Penn State Ice Hockey Arena
Schematic Design Presentation
October 5th, 2011

UPR INTEGRATED DESIGN

Construction	Structural	Lighting/Electrical	Mechanical
Jeremy Heilman	Josh Progar	Nico Pugliese	Jim Rodgers

Team

OWNER
Pennsylvania State University
Office of the Physical Plant (O.P.P.)

BIM/IPD DESIGN TEAM
HPR Integrated Design

- CONSTRUCTION MANAGER
  - Jeremy Heilman
- LIGHTING/ELECTRICAL ENGINEER
  - Nico Pugliese
- MECHANICAL ENGINEER
  - Jim Rodgers
- STRUCTURAL ENGINEER
  - Josh Progar

Contractual

Jeremy Heilman ○ Josh Progar ○ Nico Pugliese ○ Jim Rodgers

Owner Contract Language

Sensitive Content Removed
for Security Reasons

Process

BIM Uses & Goals

Project Team BIM Goals

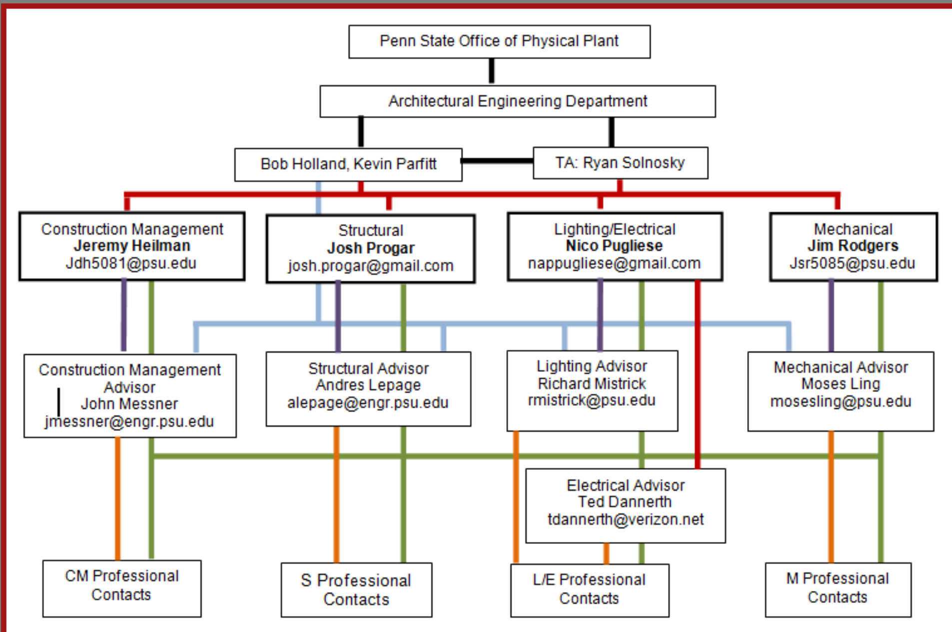
PRIORITY (HIGH/MED/LOW)	GOAL DESCRIPTION	POTENTIAL BIM USES
High	Maximize efficiency of design & coordination process to minimize clashes both in frequency and severity on-site	3D Coordination, Design Authoring, Design Reviews
High	Seamless workflow integration of all disciplines	3D Coordination, 4D Modeling, Info Exchange
High	Turnover the project on-time and on/under-budget	3D Coordination, 4D modeling
High	Increase sustainable design practices to ensure a more energy efficient product.	Energy Analysis, Sustainability (LEED) Evaluation
Medium	Perform design reviews in a virtual space for a more effective visualization of potential problems in a 3D environment	Design Review
Medium	Achieve desired LEED certification	Sustainability (LEED) Evaluation, Energy Analysis
Medium	Utilize integrated multi-disciplinary software to become proficient with advanced building modeling and model sharing	Design Authoring
Medium	To evaluate constructability and verify the feasibility of an aggressive schedule	4D Modeling, Design Reviews

Preliminary BIM Uses

X	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE
	PROGRAMMING	X	DESIGN AUTHORING		SITE UTILIZATION PLANNING		BUILDING MAINTENANCE SCHEDULING
	SITE ANALYSIS	X	DESIGN REVIEWS		CONSTRUCTION SYSTEM DESIGN		BUILDING SYSTEM ANALYSIS
		X	3D COORDINATION		3D COORDINATION		ASSET MANAGEMENT
		X	STRUCTURAL ANALYSIS		DIGITAL FABRICATION		SPACE MANAGEMENT / TRACKING
		X	LIGHTING ANALYSIS		3D CONTROL AND PLANNING		DISASTER PLANNING
		X	ENERGY ANALYSIS		RECORD MODELING		RECORD MODELING
		X	MECHANICAL ANALYSIS		OUT OF SCOPE OF THESIS PROJECT		
			OTHER ENG. ANALYSIS				
		X	SUSTAINABLITY (LEED) EVALUATION				
			CODE VALIDATION				
X	PHASE PLANNING (4D MODELING)	X	PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)
	COST ESTIMATION	X	COST ESTIMATION		COST ESTIMATION		COST ESTIMATION
X	EXISTING CONDITIONS MODELING	X	EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING

Communication

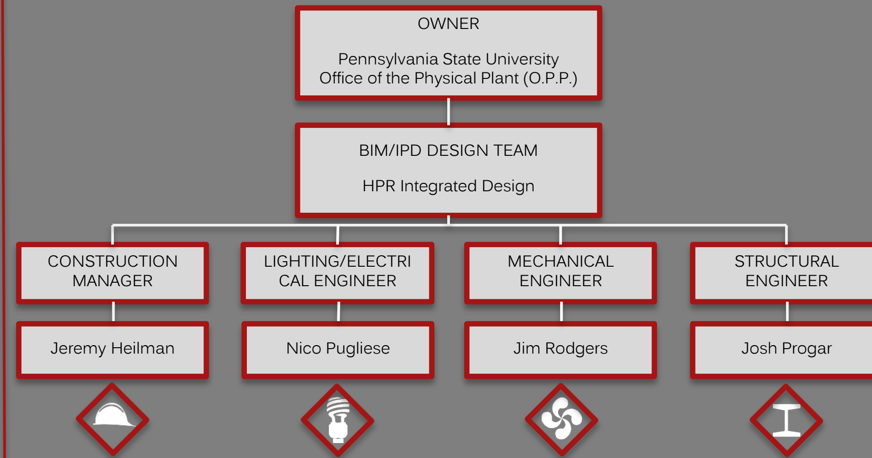
Organization Structure – Global Communication Exchange



Legend:

- Penn State to Course Administrators
- Course Administrators to BIM teams
- Course Administrators to Advisors
- BIM Teams to Advisors
- BIM Teams to Professionals
- Advisors to Professionals

Design Team Specific - Communication Exchange



Collaboration Methods

Decision Making

Meetings

- BIM Thesis Lab (Preferred)
- 307/308 Sackett Labs
- ICON Lab
- 162 Willard (Presentations)

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
6-10p	6-10p	5:30-7:30p	6-10p	5:30-7:30p	By appt.	By appt.
Design & Coord.	As needed	Weekly General	As needed	Design & Coord.	As needed	As needed

