operating Costs	\$214,983	\$1,289,898
	Cost/SF	\$5.02/ft <sup>2</sup>	
	Percent Savings	14.1%	



## Monthly Operating Costs





## Mechanical Equipment Schedule

Family and Type	Count	Total	COST
Radiant-ACB1-4: ACB1 12" Wide, Inlet 4"	1	1327.75	\$1,327.75
Radiant-ACB1-4: ACB1 12" Wide, Inlet 4"	1	1327.75	\$1,327.75

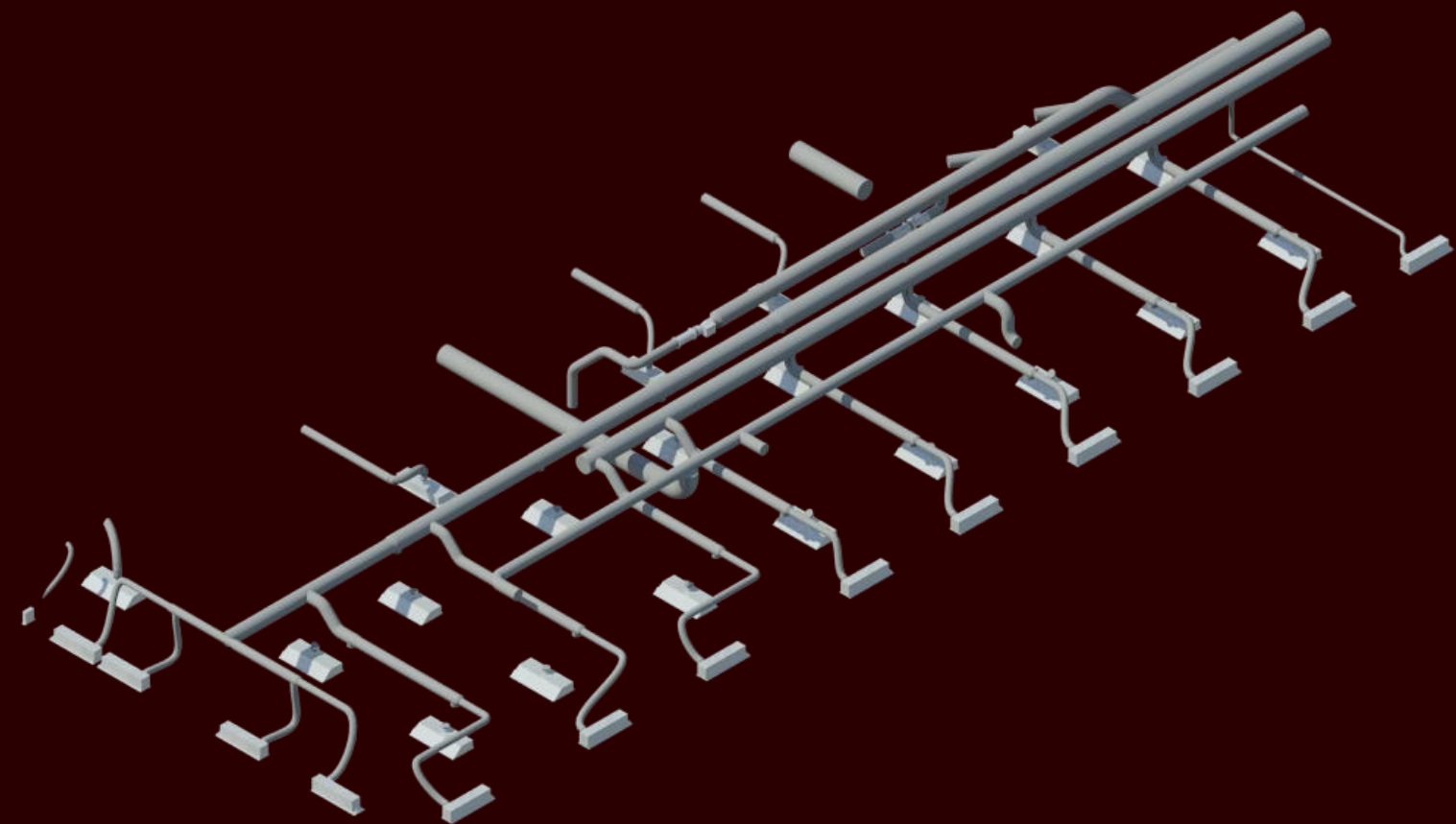
### Duct Schedule

Size	Area	Length	Unitless Length	Cross Area	Volume Per FT	Weight
13"x13"	88 SF	20' - 4 1/4"	20.354167	0.022 SF	0.02	70.34
14"ø	4 SF	1' - 0"	1.000001	5.445938	0.03781901	6.54
16"x16"	110 SF	20' - 6 7/8"	20.572917	0.026 SF	0.03	106.65
18"x18"	123 SF	20' - 6 7/8"	20.572917	0.035 SF	0.03	106.65
20"x20"	67 SF	10' - 1 9/32"	10.10551	0.038 SF	0.04	69.85

### Pipe Schedule

Family and Type	Size	Length	Unitless Length	Material	Labor	Equipmet	Total	COST
Pipe Types: Standard	1/2"ø	0' - 10 29/32"	0.909167	5.25	5.6	1.25	12.1	\$11.00
Pipe Types: Standard	1/2"ø	0' - 7 31/32"	0.662917	5.25	5.6	1.25	12.1	\$8.02
Pipe Types: Standard	1/2"ø	1' - 0 29/32"	1.075833	5.25	5.6	1.25	12.1	\$13.02

## Mechanical Redesign Cost Assessment



CHILLED BEAMS	DUCTWORK	PIPING	PUMPS	AHUs	TOTAL
\$9,608,000	\$2,966,400	\$377,840	\$165,484	\$2,274,046	\$21,035,567

**Cost Increase = \$1,847,567**

## Comparing Life Cycle Costs of Mechanical Systems

### Coal Plant Findings

	Real Rate	2% Inflation	5% Inflation
VAV	\$54,813,916	\$63,883,395	\$63,856,220
ACB	\$55,346,191	\$62,693,273	\$62,647,108
Percent Savings	<b>-0.97%</b>	1.86%	1.89%
NPV Differential	<b>(\$532,275)</b>	\$1,190,122	\$1,209,111

**If inflation occurs and PSU remains a coal fired plant, the Active Chilled Beam system should be considered**

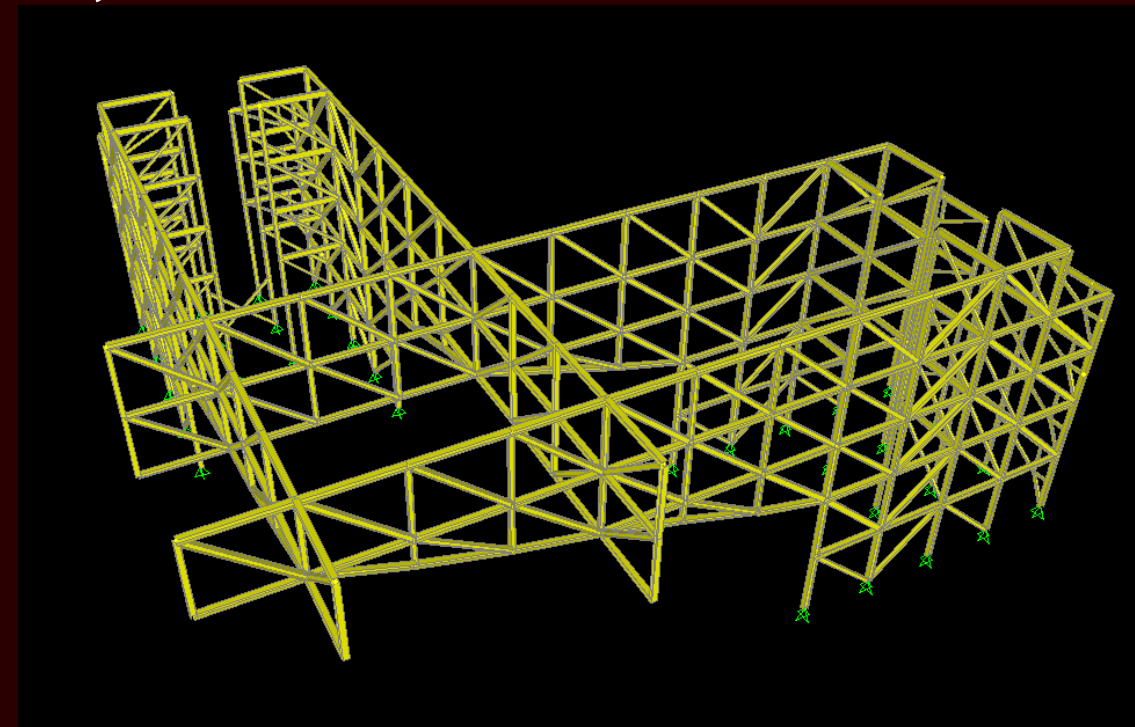
**If PSU changes to a Natural Gas plant, the Active Chilled Beam system should be considered**

### Natural Gas Plant

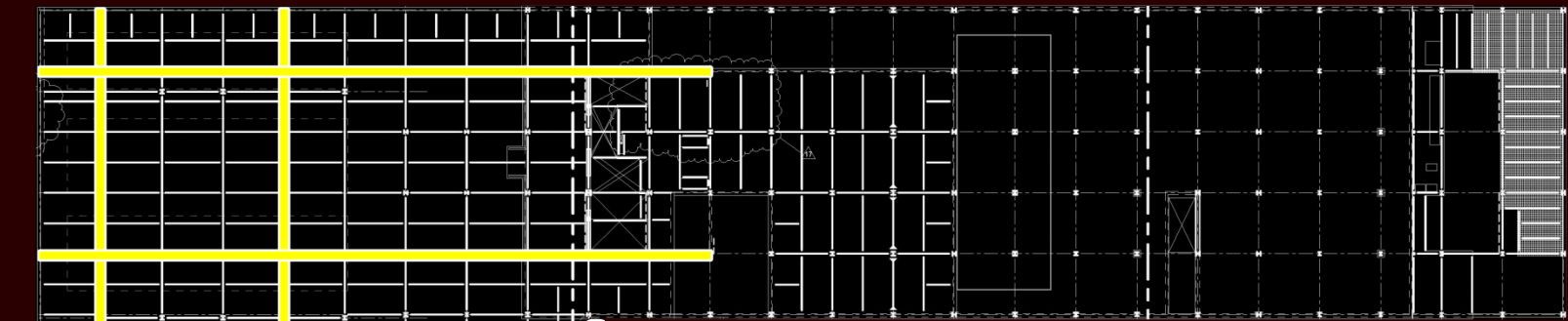
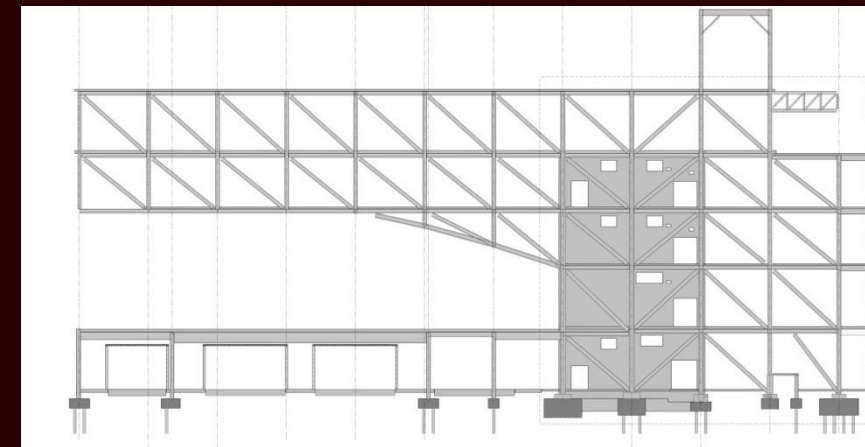
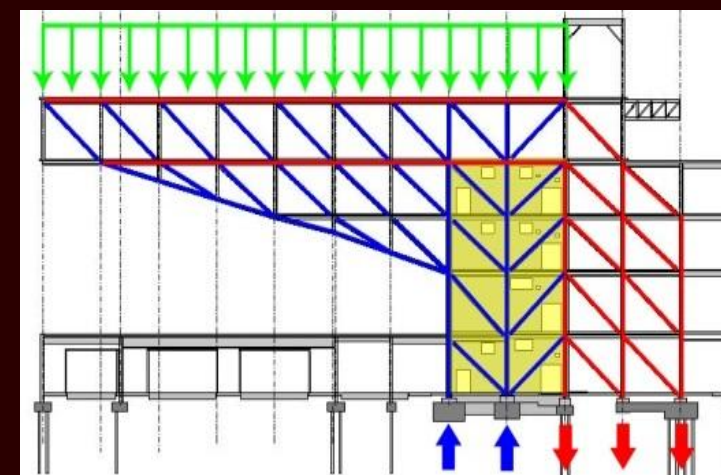
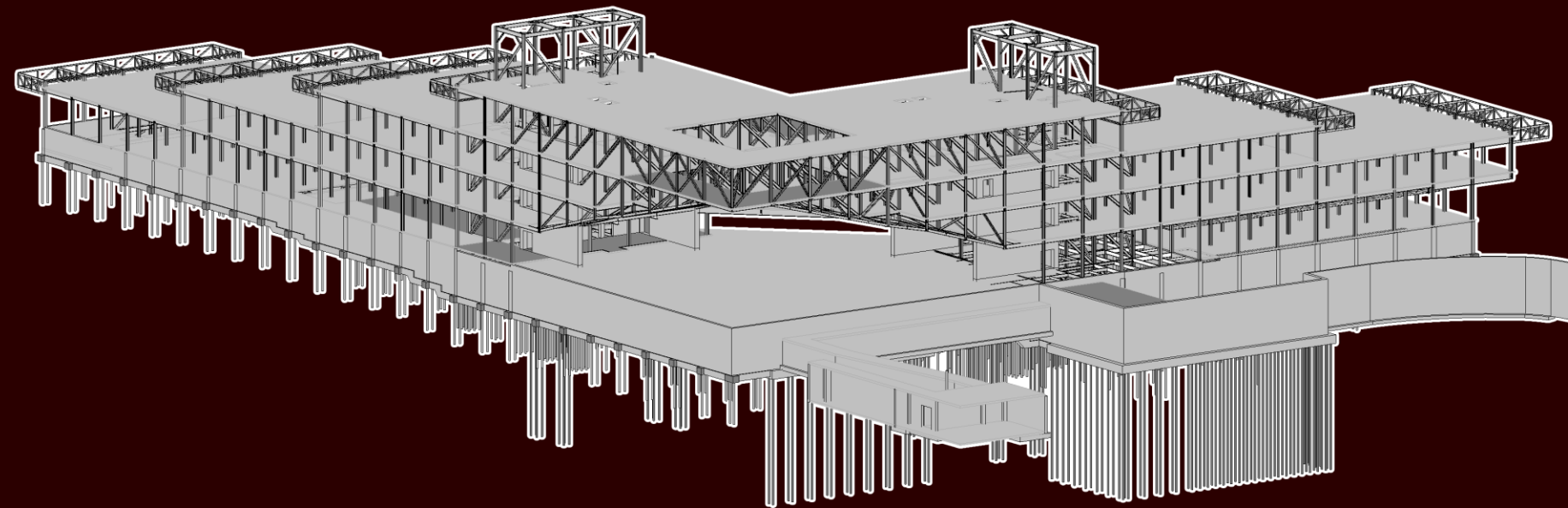
	Real Rate	2% Inflation	5% Inflation
VAV	\$64,693,985	\$72,152,832	\$72,110,021
ACB	\$59,478,486	\$69,307,263	\$69,259,831
Percent Savings	8.06%	3.94%	3.95%
NPV Differential	\$5,215,499	\$2,845,568	\$2,850,190

154ft. Overhang

- 4 Main Trusses at Gridlines 2, 5, B, & E
- **11 Bays** Lengthwise
- **Moment** Connections
- Members Oriented for **Compression**
- Sizes Ranging from W14X90 to W14X550
- Controlled by **Deflection**



## Existing Cantilever



Autodesk Revit

Cantilever Model to Serve as Base

Considerations

Integration with Lighting and Mechanical

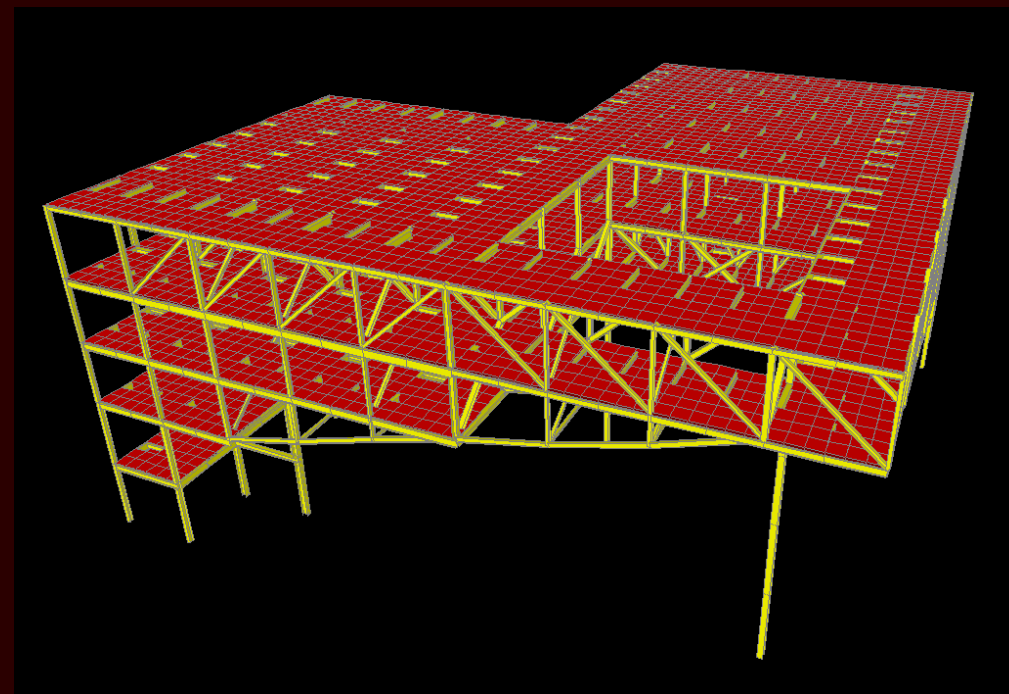
Utilities to be Taken

Redesign Location

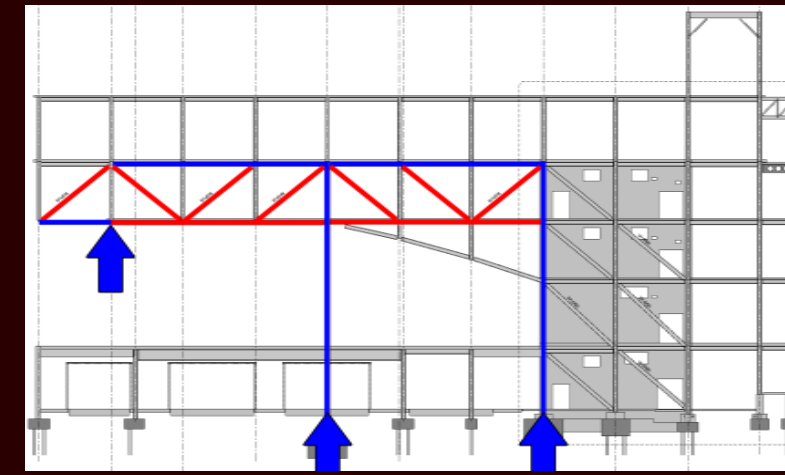
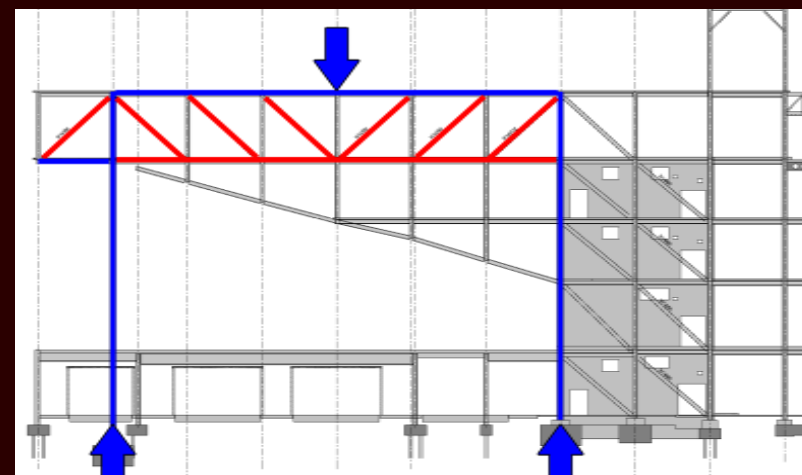
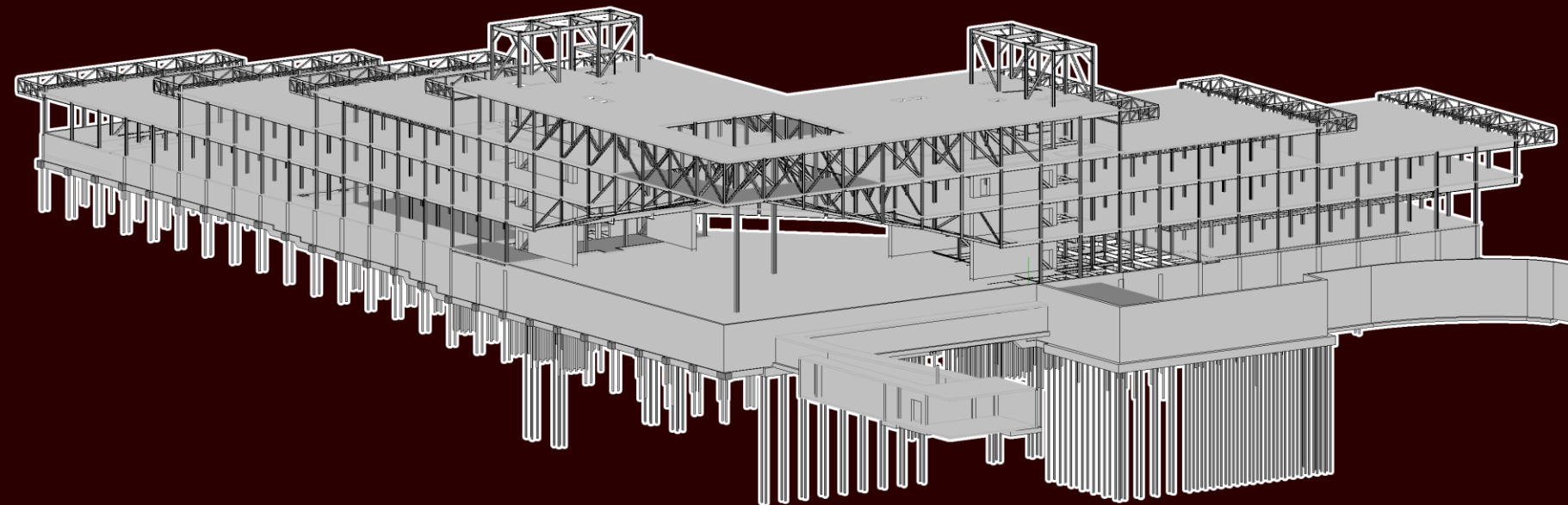


154ft. Overhang

- 4 Main Trusses at Gridlines 2, 5, B, & E
- **9 Bays** Lengthwise
- **Pin** Connections
- Members Oriented for **Tension**
- Sizes Ranging from W14X90 to W14X311
- Controlled by **Strength**