Decision Making

Conflict Occurs

Team Discussion – Pros/Cons

Issue Resolved?
Yes - End

Democratic Vote

Issue Resolved?
Yes - End

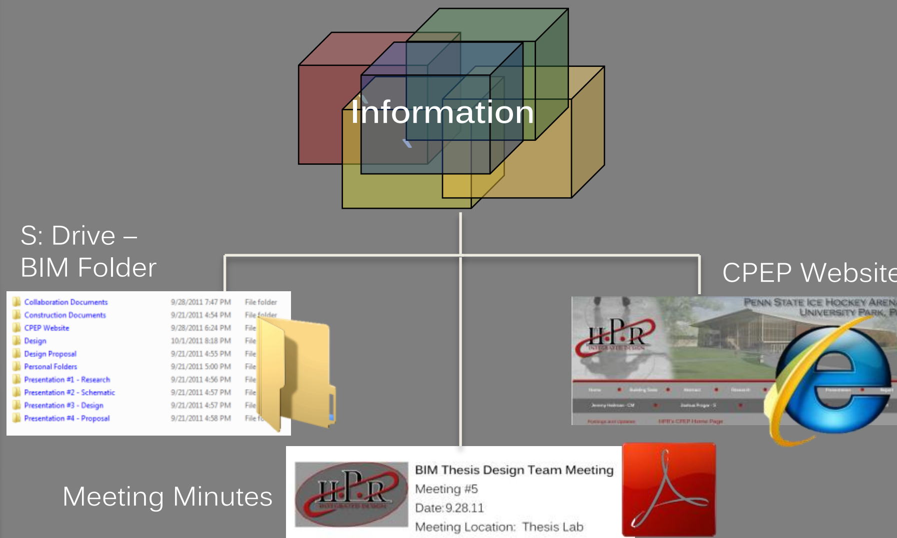
Unbiased Advisor Input

Issue Resolved?
Yes - End

Democratic Vote

Issue Resolved?
No - Reiterate

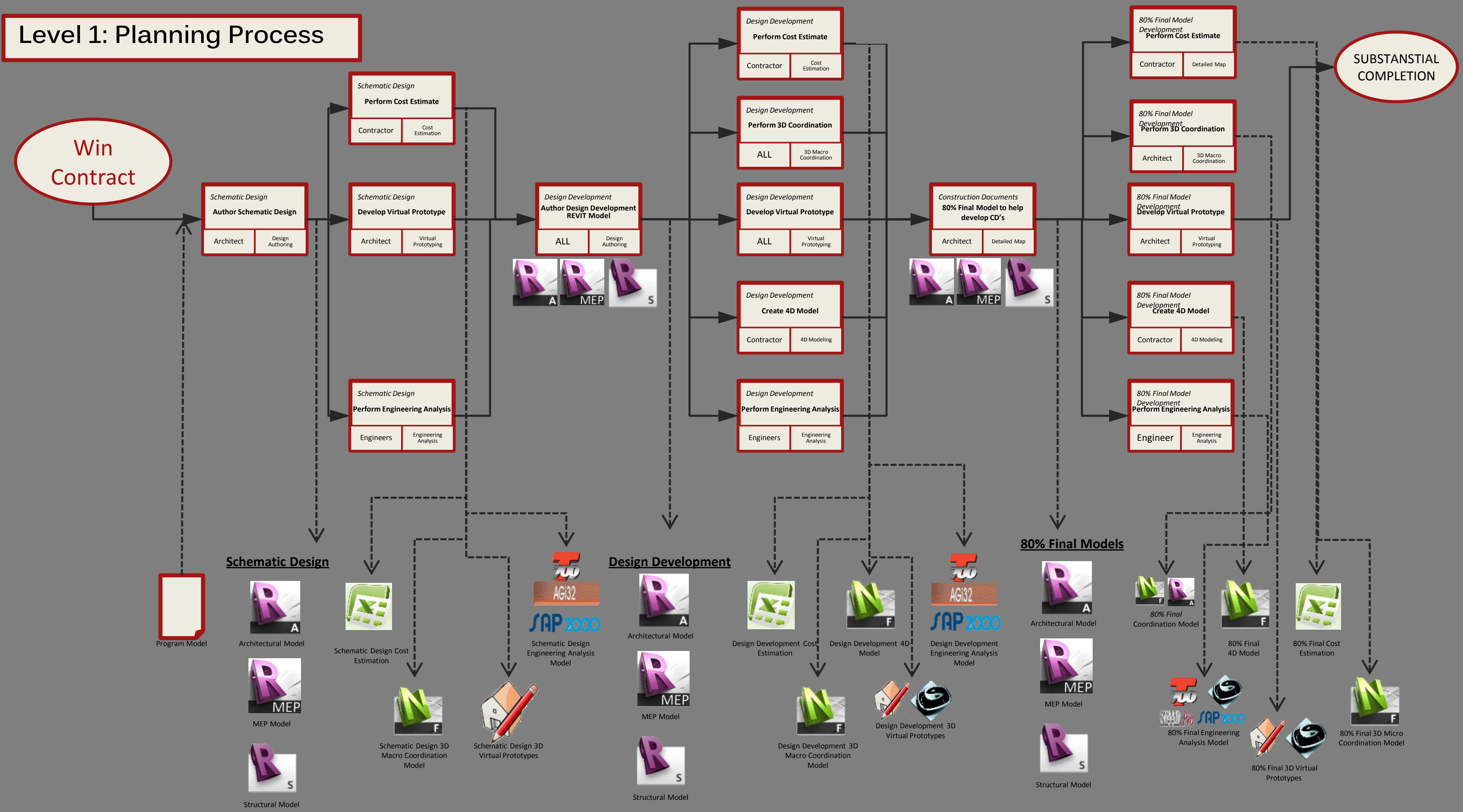
Information Exchange



BIM EX Process Map

Contractual | **Process** | Investigation | Vision | Reflection

Level 1: Planning Process



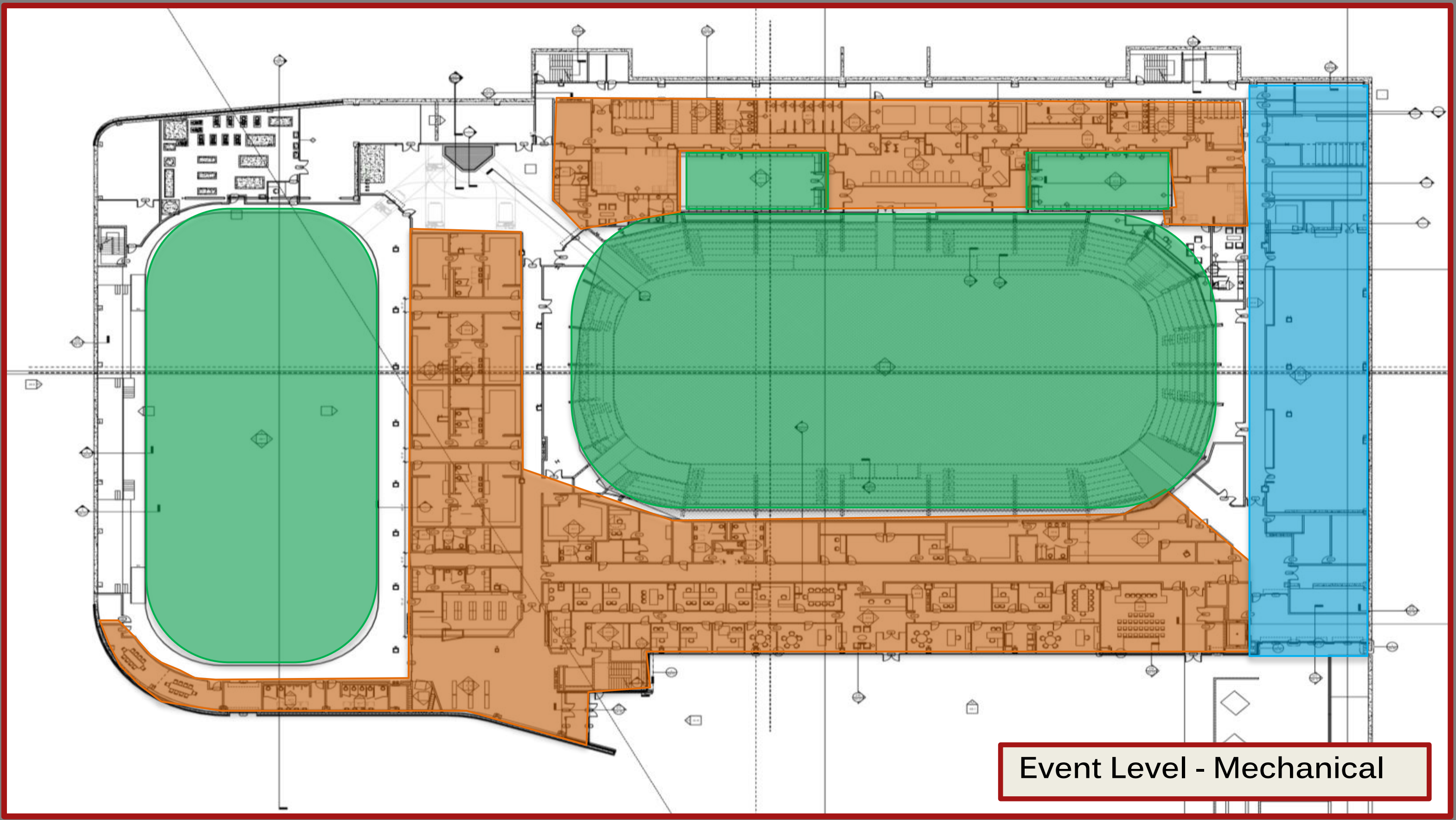
Jeremy Heilman ○ Josh Progar ○ Nico Pugliese ○ Jim Rodgers

Investigation

Jeremy Heilman ○ Josh Progar ○ Nico Pugliese ○ Jim Rodgers

Zones & Loads – Event Level

Types of Zones:



Dehumidification

Heat Recovery

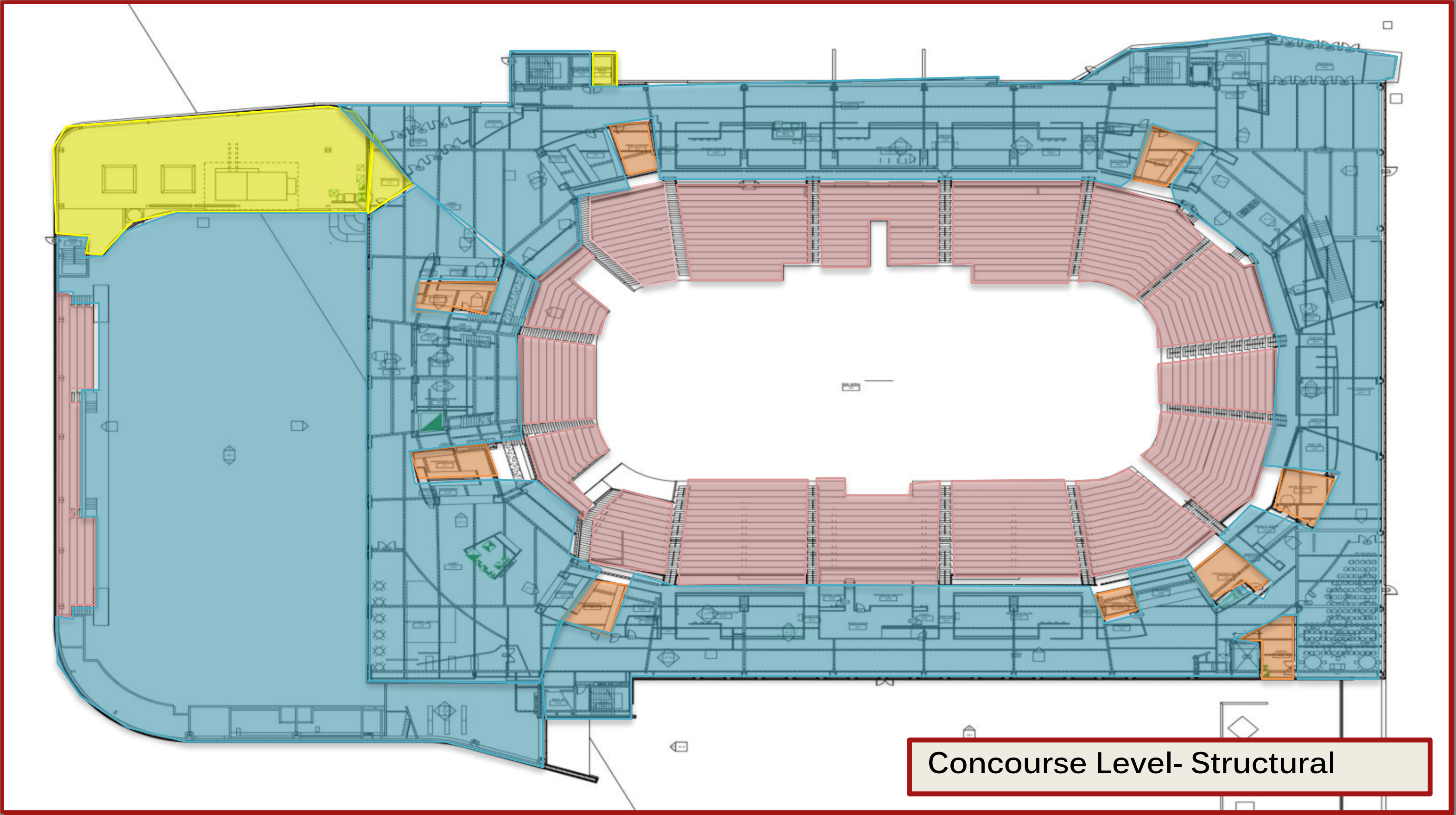
Standard AHU

Zones & Loads – Concourse Level

Live Loads:

Mechanical Rooms
150 psf

Arena Seating
60 psf



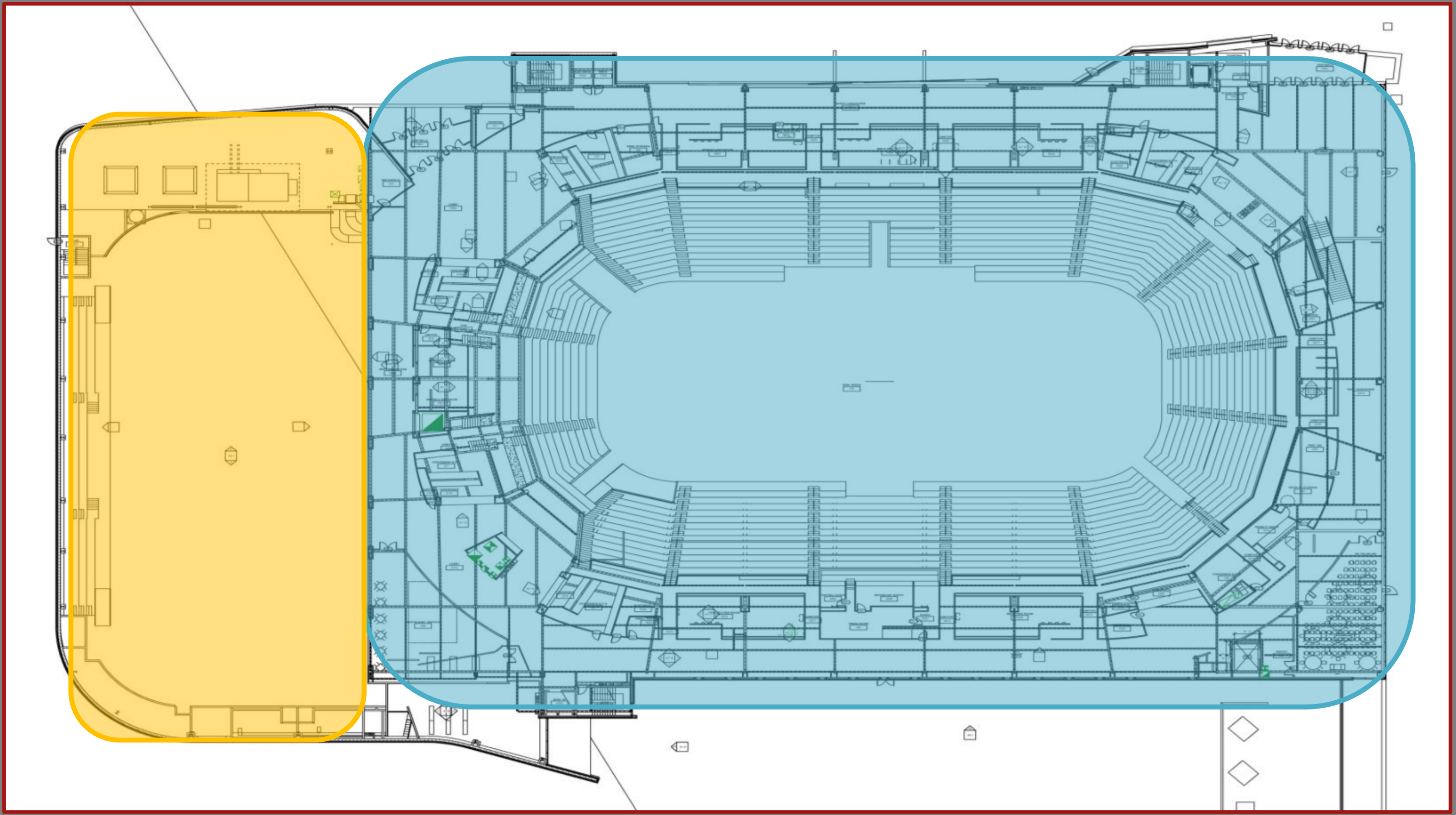
Concourse Level- Structural

All Other Areas
100 psf

Light Storage
125 psf

Zones & Loads – Concourse Level

Phasing Plans:



1st Phase – Main Arena

2nd Phase – Main Arena

Zones & Loads – Club Level

Contractual | Process | Investigation | Vision | Reflection

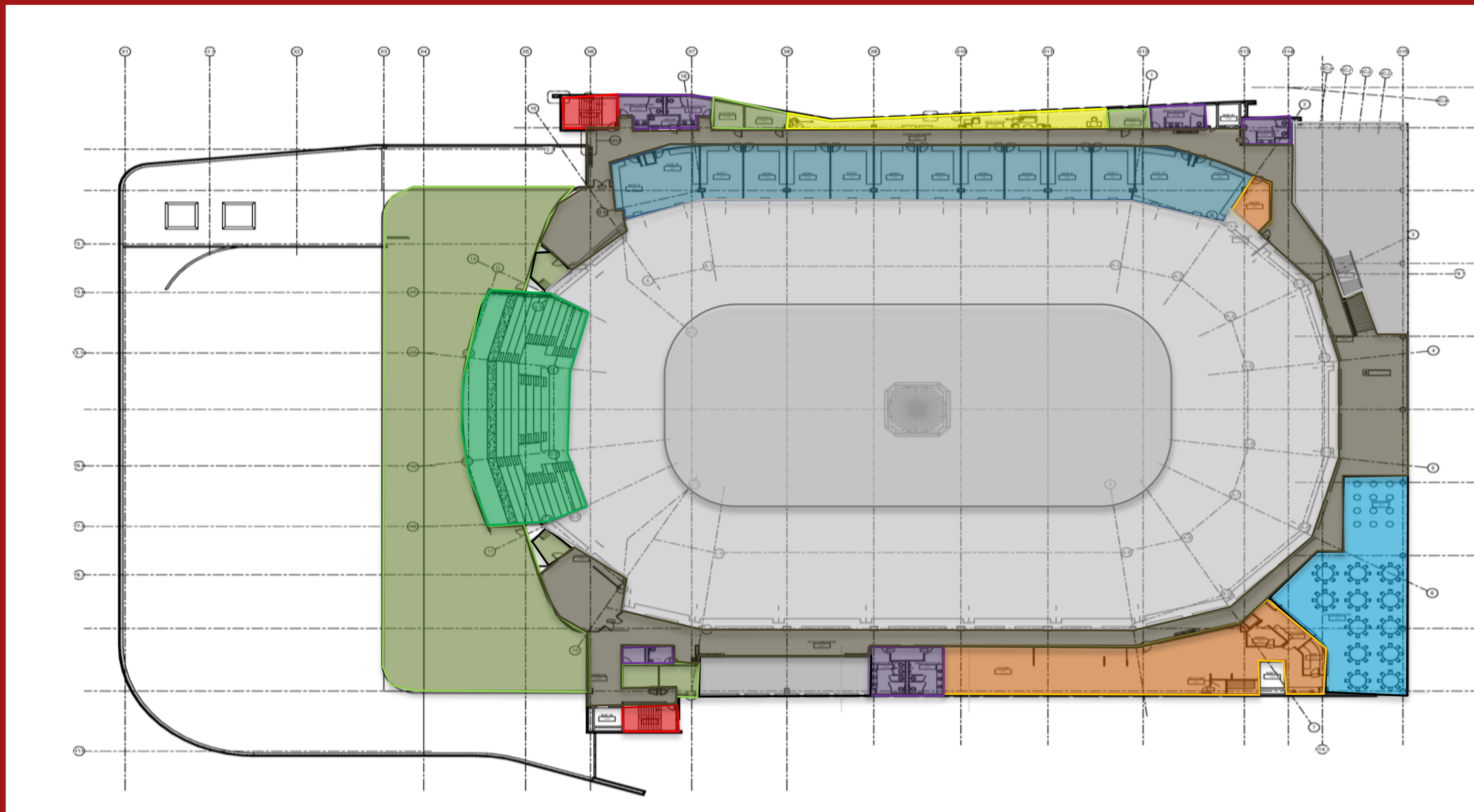
Lighting Power Density:

Suite – *0.82 [w/sf]*

Suite Lounge – *0.73 [w/sf]*

Restrooms – *0.98 [w/sf]*

Stairs– *0.66 [w/sf]*



Seating – *0.43 [w/sf]*

MEP – *0.95 [w/sf]*

Dining– *1.31[w/sf]*

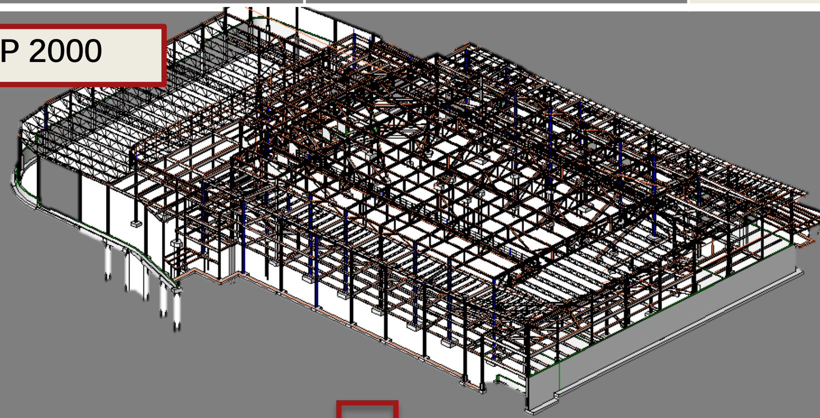
Rest. Serv– *0.99 [w/sf]*

Jeremy Heilman ○ Josh Progar ○ Nico Pugliese ○ Jim Rodgers

Models and Calculations

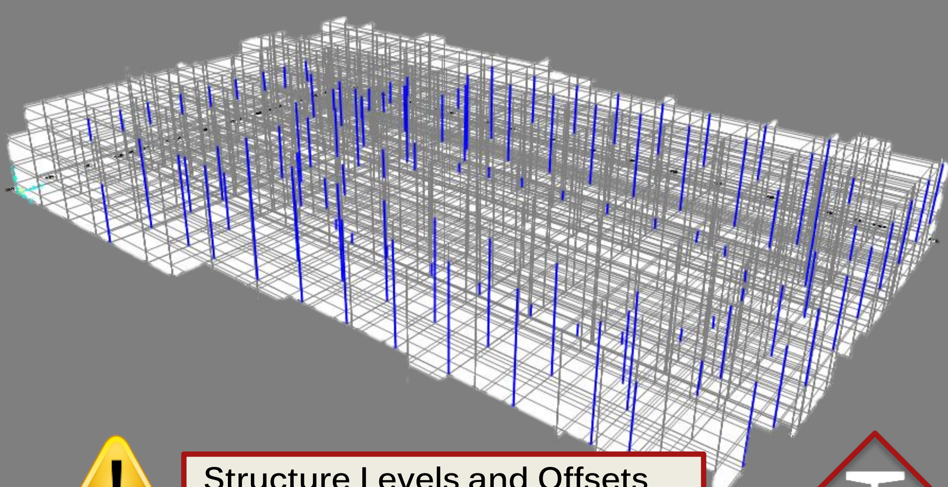
Contractual | Process | **Investigation** | Vision | Reflection

SAP 2000



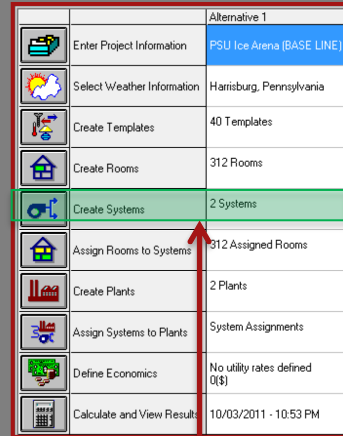
VERIFICATION

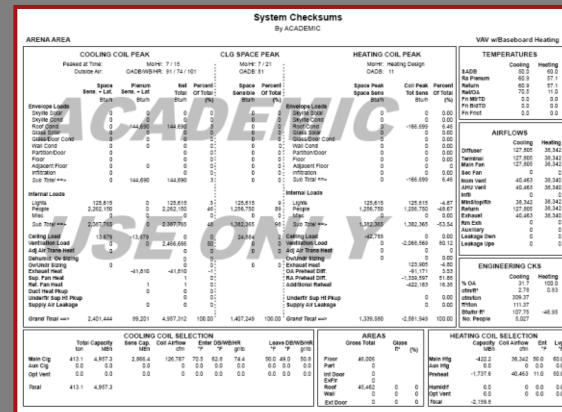
SPOT CHECKS



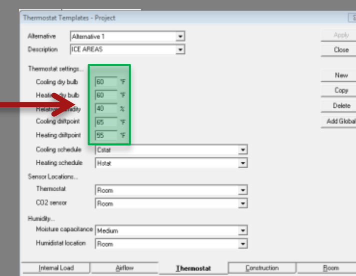
Structure Levels and Offsets

Trace 700





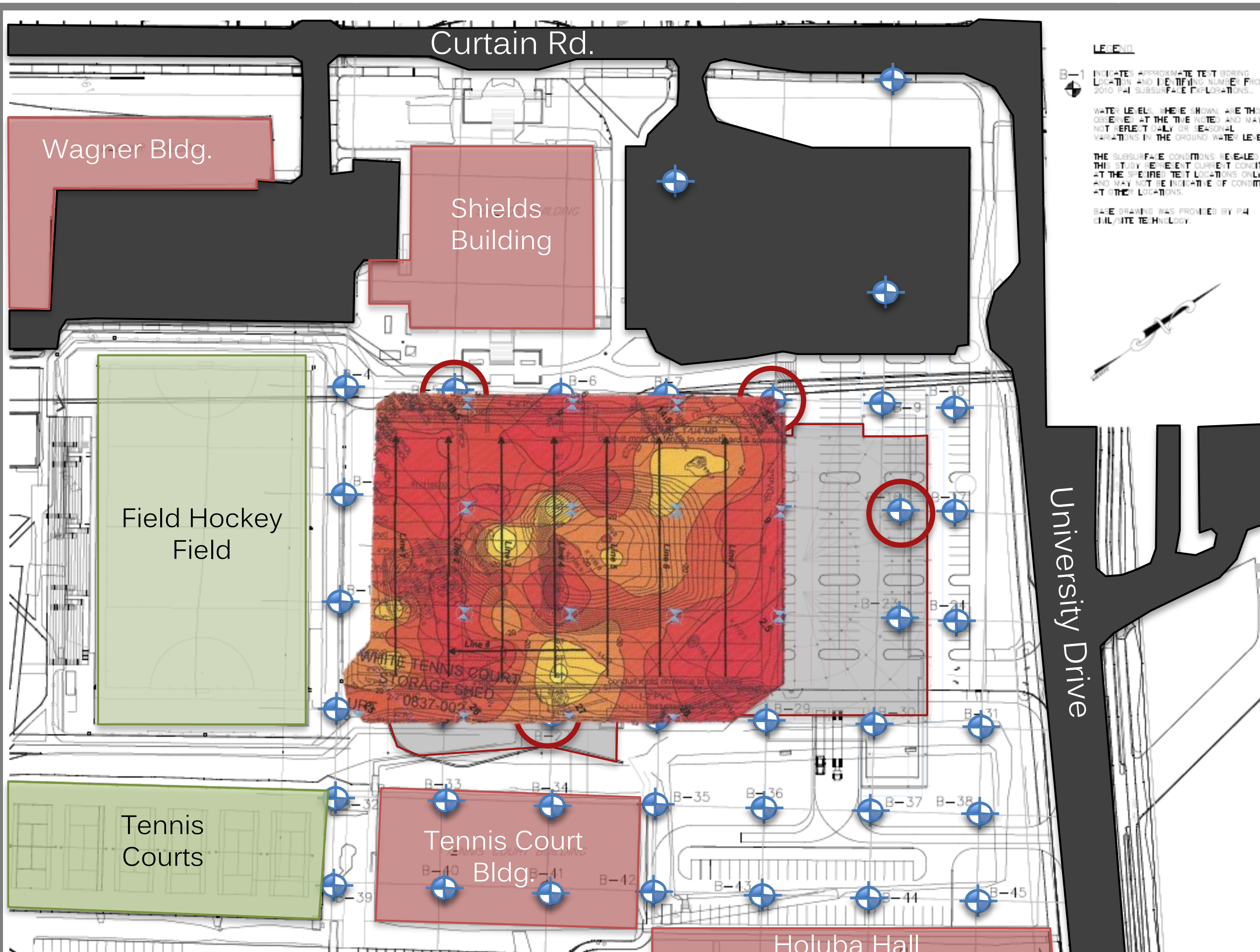
Two systems with different supply temperatures because of different set points

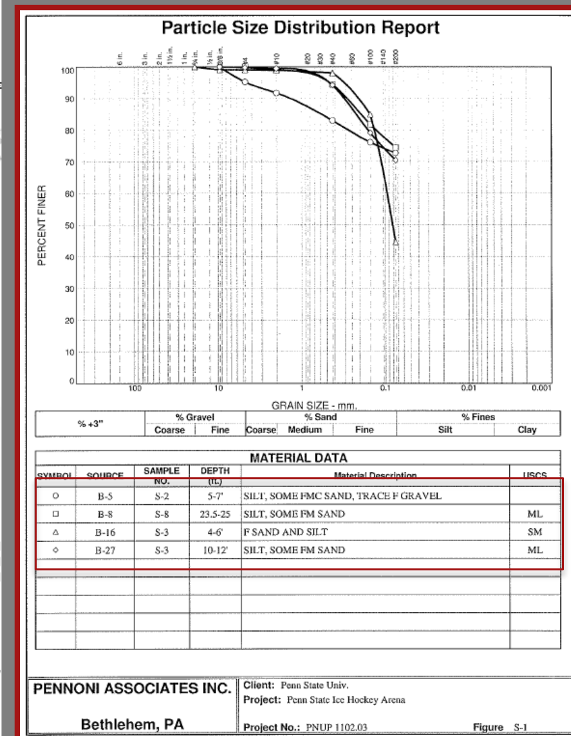


System	Cooling Load	Heating Load	CFM	CFM/SF
Arena	413.1 tons	422 MBTU	126,787	2.78
Event Level/Suites	362.3 tons	53,972 MBTU	151,989	.89

Trace Total CFM = 278,776 CFM
Existing Drawings = 250,000CFM

Geotechnical Report




Particle Size Distribution Report

PERCENT FINER

GRAIN SIZE - mm.