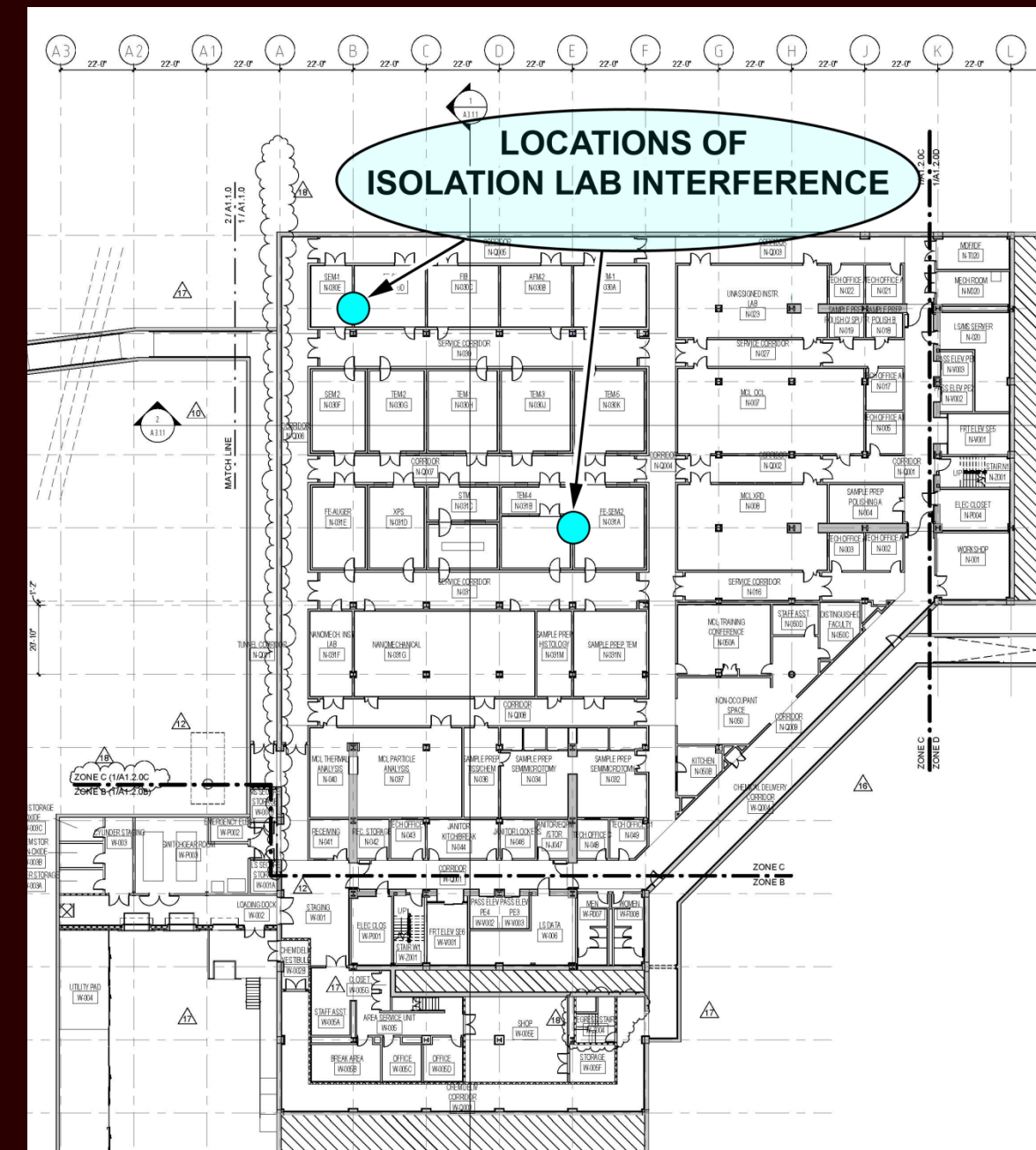
## Redesign



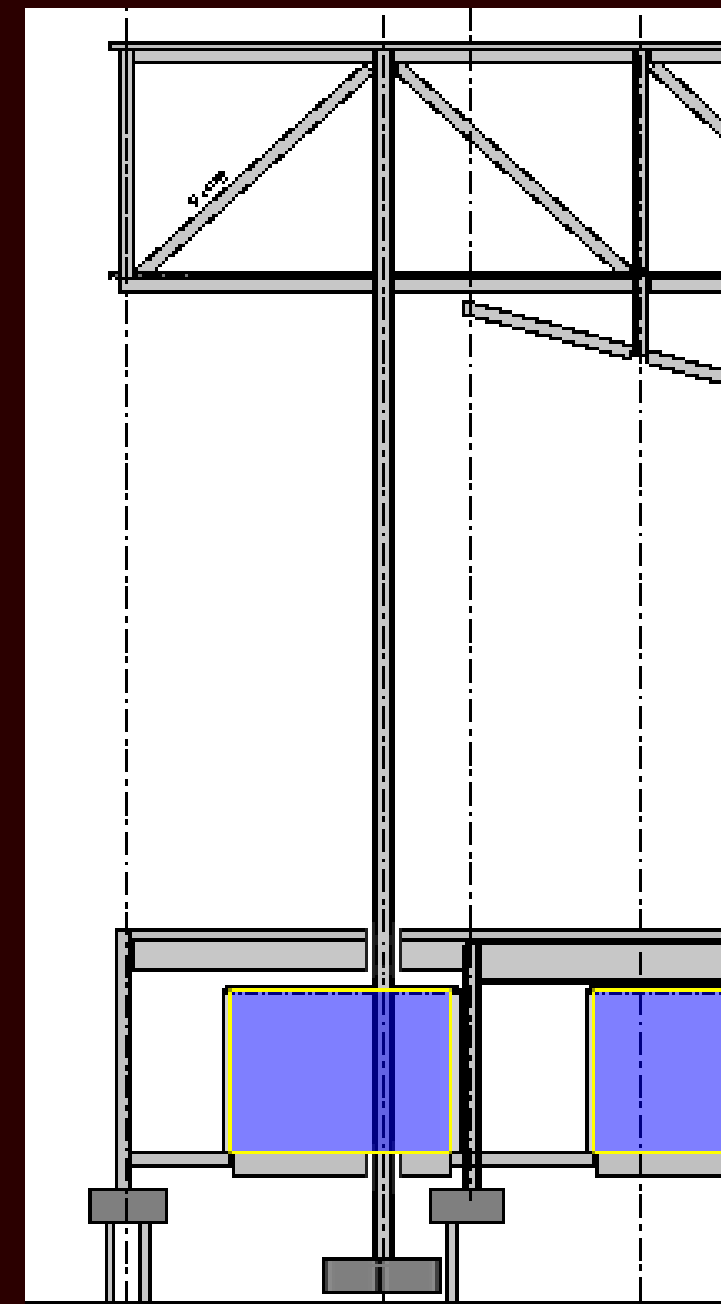
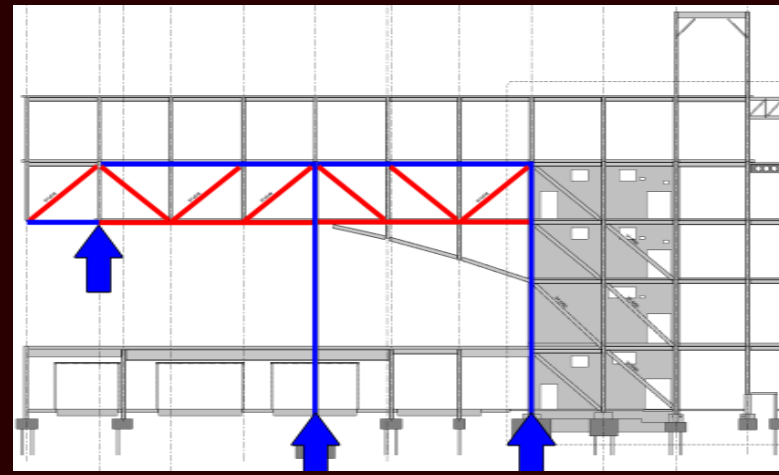
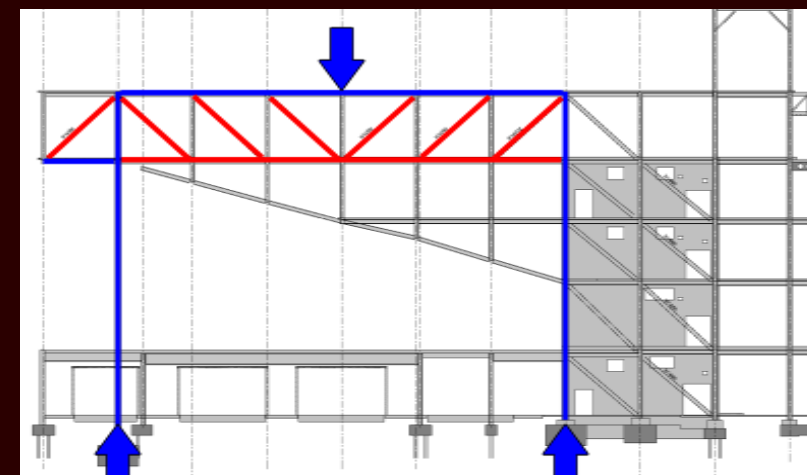
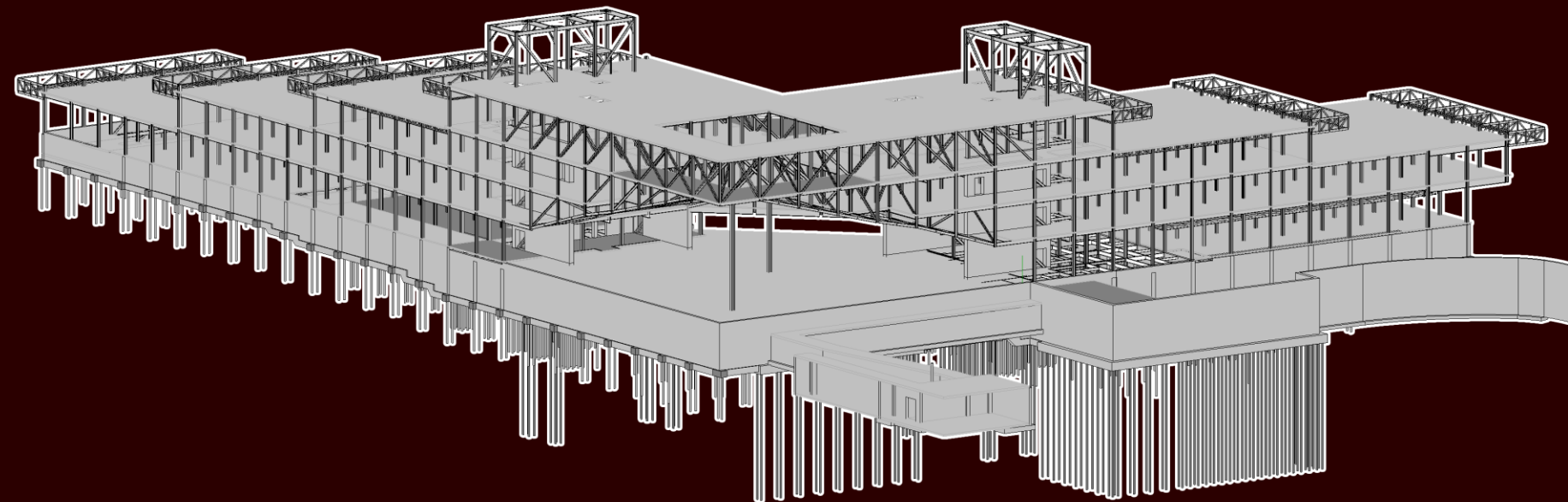
### Actual BIM Process

- Build Complete Cantilever in SAP
- Analyze in SAP
- Redesign in SAP
- **Replicate** in Revit
- Use Existing Conditions Model and Modify IPD Considerations
- Integration with Lighting and Mechanical
- Quantities to be Taken from Redesigned Model





# Redesign



## Isolation Lab Interference

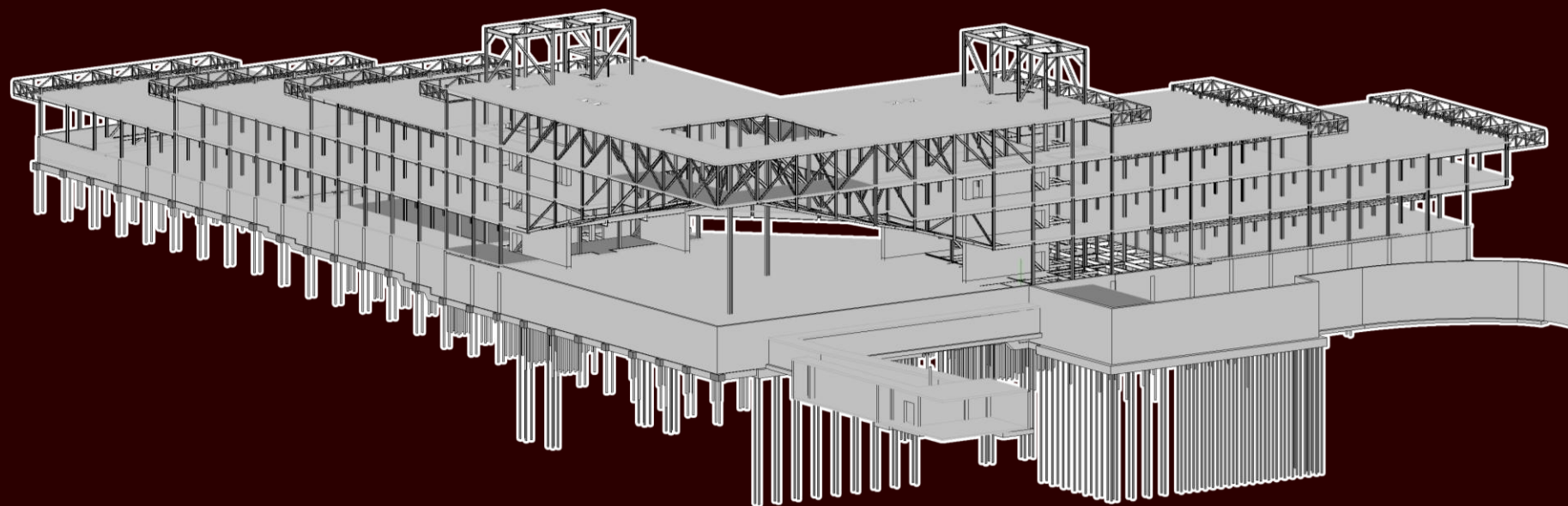
- Column **Penetrates** Through Slab
- Labs Limited to 130 micro inches/second
- Labs Sequestered from Foundation

## Proposed Solution

- Column Pile Caps 3ft. Beneath Bottom of Isolation Slabs
- Isolation Slabs **Poured Around** Columns
- **Compressive Material** to Fill Gap

# Structural Redesign Cost Implications

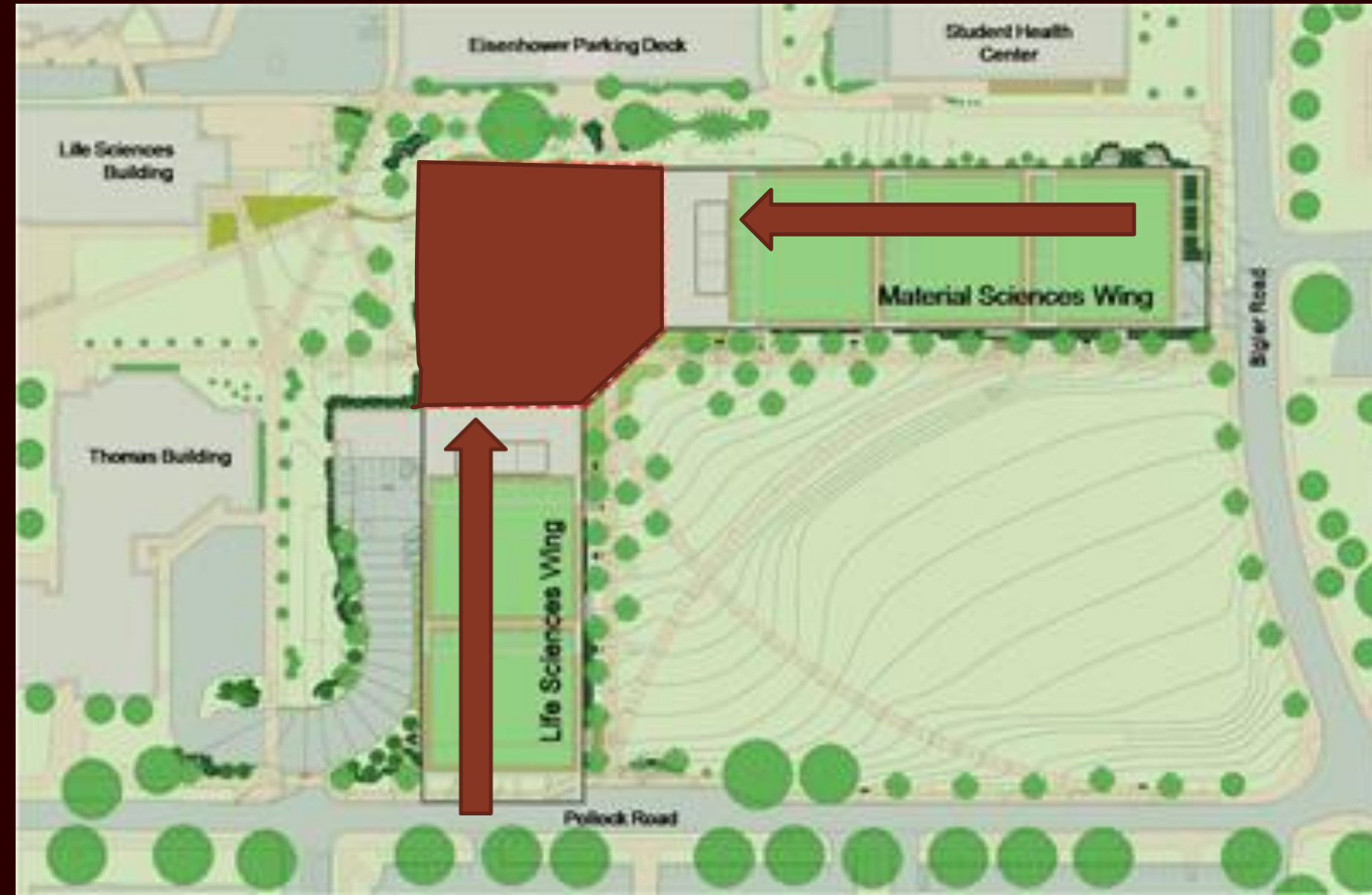
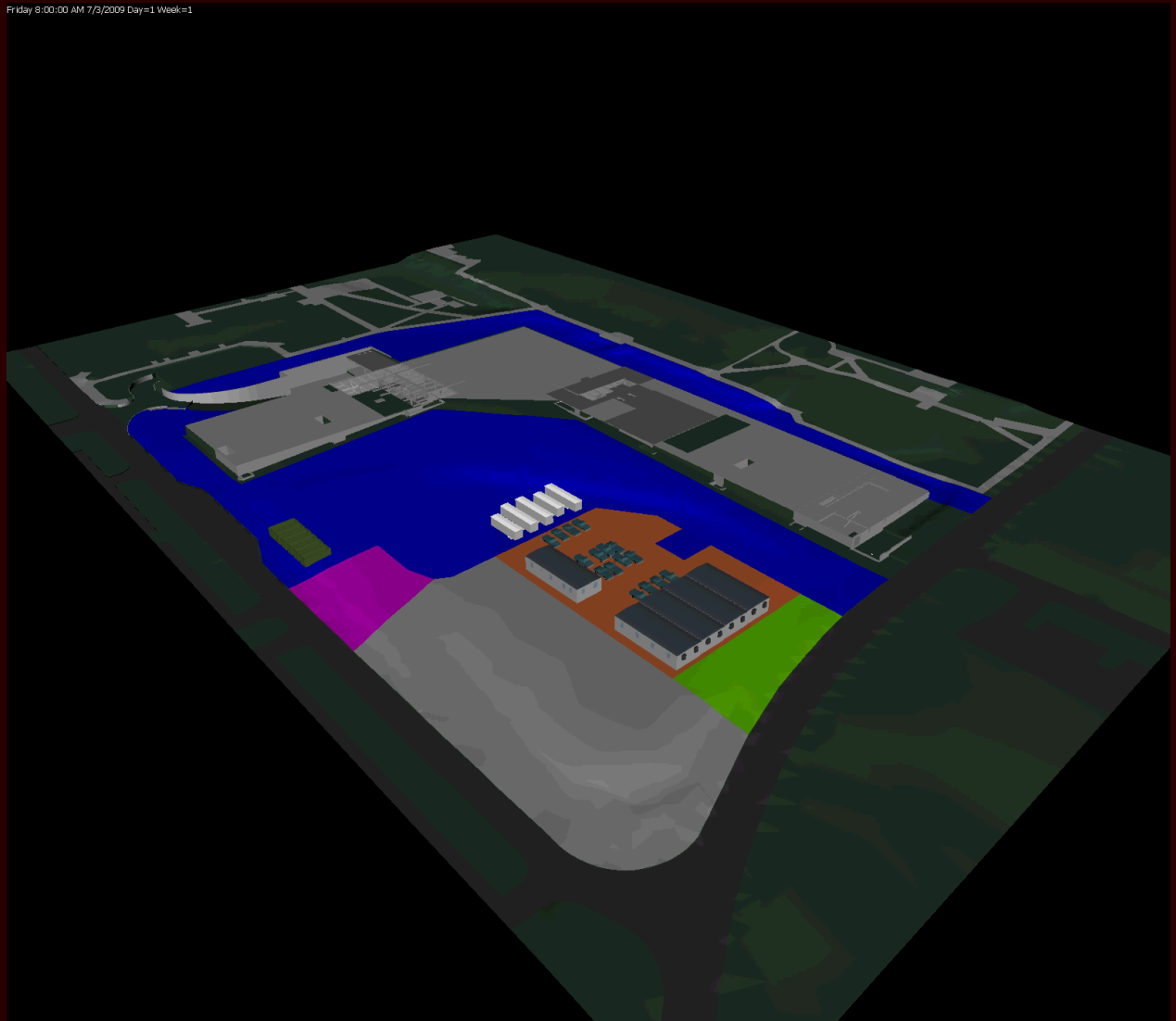
Existing Entire Structure				
Framing Tons	Column Tons	Framing Cost	Column Cost	
3058.7 Tons	953.84 Tons	\$8,179,891.34	\$2,386,659.20	
	<b>Total =</b>	<b>\$10,566,550.54</b>		
Existing 3rd Floor Structure				
Framing Tons	Column Tons	Framing Cost	Column Cost	
595.72 Tons	231.47 Tons	\$1,848,680.85	\$434,508.19	
	<b>Total =</b>	<b>\$2,283,189.04</b>		



**Cost Savings = \$2,290,815**

Redesign 3 <sup>rd</sup> Floor Structure				
	Framing Tons	Column Tons	Framing Cost	Column Cost
	459.79 Tons	202.92 Tons	\$1,310,896.61	\$539,218.72
		<b>Total =</b>	<b>\$1,850,115.33</b>	
Cost Implications to Entire Structure				
	Savings/SF	Total SF	Total Savings	Total Cost
	\$8.3326/SF	274,922 SF	\$2,290,815.05	\$8,275,735.48

# Steel Sequencing 4D Model



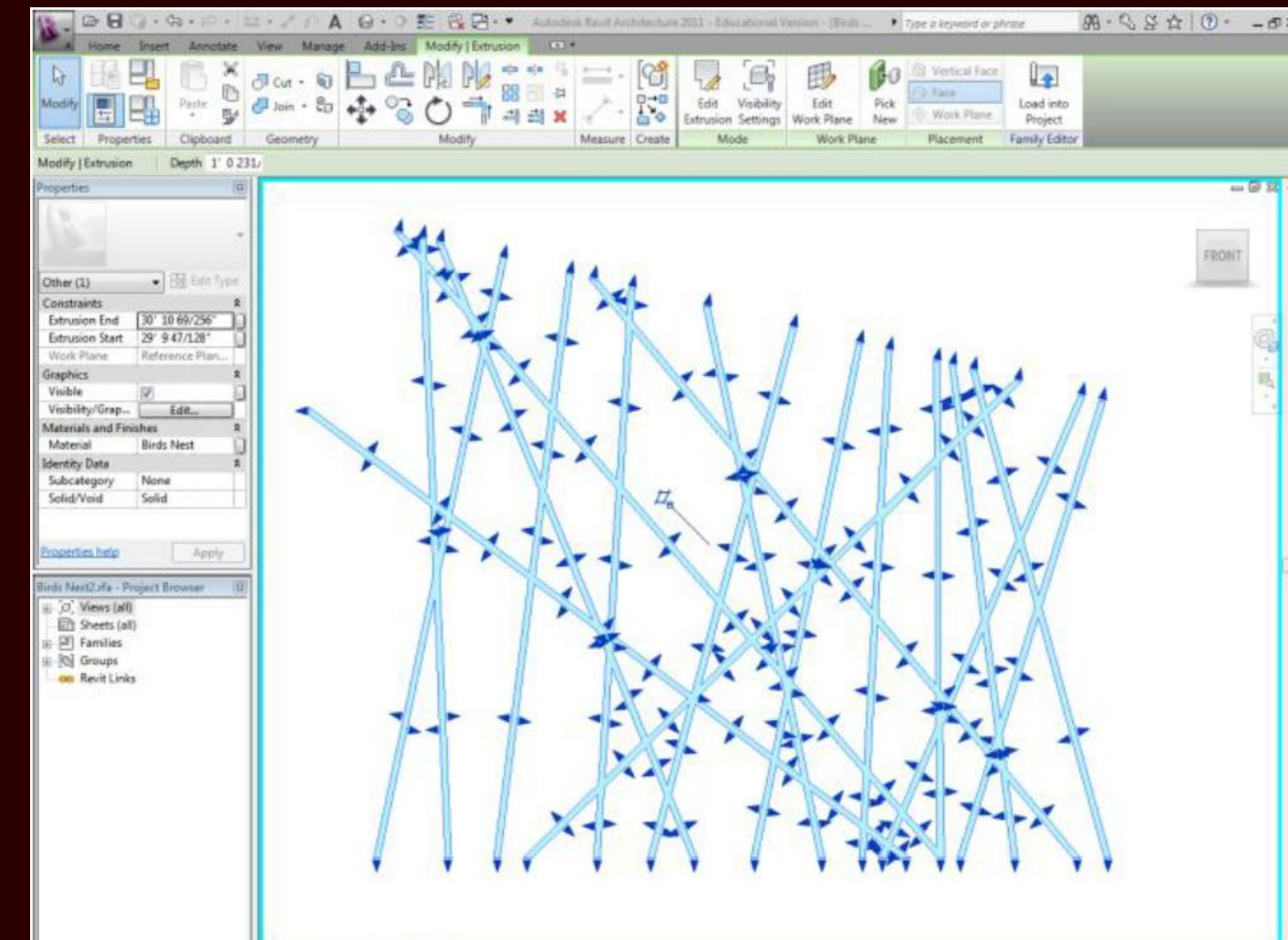
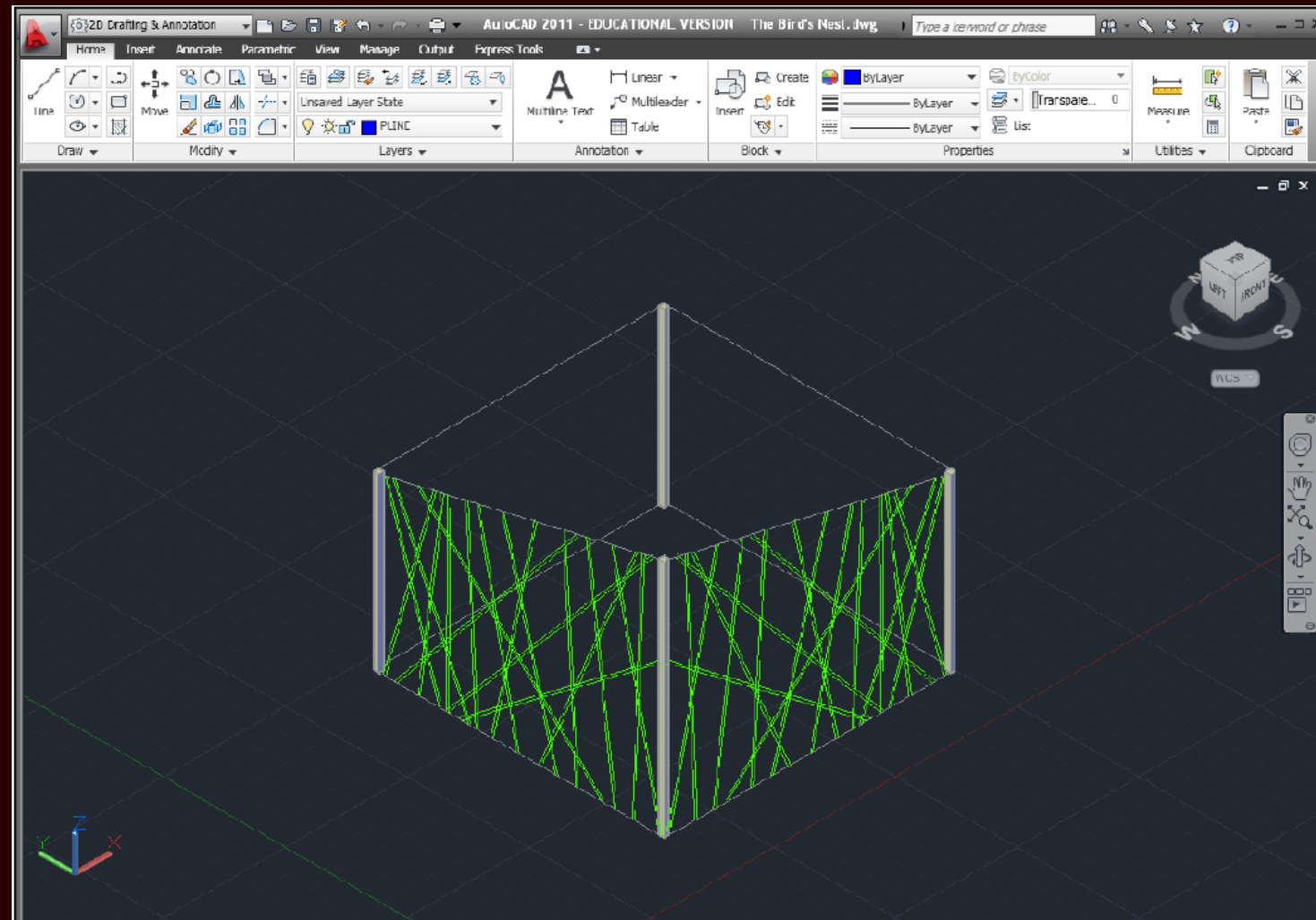
# Existing Courtyard Design