% +3"	% Gravel Coarse	% Gravel Fine	% Sand Coarse	% Sand Medium	% Sand Fine	% Fines Silt	% Fines Clay

MATERIAL DATA

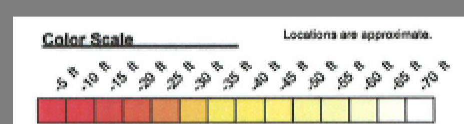
SYMBOL	SOURCE	SAMPLE NO.	DEPTH (ft.)	Material Description	USCS
○	B-5	S-2	5-7'	SILT, SOME FMC SAND, TRACE F GRAVEL	
□	B-8	S-8	23.5-25	SILT, SOME FM SAND	ML
△	B-16	S-3	4-6'	F SAND AND SILT	SM
◇	B-27	S-3	10-12'	SILT, SOME FM SAND	ML

PENNONI ASSOCIATES INC.
Bethlehem, PA

Client: Penn State Univ.
Project: Penn State Ice Hockey Arena
Project No.: PNUP 1102.03
Figure S-1

- Boring Plan – 45 Boring Locations
- Soils based on Borings
  - Sand and Silt
  - 3"-12" topsoil
- Bearing Capacity = 15 ksf
- Sinkhole Potential
- Site Class - C
- Top of Bedrock Plan

- Blasting May be Required to Excavate Bedrock
- Penn State has Established Procedures
- Construction Operation: 7am-7pm wkdays, 9am-7pm wkends

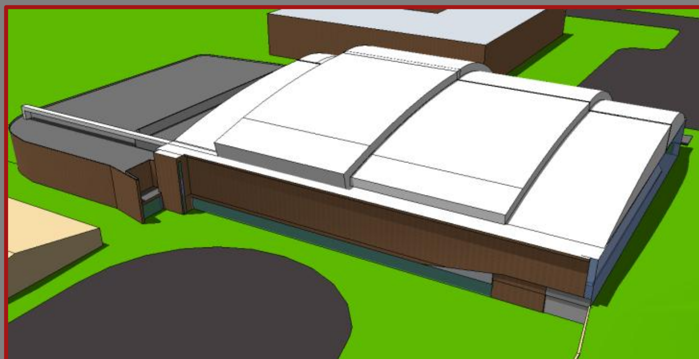


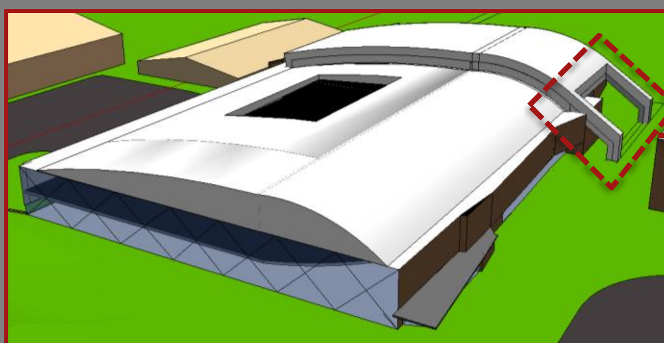
UPR INTEGRATED DESIGN

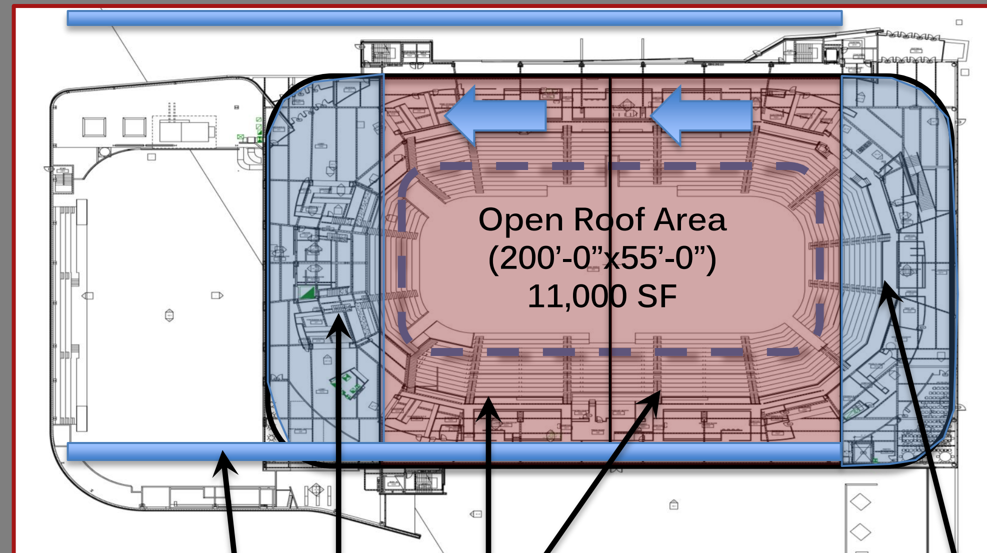
Vision

Team Vision

Contractual | Process | Investigation | **Vision** | Reflection





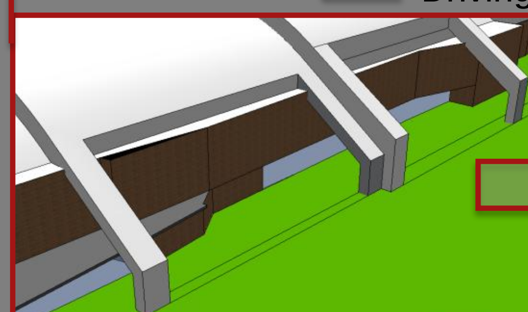


(2) Moving Panels
(110’-0” x 256’-0” each)

End Panels - Stationary

Driving Mechanism Rail

PRELIMINARY COST BREAKDOWN

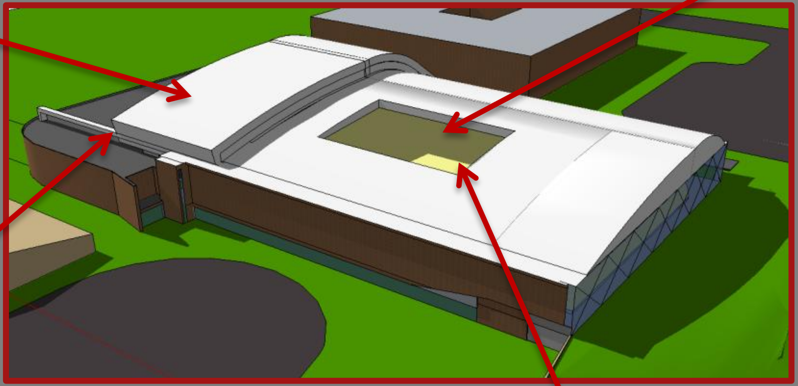


http://seacranes.com/

Team Challenges

Constructability: Logistics of erecting the roof and keeping the project on schedule.

Direct Sun: Reduce amount of direct sunlight striking playing surface.

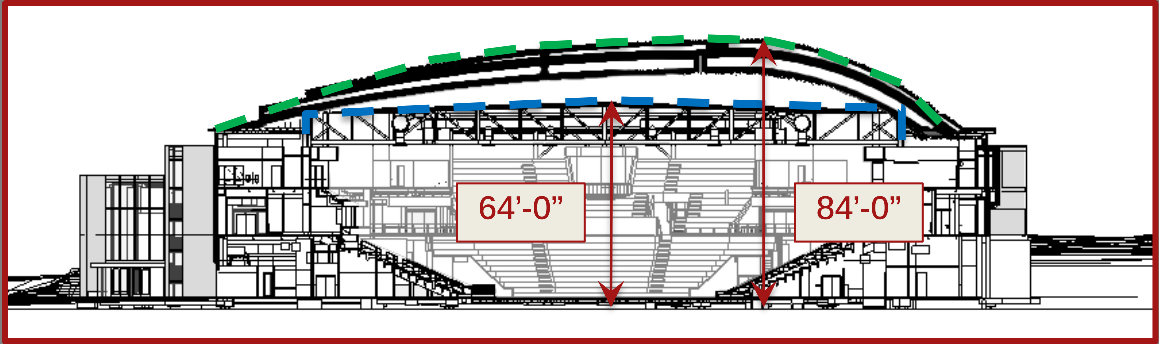


Driving Mechanism: Moving the structure means technical systems and requirements for safety and stability.

Open Roof Area: Open roof increases the concerns about humidity control and fogging.