Type	Total	Unit	Cost Total	Cost Unit	Cost
RPC Shrub: Century 1'-10"	244	EA	22	EA	\$5,368.00
RPC Shrub: Switchgrass (2) 4'-0"	327	EA	17.1	EA	\$5,591.70
Basic Wall: Concrete Panel Wall	214.5	FT	11.45	LF	\$2,456.03
Custom Park Bench 6'-0"	5	EA	526.5	EA	\$2,632.50
Bicycle Racks	8	EA	649	EA	\$5,192.00
Stamped Stone Path	4271.75	SF	17.05	SF	\$72,833.34
Mulch	4624.63	SF	2.91	SY	\$498.43
Bermuda Ornamental Grass	1298.57	SF	50	SY	\$2,404.76
Ground Cover Grass	8487.97	SF	220	MSF	\$ 1,867.35
Fern/Boulder Area	<b>Total Including O &amp; P, Waste, Delivery, &amp; Time Modifications = \$271,745.24</b>				
Exposed Aggregate Concrete					
Decorative Pea Gravel					
Decorative Boulders					

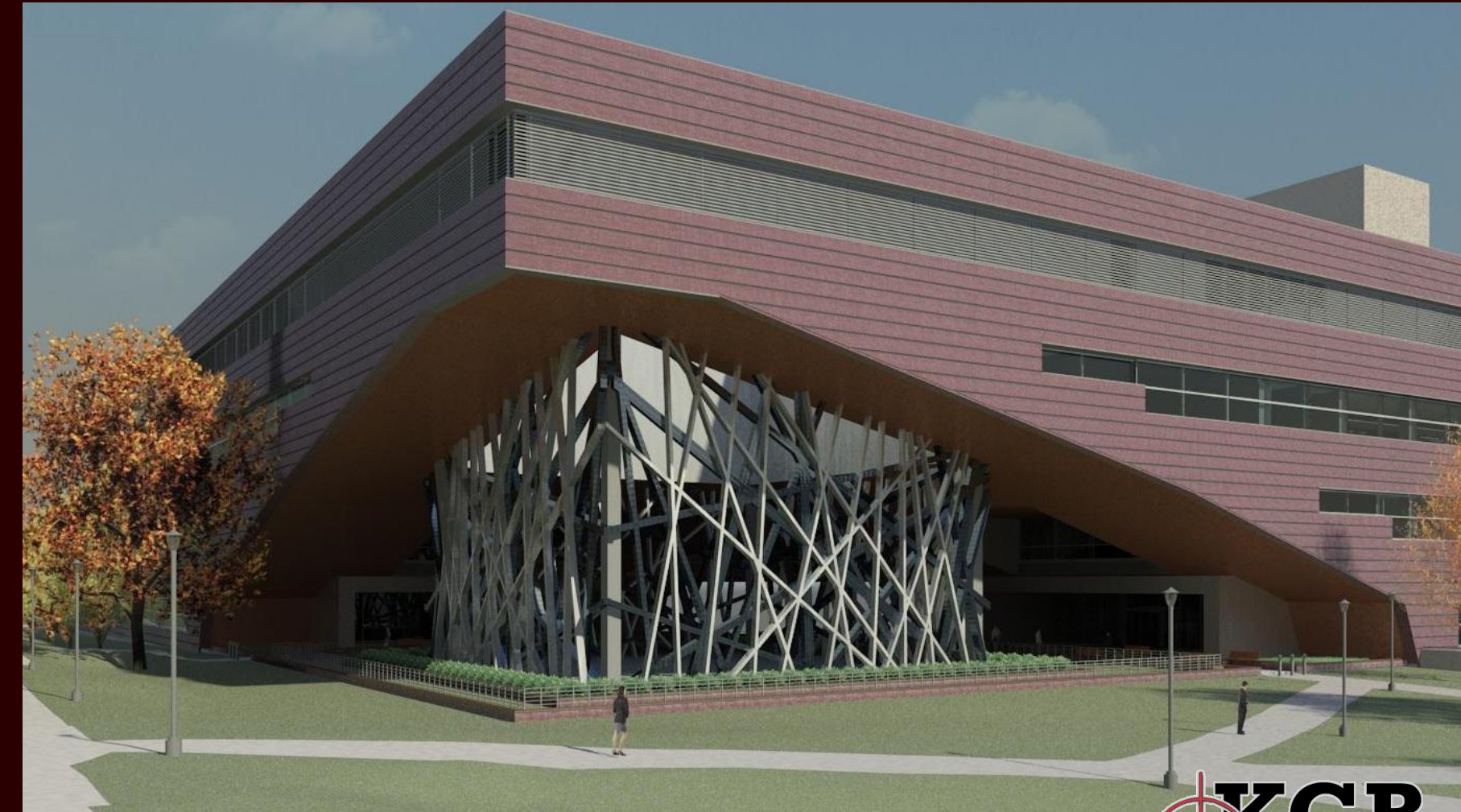
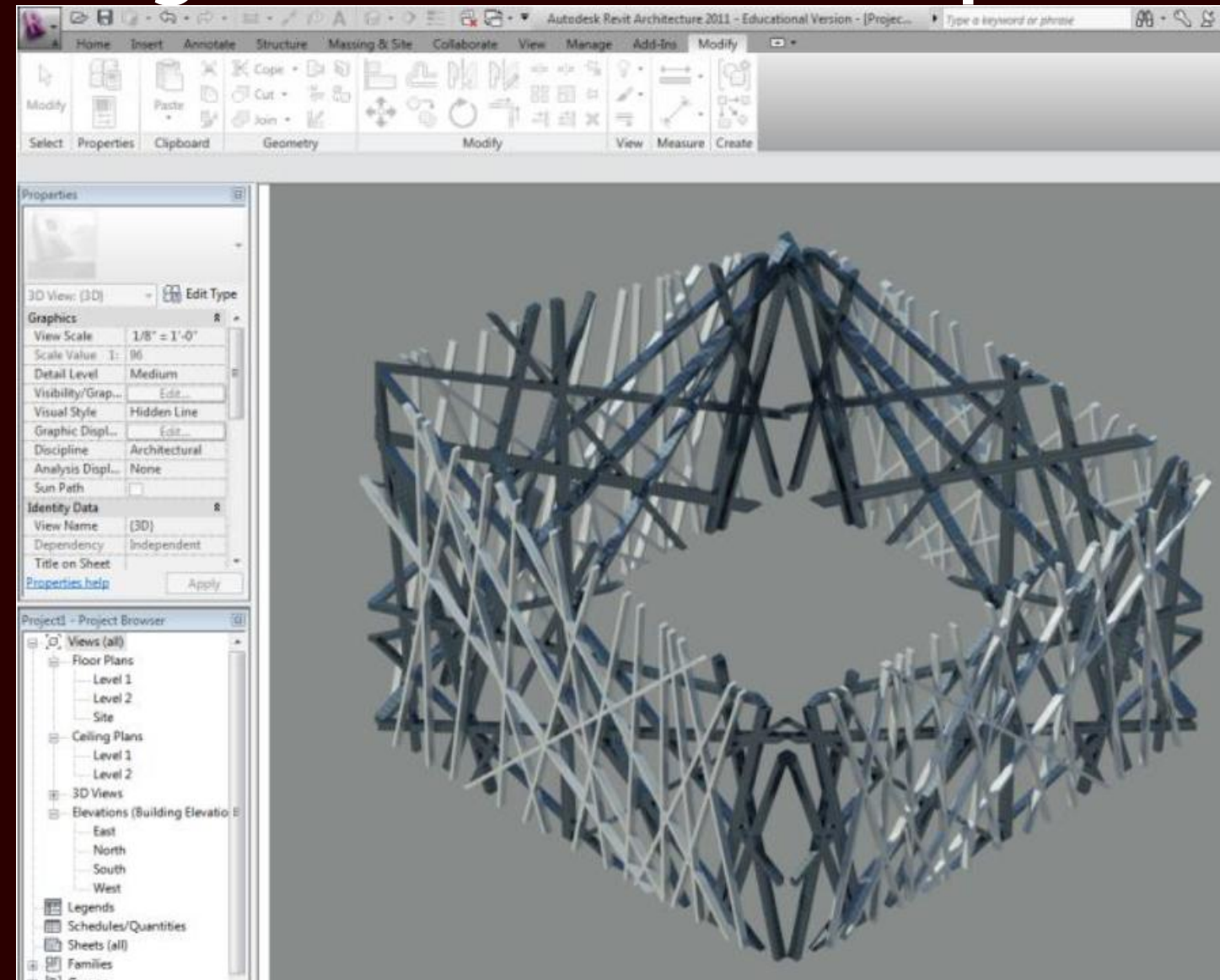
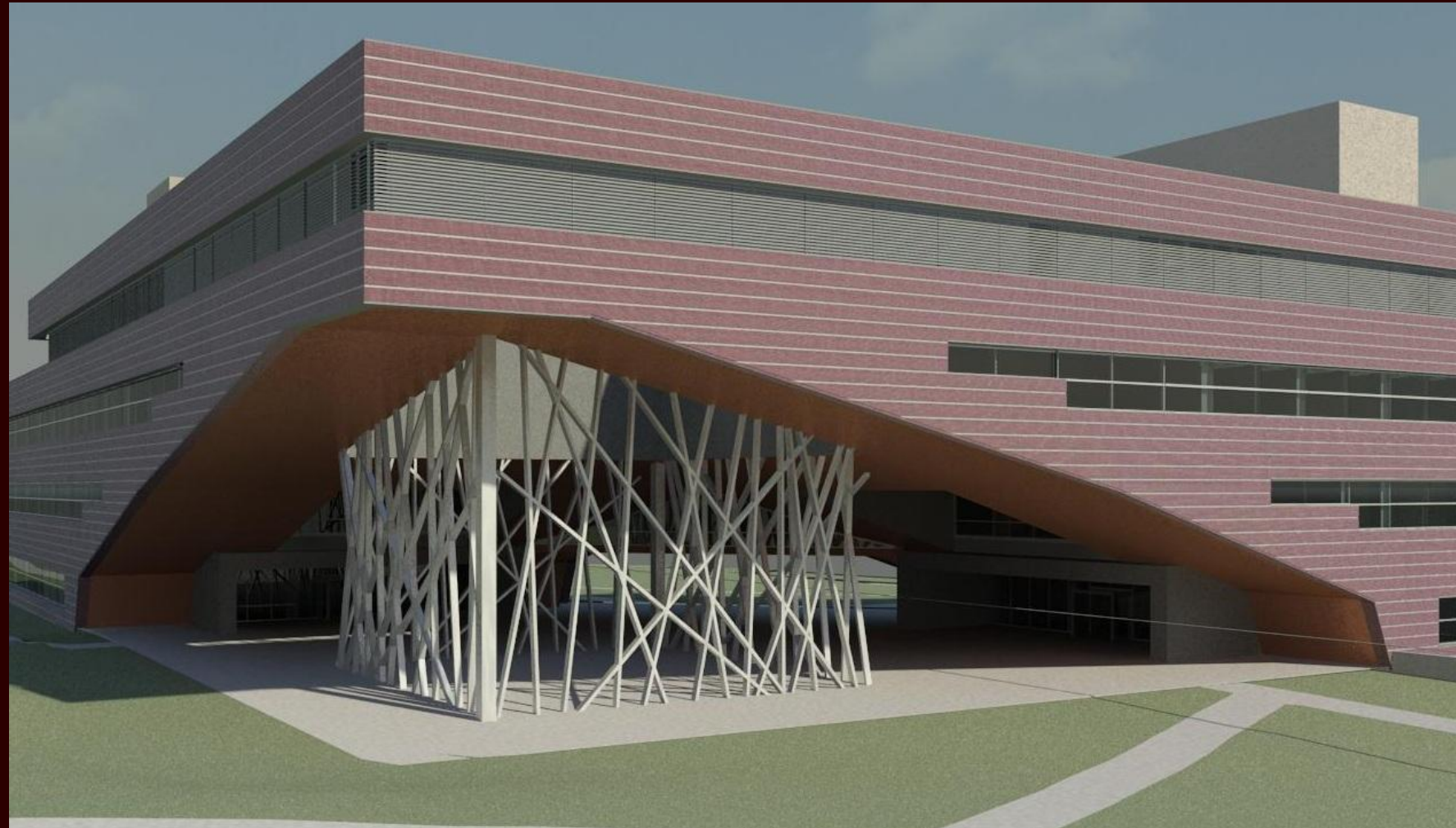




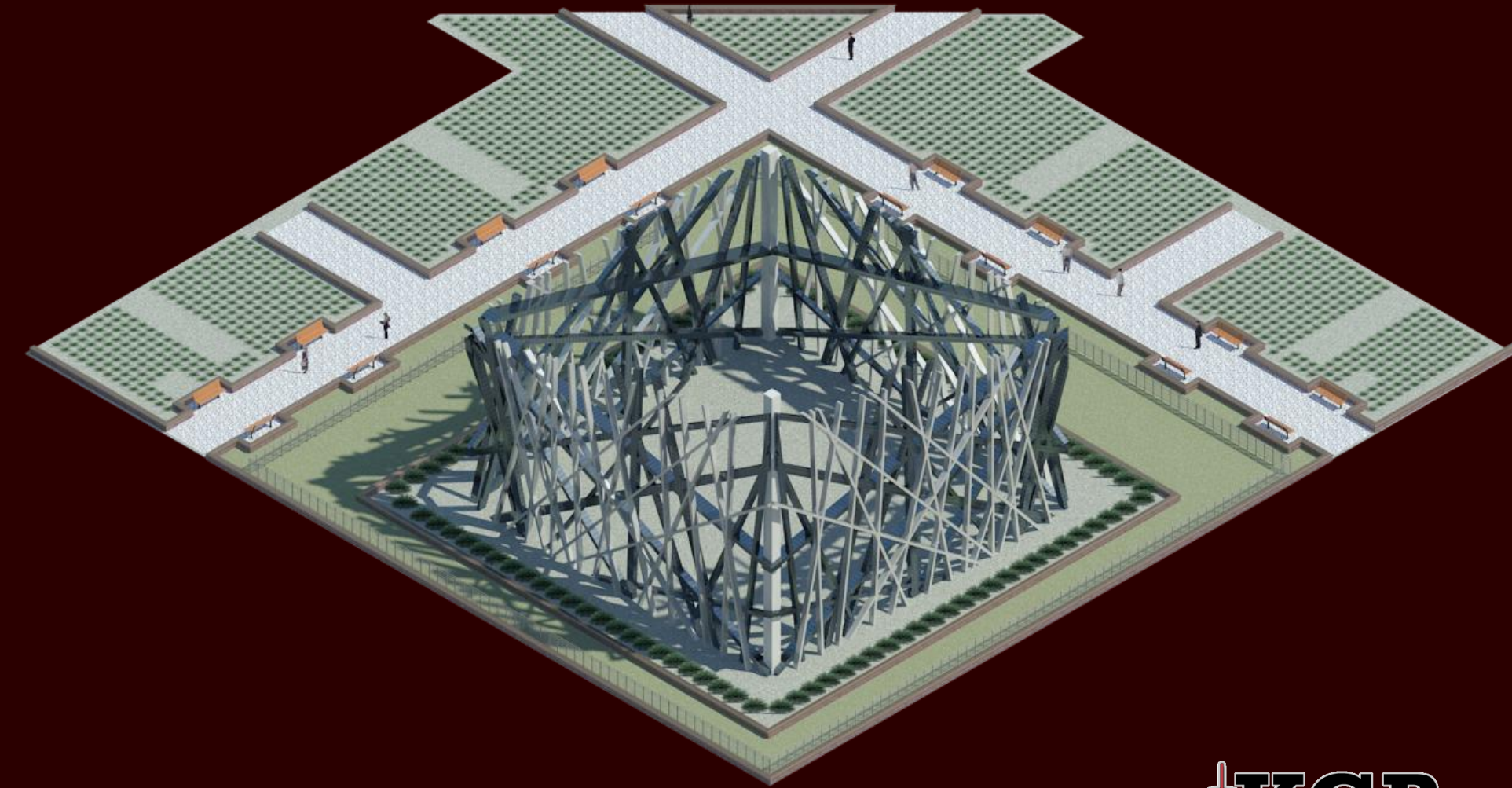
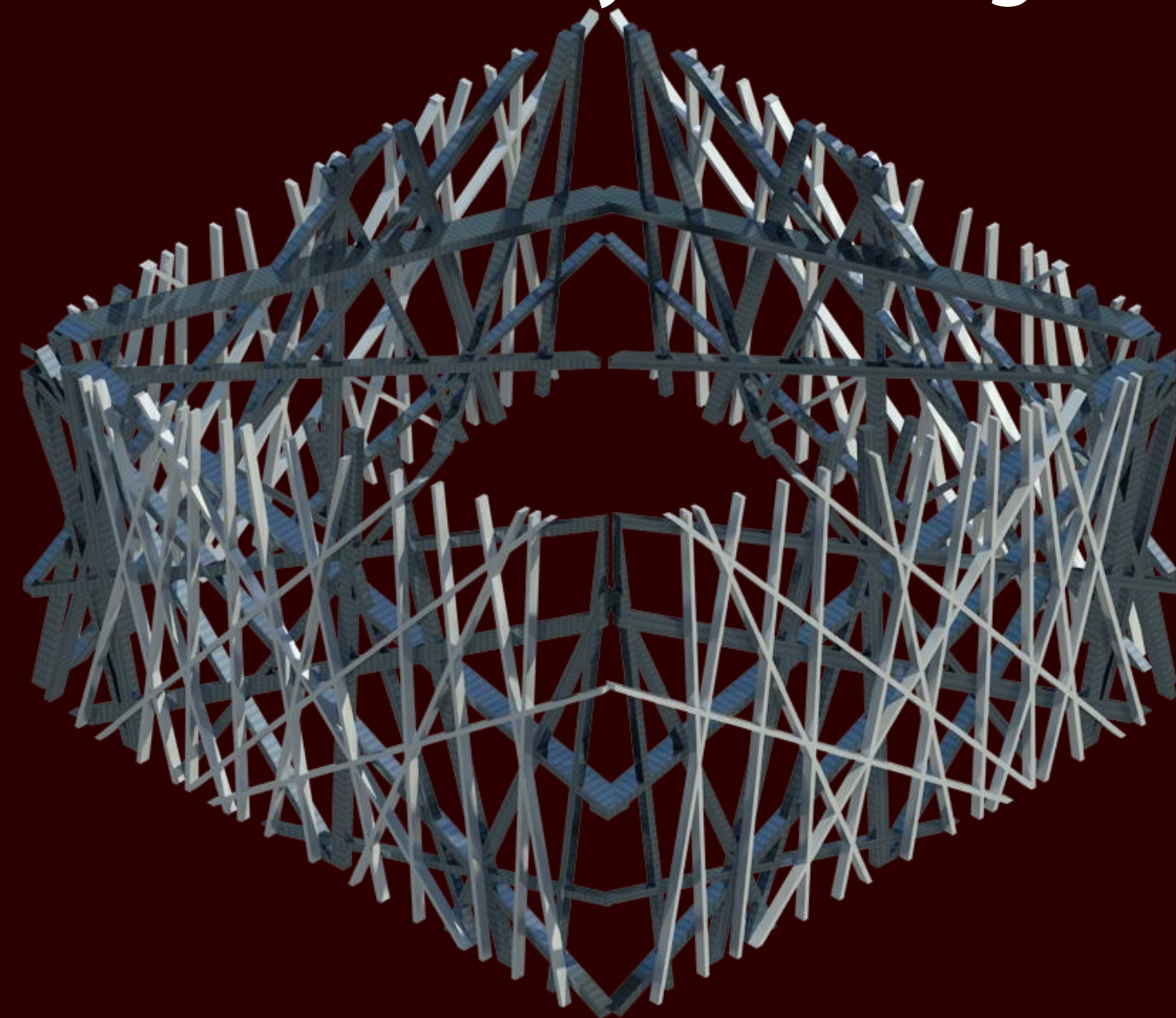
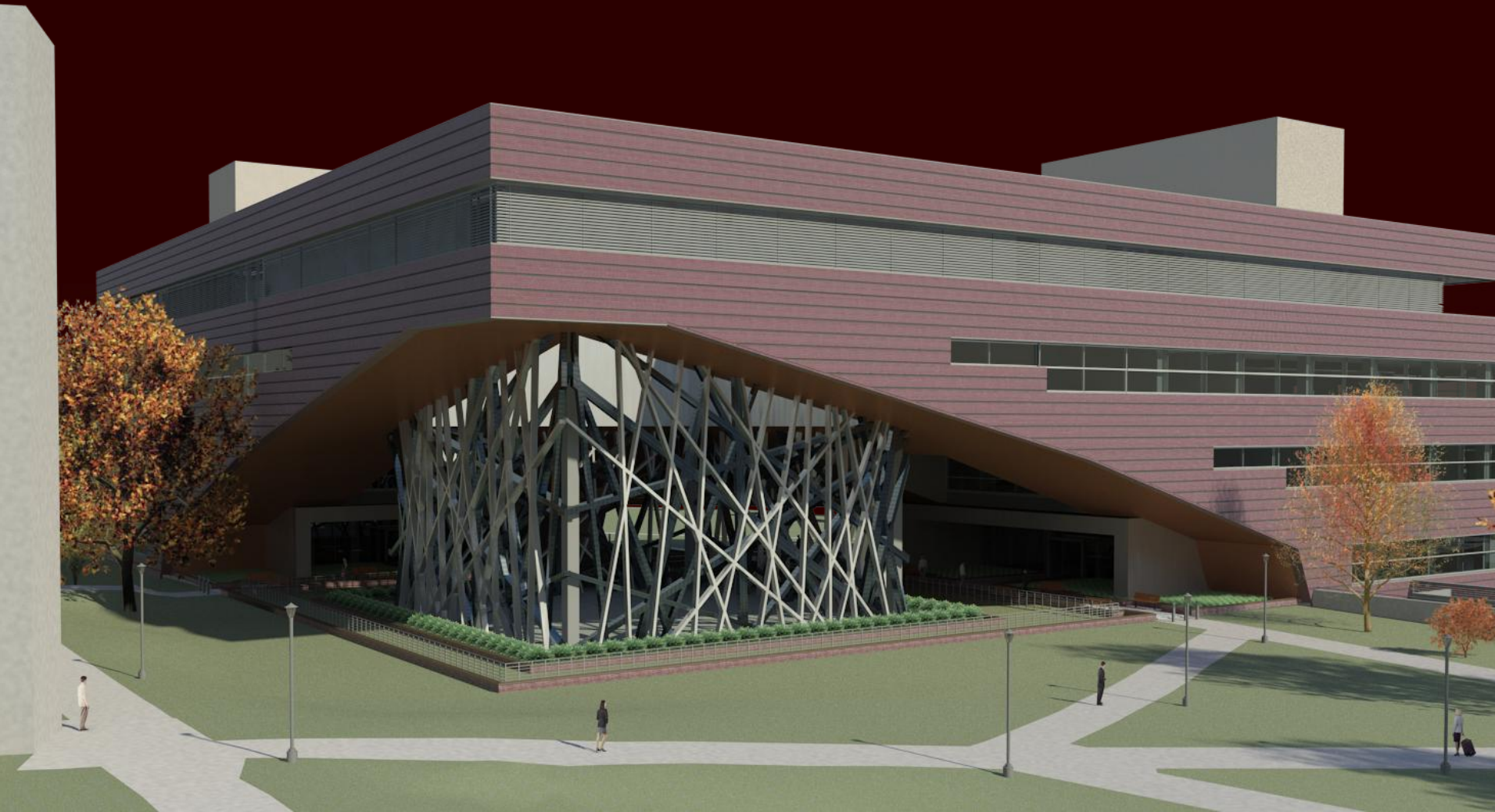
# Cage Structure Development