Alternative Roof Profile

Offset Curve Profile



How it effects design…

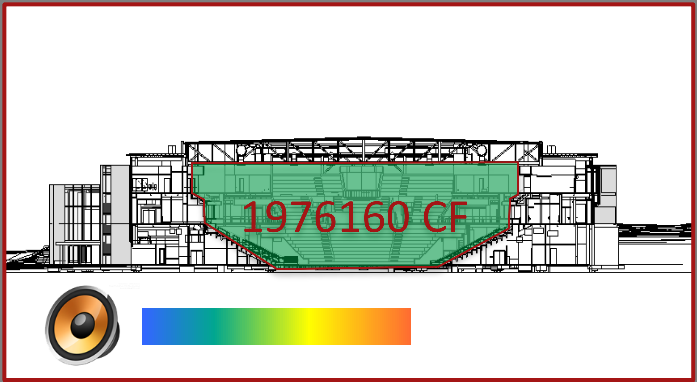
- **Curved Long Span Trusses:** Effects the design of the long span trusses both in depth and span length from 196' to approximately 250'

- **Production:** May increase lead times
- **Assembly:** Will the trusses for the roof be brought to the site assembled, or can they be constructed on-site

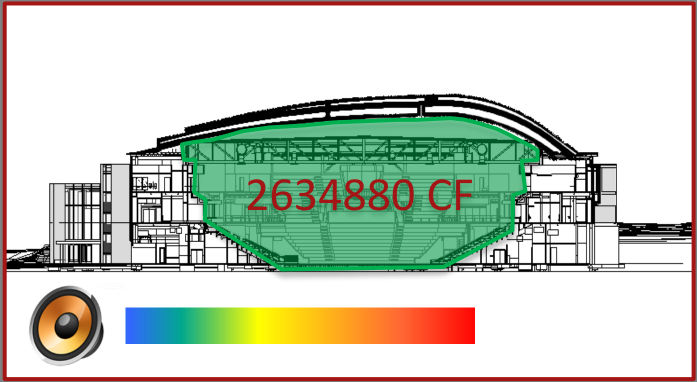
- **Architectural Interest:** Adds architectural form and interest to the building in both the interior and exterior

- **Added Volume Dimension:** Added volume can add a ventilation load depending on system type and can create acoustical concerns.

Volume Comparison

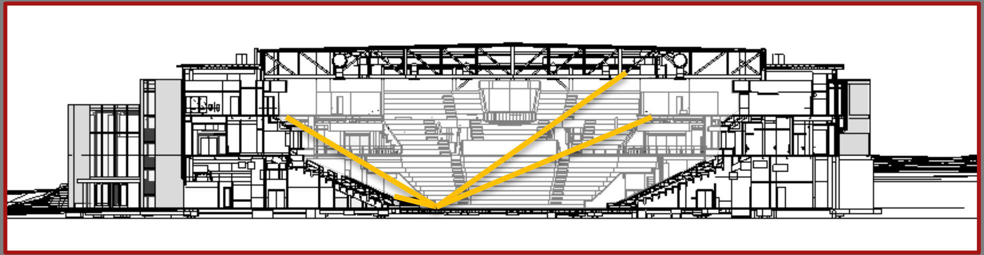


$T_{60} = V/sa$

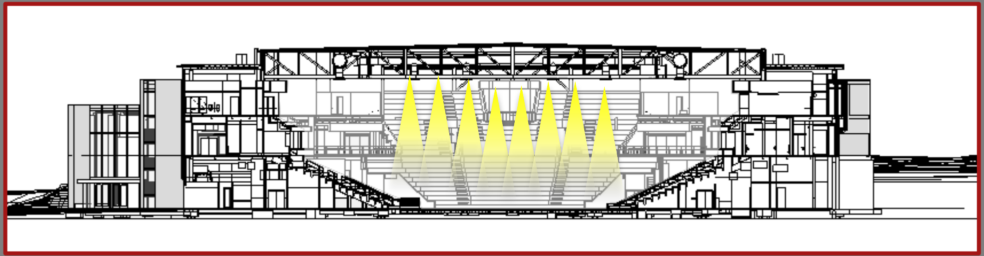


If volume increases faster than SxA then Reverb time should Increase.
Result: LOUDER

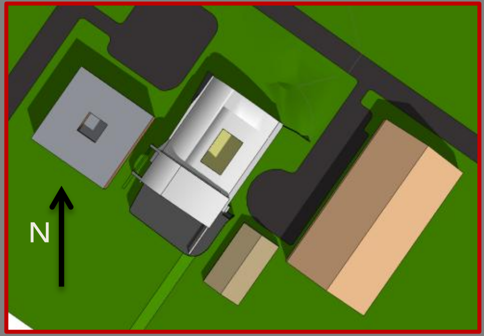
Line of Sight



Arena Lighting: Due to high reflectance of the ice playing surface, luminaires must not be placed in the line of site of spectators. Therefore, an overhead array of luminaires is the best solution.



Building Orientation



Due to the proximity to neighboring buildings the orientation of the building has little room for improvement. Shading devices may need to be employed to create more comfortable spaces for occupants.

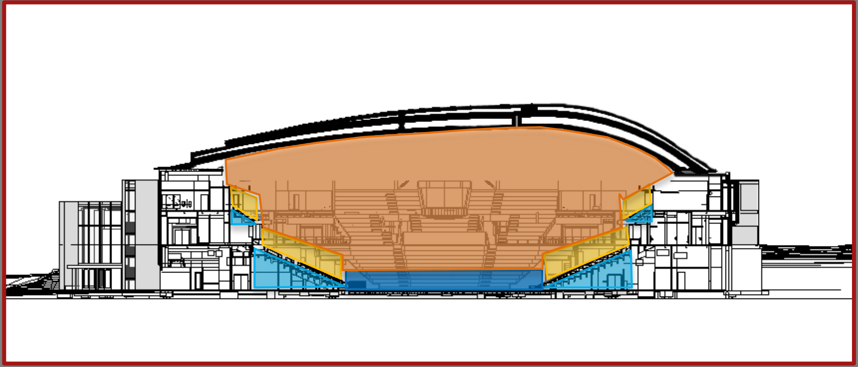
Lighting Theme

This image is of the University of Oregon and their new Matthew Knight Arena. It serves as inspiration for the concourse on the PSU ice arena.

http://sworegonarchitect.blogspot.com/2011/02/matthew-knight-arenaa-new-landmark-for.html

Transparency and Breathability: The lighting concept for the PSU Ice hockey arena was given birth from the building itself. With the amount of activities that need to take place in this building , the lighting solution will need to reflect that versatility and be able to adapt to different event and venue configurations. With the introduction of a retractable roof the building opens itself up to have a transparent property that can be exploited to enhance the architectural form of the building. Daylighting will play a large role in the lighting of public spaces, creating another connection to the exterior reinforcing the transparency provided by the roof.

Ventilation Strategy



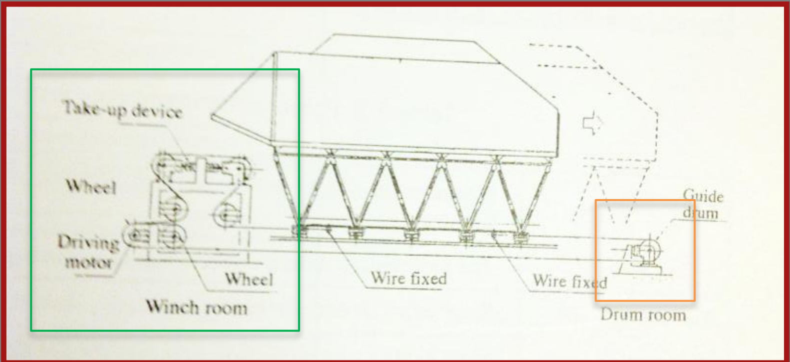
- Advantages to displacement Ventilation
  - Lower CFM required to meet the thermal and ventilation load.
  - Higher temperature supply air for cooling
  - Lower temperature supply air for heating
  - Reduced energy with better thermal comfort

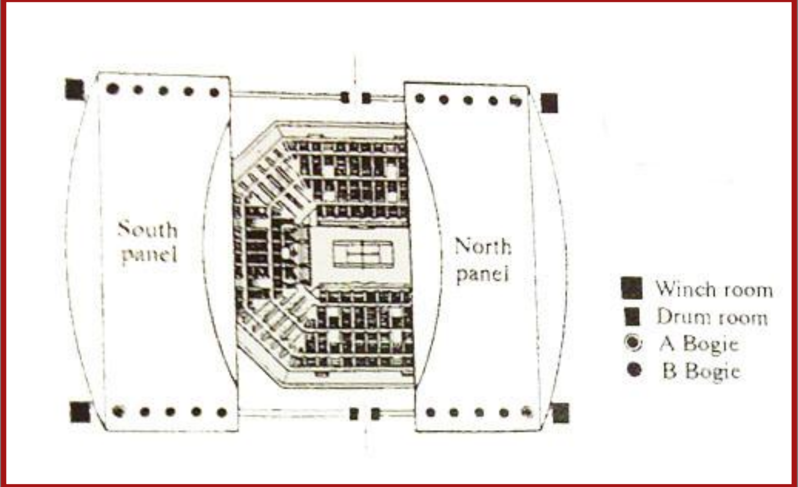
- How is the Ice Area itself ventilated?

  Displacement?
  Overhead?
  Is it Required?