# Cage Structure Development



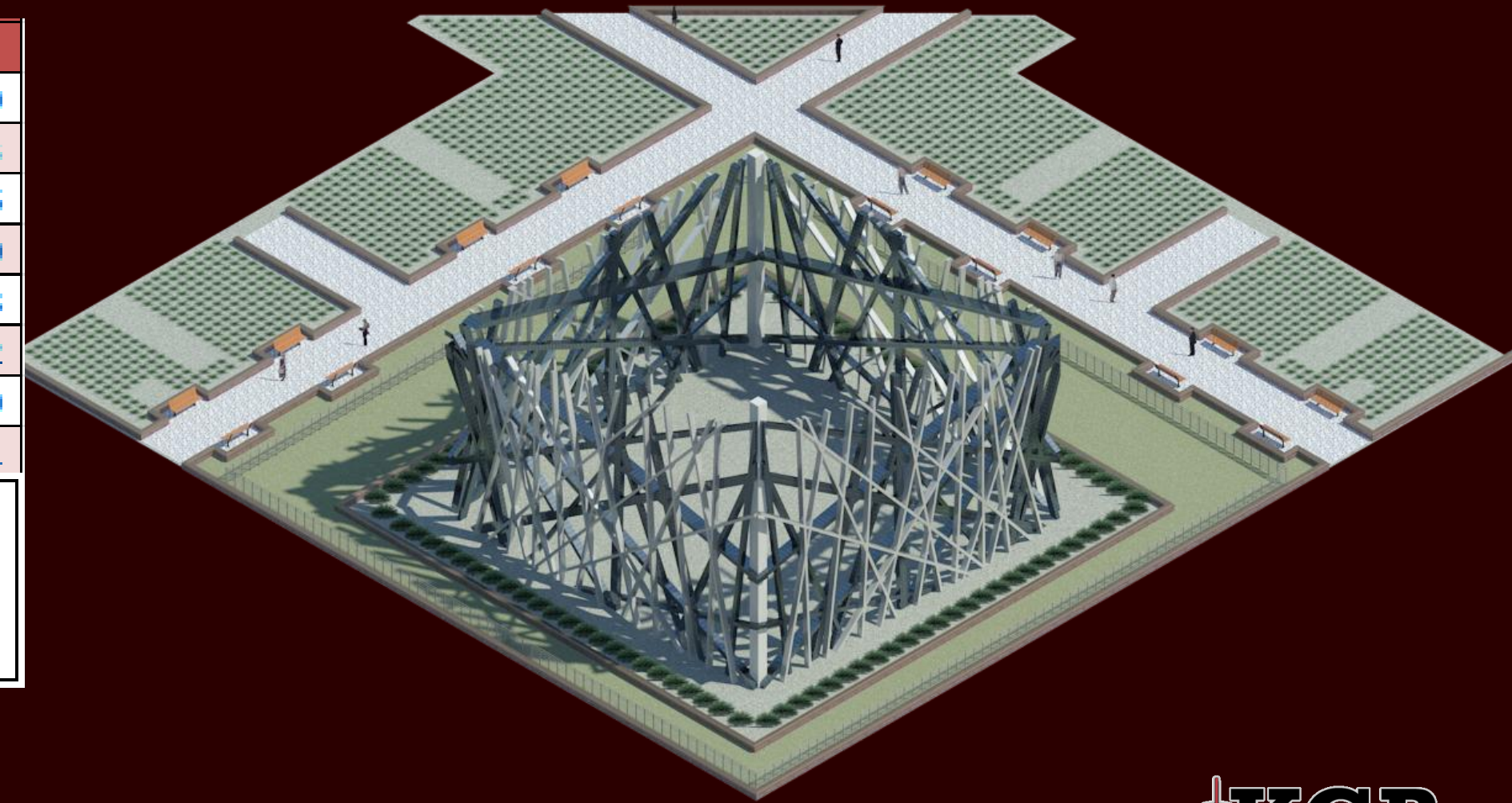
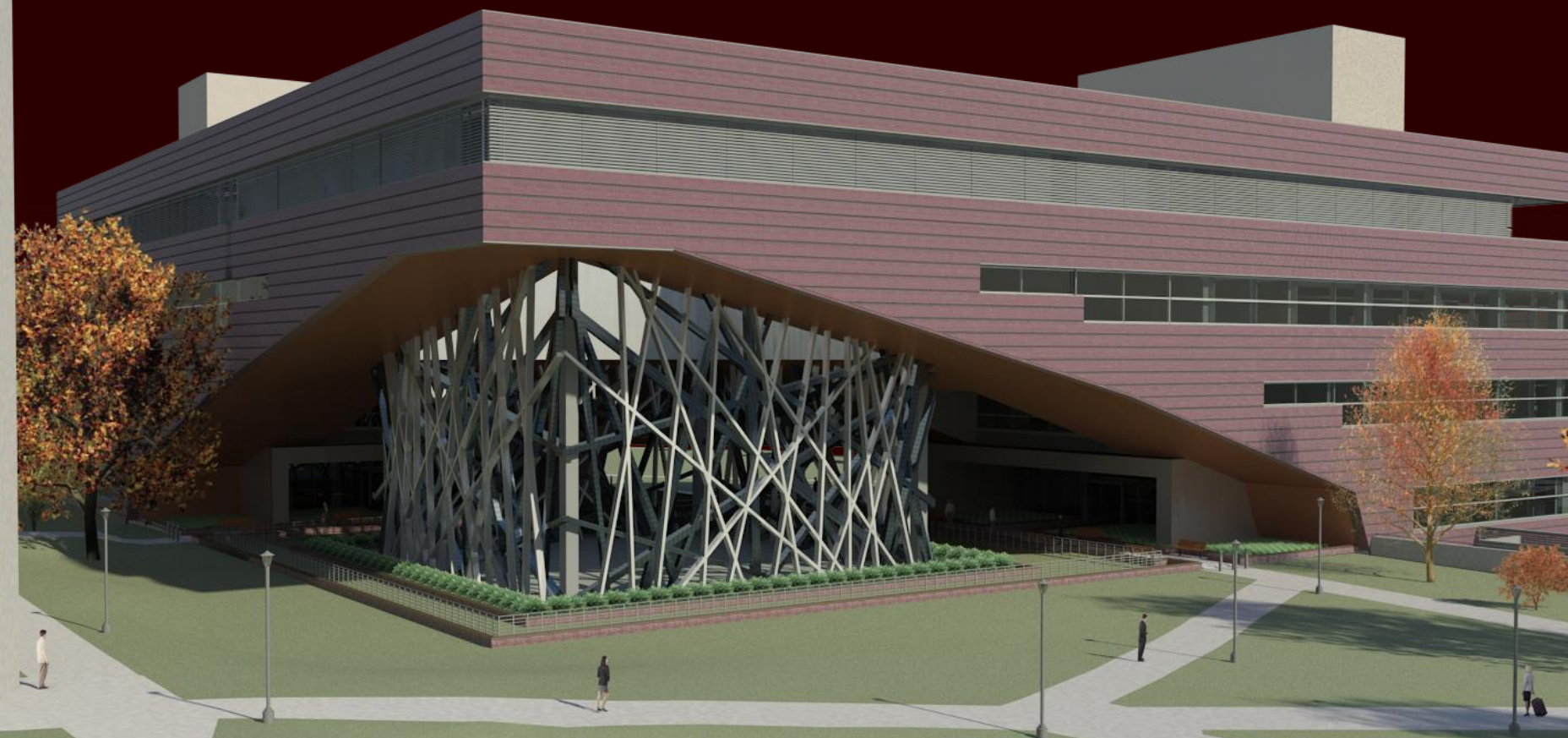
# Final Courtyard Design



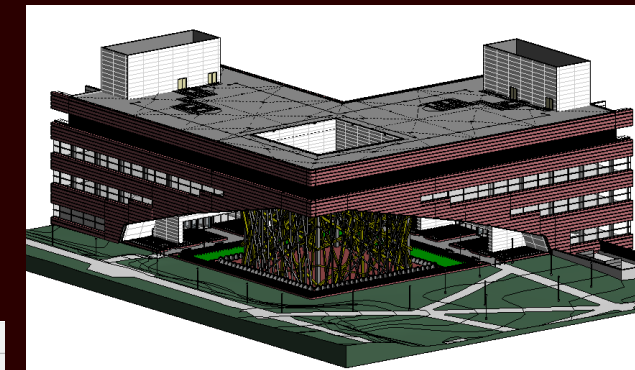
# Final Courtyard Design

Type	Total	Unit	Total	Unit	Cost
RPC Shrub: Acacia 3'-6"	101	EA	63.8	EA	\$ 6,443.80
RPC Shrub: Fountain Grass 1'-6"	733	EA	21.01	EA	\$ 15,400.33
Basic Wall: Courtyard Path Wall	1617.89	LF	12.34	LF	\$ 19,964.76
Park Bench 6'-0"	16	EA	448.5	EA	\$ 7,176.00
Courtyard Railing	486.5	LF	22.92	LF	\$ 11,150.58
Mulch	14492.05	SF	2.91	SY	\$ 1,561.92
Cage Structure	1	EA	1	EA	\$ 500,000.00
Courtyard Sod	9356.29	SF	265.95	MSF	\$ 2,488.31

Total Including O & P,  
Delivery, Waste, & Time  
Modifications = **\$866,984.16**

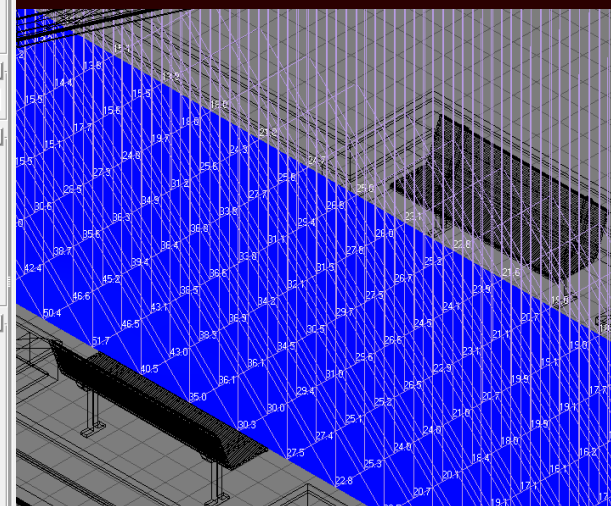
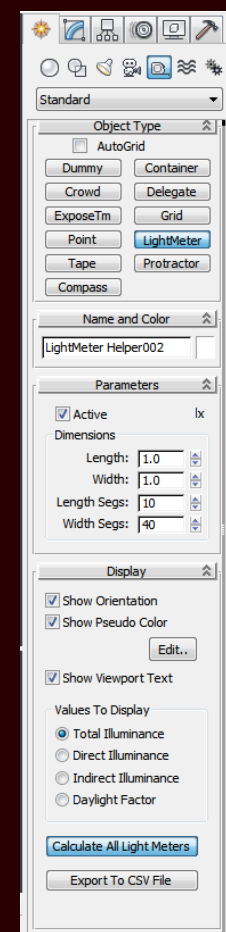