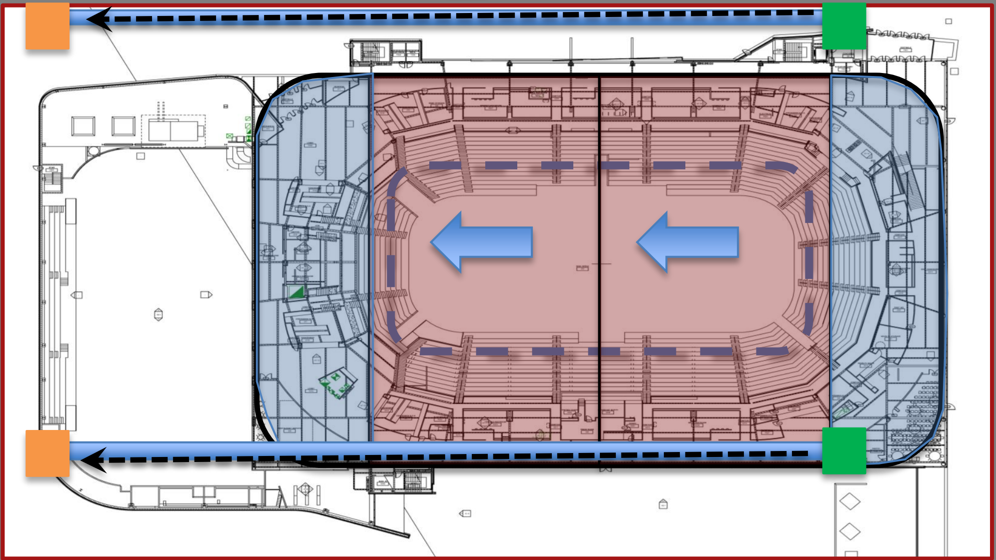
Team Vision

Cable Traction System:





Winch   Drum



Advantages	Disadvantages
Minimal equipment needed	Alteration or addition of architectural elements
Bogies are not driving mechanisms	Backup power system required
One motor per rail	Cannot be on an inclined plane (over 5 deg.)
Economic for lightweight roof structures	Pushing devices needed to start panel movement

LEED Check List

Contractual | Process | Investigation | Vision | Reflection

Volume Comparison

- Construction Manager
- Lighting/Electrical
- Mechanical
- Structural

- The Y column means we will get it and prove it
- The ? column means we think we will get it but can't prove it
- The highlighted points indicate who is responsible for proving it

LEED 2009 for New Construction and Major Renovations

Project Checklist

Project Name

Date

Y	?	N		Sustainable Sites	Possible Points: 26
Y			Prereq 1	Construction Activity Pollution Prevention	
x			Credit 1	Site Selection	1
x			Credit 2	Development Density and Community Connectivity	5
			Credit 3	Brownfield Redevelopment	1
x			Credit 4.1	Alternative Transportation—Public Transportation Access	6
x			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Roon	1
	x		Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Ve	3
	x		Credit 4.4	Alternative Transportation—Parking Capacity	2
x			Credit 5.1	Site Development—Protect or Restore Habitat	1
x			Credit 5.2	Site Development—Maximize Open Space	1
x			Credit 6.1	Stormwater Design—Quantity Control	1
x			Credit 6.2	Stormwater Design—Quality Control	1
	x		Credit 7.1	Heat Island Effect—Non-roof	1
x			Credit 7.2	Heat Island Effect—Roof	1
x			Credit 8	Light Pollution Reduction	1

				Water Efficiency	Possible Points: 10
Y			Prereq 1	Water Use Reduction—20% Reduction	
			Credit 1	Water Efficient Landscaping	2 to 4
x			Credit 2	Innovative Wastewater Technologies	2
x			Credit 3	Water Use Reduction	2 to 4

				Energy and Atmosphere	Possible Points: 35
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
x			Credit 1	Optimize Energy Performance	1 to 19
			Credit 2	On-Site Renewable Energy	1 to 7
	x		Credit 3	Enhanced Commissioning	2
x			Credit 4	Enhanced Refrigerant Management	2
x			Credit 5	Measurement and Verification	3
	x		Credit 6	Green Power	2

				Materials and Resources	Possible Points: 14
Y			Prereq 1	Storage and Collection of Recyclables	
			Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
			Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Element	1
x			Credit 2	Construction Waste Management	1 to 2
x			Credit 3	Materials Reuse	1 to 2

Y	?	N		Materials and Resources, Continued	
	x		Credit 4	Recycled Content	1 to 2
x			Credit 5	Regional Materials	1 to 2
			Credit 6	Rapidly Renewable Materials	1
	x		Credit 7	Certified Wood	1

				Indoor Environmental Quality	Possible Points: 15
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
x			Credit 1	Outdoor Air Delivery Monitoring	1
			Credit 2	Increased Ventilation	1
x			Credit 3.1	Construction IAQ Management Plan—During Construction	1
x			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
	x		Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
	x		Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
	x		Credit 4.3	Low-Emitting Materials—Flooring Systems	1
	x		Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Product	1
x			Credit 5	Indoor Chemical and Pollutant Source Control	1
x			Credit 6.1	Controllability of Systems—Lighting	1
			Credit 6.2	Controllability of Systems—Thermal Comfort	1
x			Credit 7.1	Thermal Comfort—Design	1
	x		Credit 7.2	Thermal Comfort—Verification	1
x			Credit 8.1	Daylight and Views—Daylight	1
x			Credit 8.2	Daylight and Views—Views	1

				Innovation and Design Process	Possible Points: 6
x			Credit 1.1	Innovation in Design: Specific Title	1
			Credit 1.2	Innovation in Design: Specific Title	1
			Credit 1.3	Innovation in Design: Specific Title	1
			Credit 1.4	Innovation in Design: Specific Title	1
			Credit 1.5	Innovation in Design: Specific Title	1
	x		Credit 2	LEED Accredited Professional	1

				Regional Priority Credits	Possible Points: 4
			Credit 1.1	Regional Priority: Specific Credit	1
			Credit 1.2	Regional Priority: Specific Credit	1
			Credit 1.3	Regional Priority: Specific Credit	1
			Credit 1.4	Regional Priority: Specific Credit	1

72				Total	Possible Points: 110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Collaborative Effects

Team Design Goals/Effects:

System Type	System Impacted	Players Impacted
Retractable Roof	Daylighting, Light locations, Mechanical system, Humidity Control, Cost, Schedule, Manufacturing Lead Times, Erection Sequence, Architecture.	
Displacement Ventilation	Structural supports of seating bowl, Construction Sequence.	
Daylighting Options	Mechanical Heating and Cooling Loads, Structural System, Architecture.	

Site Limitations and Zoning:

System Type	System Impacted	Players Impacted
Zoning Requirements	"Crane" design for roof system did not allow for both sides of structure to have the buttresses.	
Blasting Ordinance	Follow up with OPP on Procedures	

Reflection

Moving Forward

Contractual | Process | Investigation | Vision | **Reflection**

Future Goals:

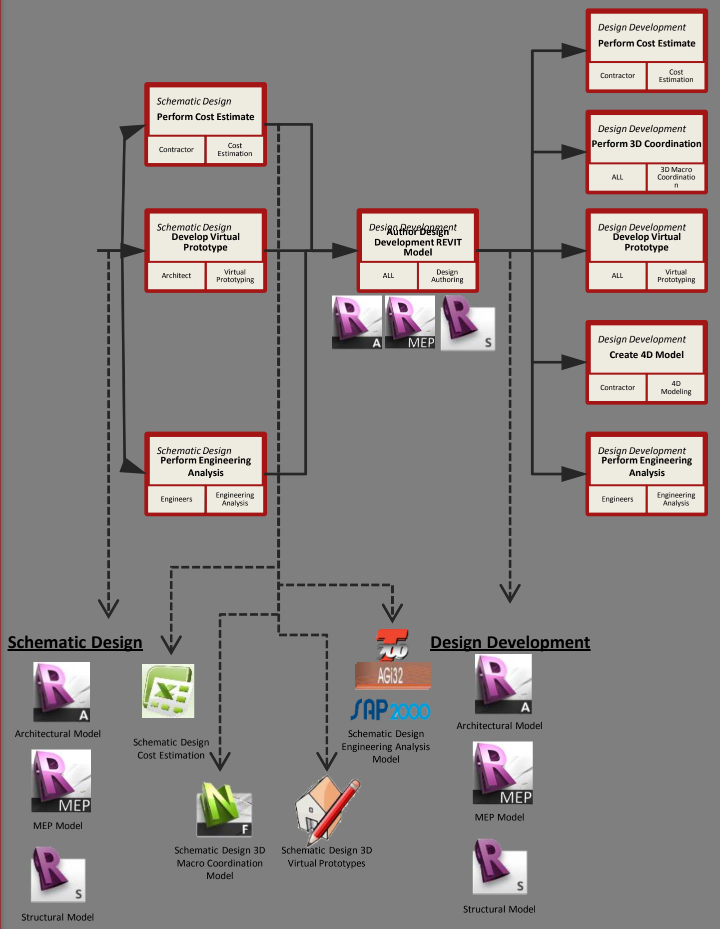
- Create Energy Model for alternative system types.
- Explore the pros and cons to campus utilities vs. "local."
- Develop matrix for determining the more efficient system.
- Calculate an accurate ice generation load.

- Develop detailed daylighting analysis model
- Preliminary lighting calculations in selected areas
- Investigate power distribution system further

- Continue with researching case studies to determine construction sequence of retractable roof
- Develop schedule for construction
- Observe alternative systems for value engineering to keep project within budget

- Finish analysis of existing structural model
- Develop preliminary driving mechanism
- Design long span curved trusses
- Begin to develop primary gravity and lateral systems

Schematic → Design Development



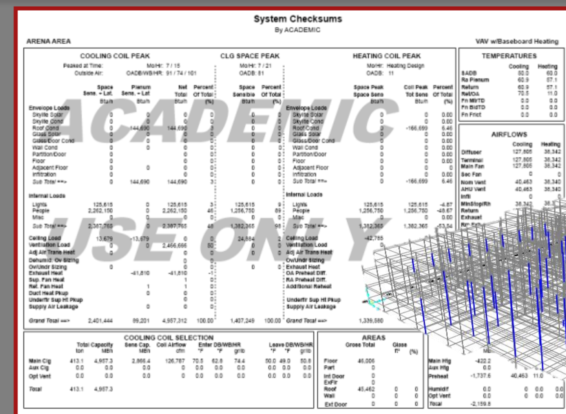
Summary

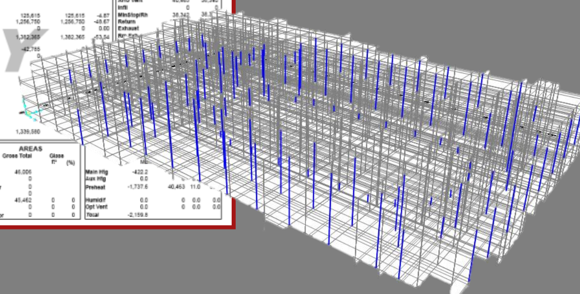
Contractual | Process | Investigation | Vision | Reflection