# Final Courtyard Design Lighting

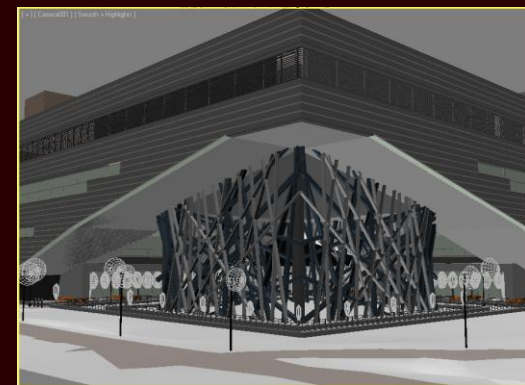


CantileverModel.rvt

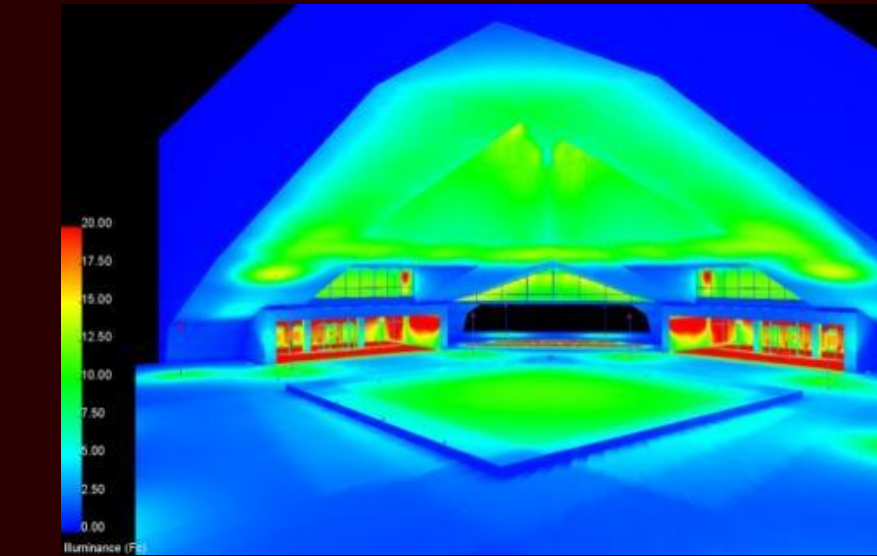
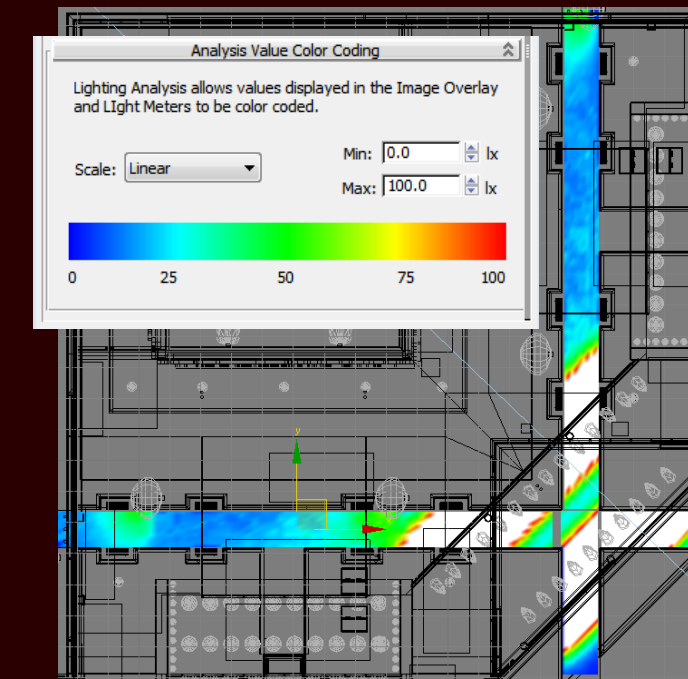
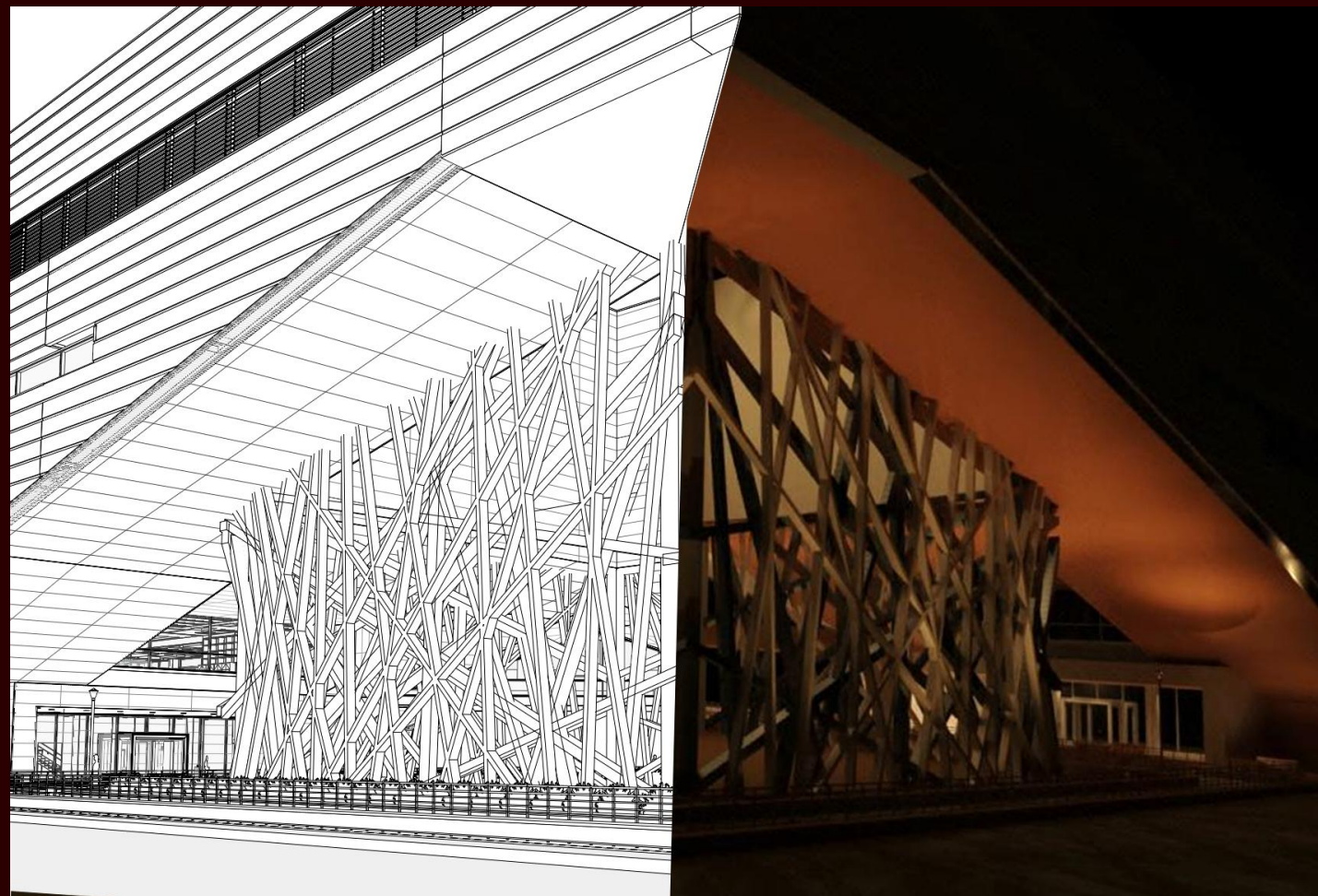
Export from Revit as  
Cantilever.fbx;  
Import to 3ds Max Design  
with File Link Manager



3ds Max Calc Points



CantileverModel.max



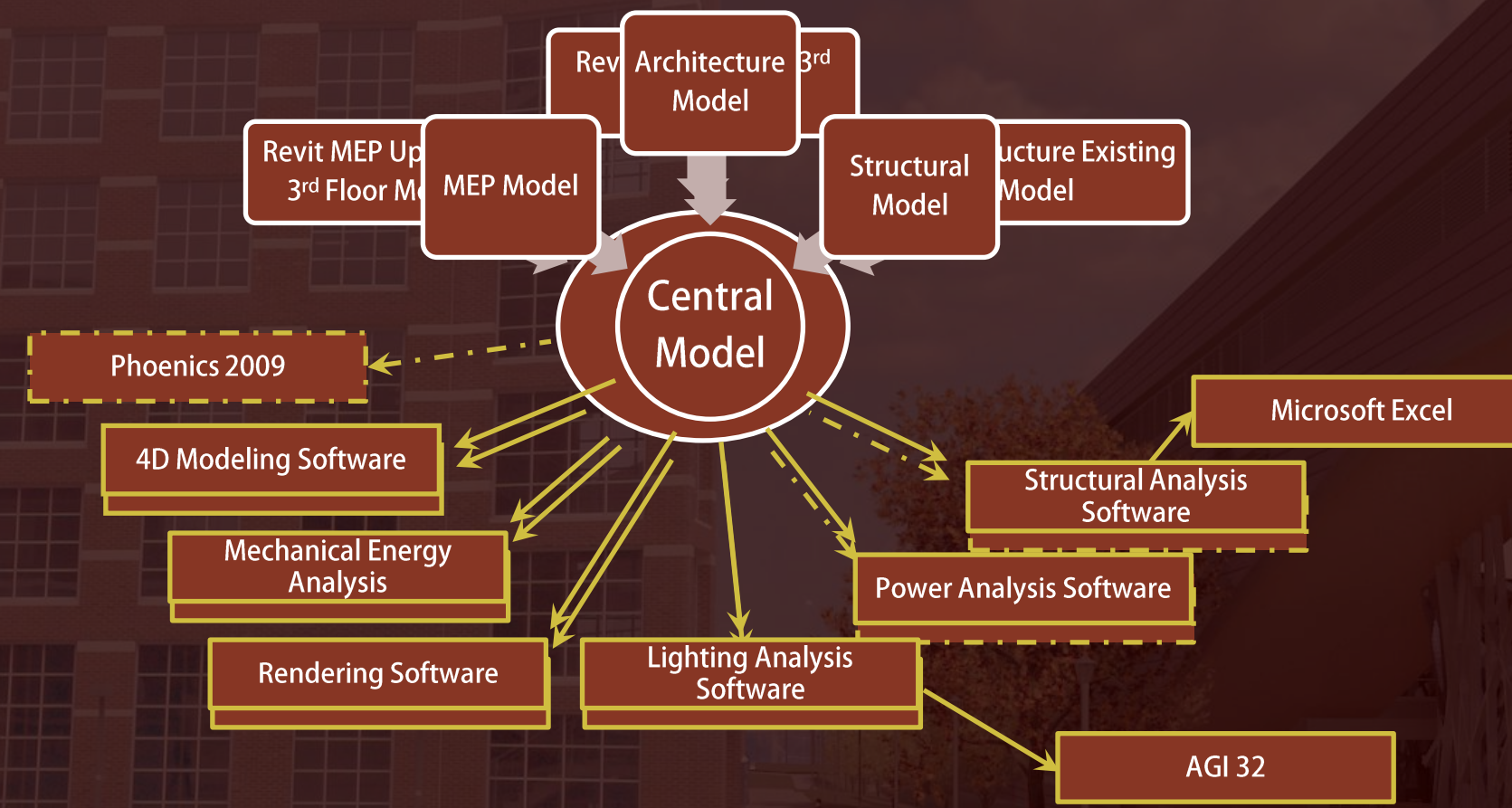
Courtyard Illuminance Summary

Calculation Grid	AGI Illuminance (fc)			3ds Illuminance (fc)			AGI Specific Values		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Max./Min	Coeff. Of Variation	Uniformity Gradient
Paths	1.10	7.72	63.20	0.102	23.15	59.00	57.45	1.16	3.10
LS Interior Well	1.90	10.32	72.40	Not Measured			38.11	0.59	13.30
LS Exterior Well	1.80	9.33	39.10				21.72	0.41	7.48
MS Interior Well	1.90	9.91	47.60				25.05	0.49	15.03
MS Exterior Well	2.00	9.68	54.10				27.05	0.51	18.03

# Summary of Cost Implications

SUMMARY OF SYSTEM FIRST COSTS				
	FAÇADE REDESIGN	STRUCTURAL REDESIGN	MECANICAL/ENERGY REDESIGN	COURTYARD REDESIGN
EXISTING COST	\$3,295,766	\$10,566,550	\$19,188,000	\$271,745
PROPOSED COST	\$3,051,834	\$8,275,735	\$21,040,000	\$604,910
SAVINGS/EXPENSE	\$243,932	\$2,290,815	\$1,852,000	\$333,165
<b>TOTAL FIRST COST SAVINGS = \$349,582</b>				

# KGB Maser Conclusions



- Decreased energy consumption by **14.2%**
- **Reduced size** and **cost** of structural system: **\$2,290,815**
- Proposed façade provided **marginal operating cost savings** and **lower initial cost** in lighting and structural systems

## IPD/BIM Lessons Learned

- Must work consistently in **communicative** environment
- Challenging to keep **uniform** group formatting **standards**
- Need to **explain technical reasoning** behind each decision **to all disciplines**

- Adequate time must be allotted for **overcoming** software design issues
- **Not all information** can be shared between modeling platforms; intermediate steps must be taken
- A **higher level of coordination** can be achieved during system designs
- Model sharing is a **one way street** outside of Revit platforms





MILLENNIUM SCIENCE COMPLEX - UNIVERSITY PARK, PA

# Acknowledgements

## The Thornton Tomasetti Foundation

## The Leonhard Center Penn State

## Faculty Advisors

Bob Holland

Andres Lepage

Richard Mistrick

Ted Dannerth

Kevin Parfitt

Jelena Srebric

John Messner

Moses Ling

## Whiting Turner

Chris Dolan

## Penn State OPP

Dick Harris

## Corey Wilkinson

Paul Bowers

## Thornton Tomasetti Engineers

## Flack & Kurtz MEP Engineers

## HOK

John Jackson

## Penn State Students

Ryan Solnosky

Building Stimulus IPD/BIM Team

BIMception IPD/BIM Team

## SKM Systems Analysis

Johnny Ma

Ruperto Sanchez

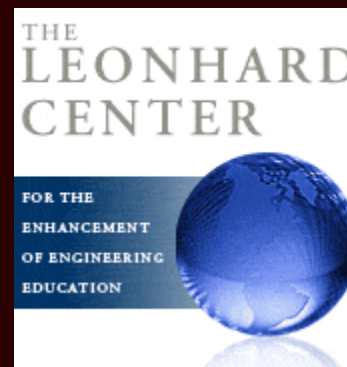
## BR+A Consulting Engr.

Britt Ellis

Michael Lucas

Patrick Morgan

PENNSSTATE





Questions and Comments

Thank you for your time