Contractual:

Sensitive Content Removed
for Security Reasons

Investigation:

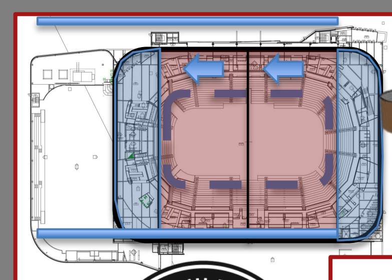


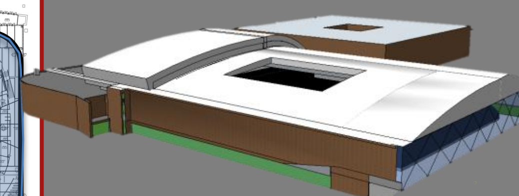


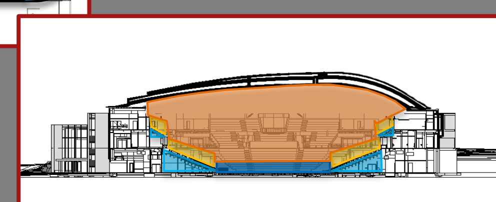
Process:

- Conflict Occurs
- Team Discussion – Pros/Cons
- Democratic Vote
- Unbiased Advisor Input
- Democratic Vote

Vision:







U.S. GREEN BUILDING COUNCIL
LEED GOLD
2007

Penn State Ice Hockey Arena
Schematic Design Presentation
October 5th, 2011

Questions?

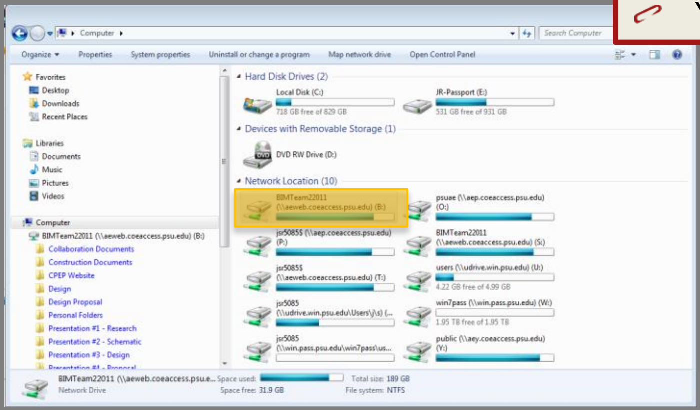
Jeremy Heilman ○ Josh Progar ○ Nico Pugliese ○ Jim Rodgers

Appendix

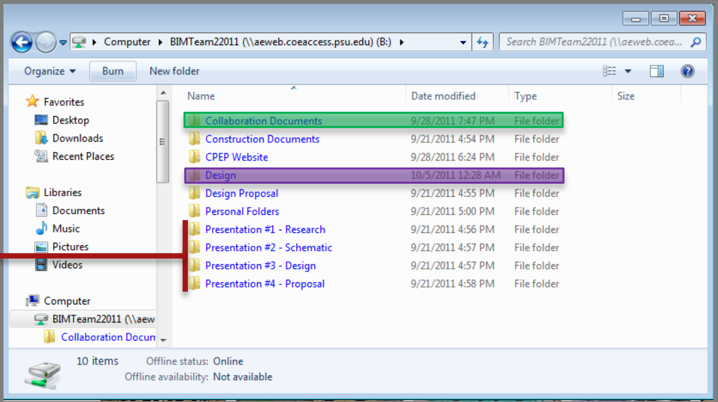
Jeremy Heilman ○ Josh Progar ○ Nico Pugliese ○ Jim Rodgers

Organization

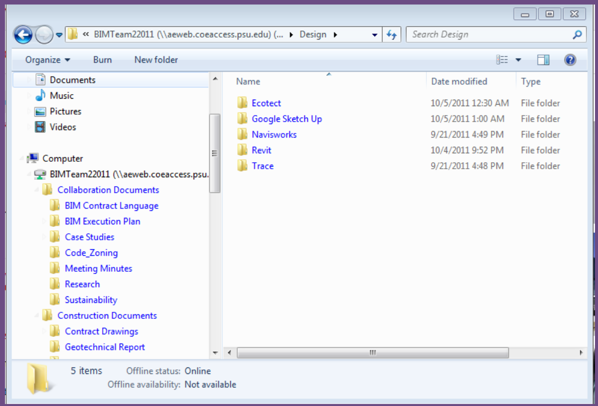
File Structure



- B:Drive-BIM Thesis Shared Drive.
- Y:Drive-AE Shared Drive

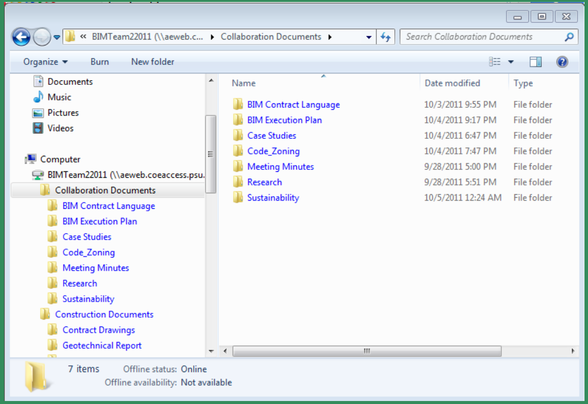


- Folders for each presentation (contains a .PPT file and folders for images and the proposal)



- Contains Folders containing different model types we will be using.

- Each team member has a personal file where they can store personal files like research items.
- There is a file for managing the CPEP website.

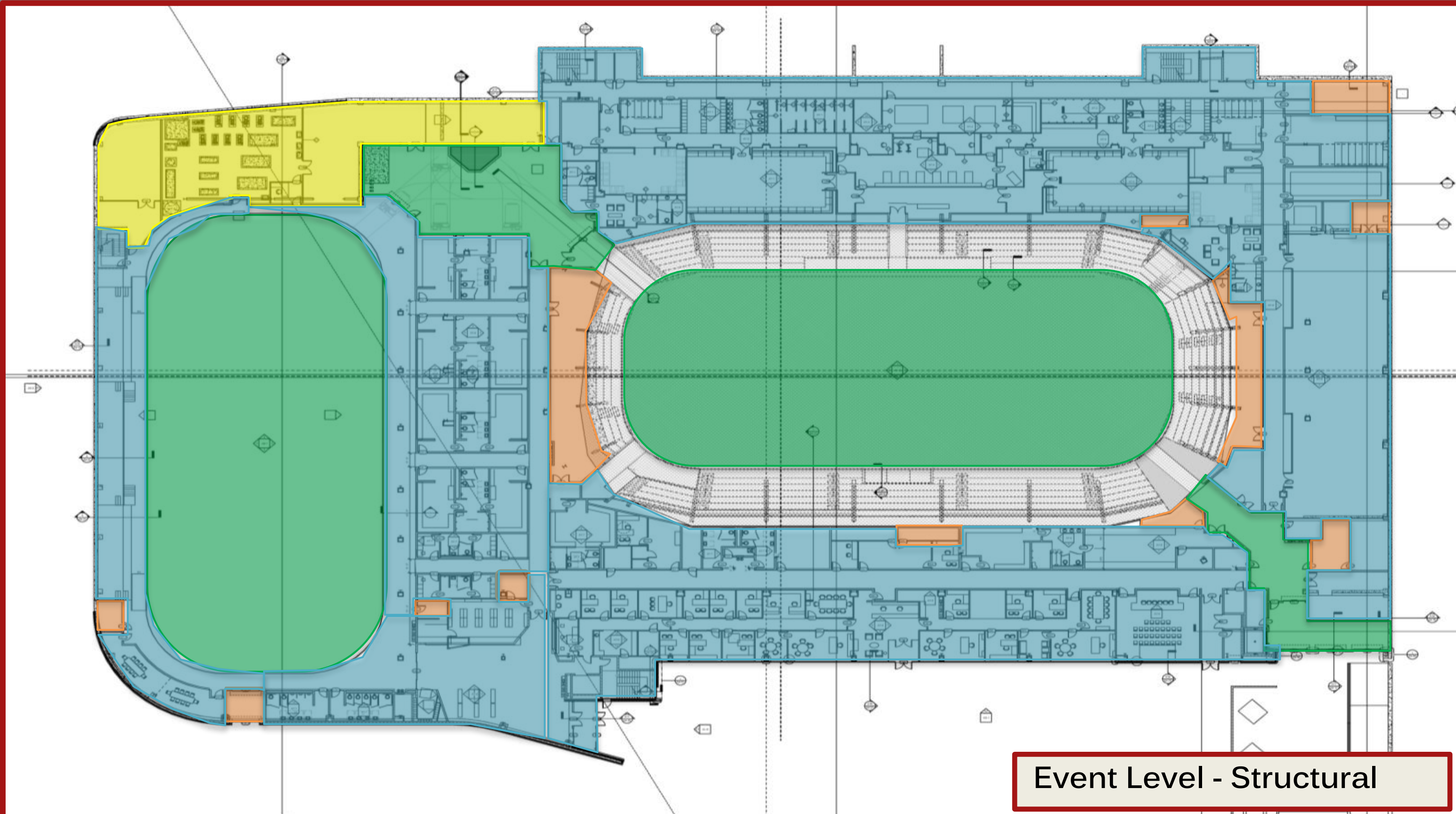


- Contains Folders for items like contract language, zoning, meeting minutes, and the BIM EX plan.

Zones & Loads – Event Level

All Other Areas
100 psf

Mechanical Rooms
150 psf



Event Level - Structural

Event Floor/Truck Access
150 psf

Light Storage
125 psf

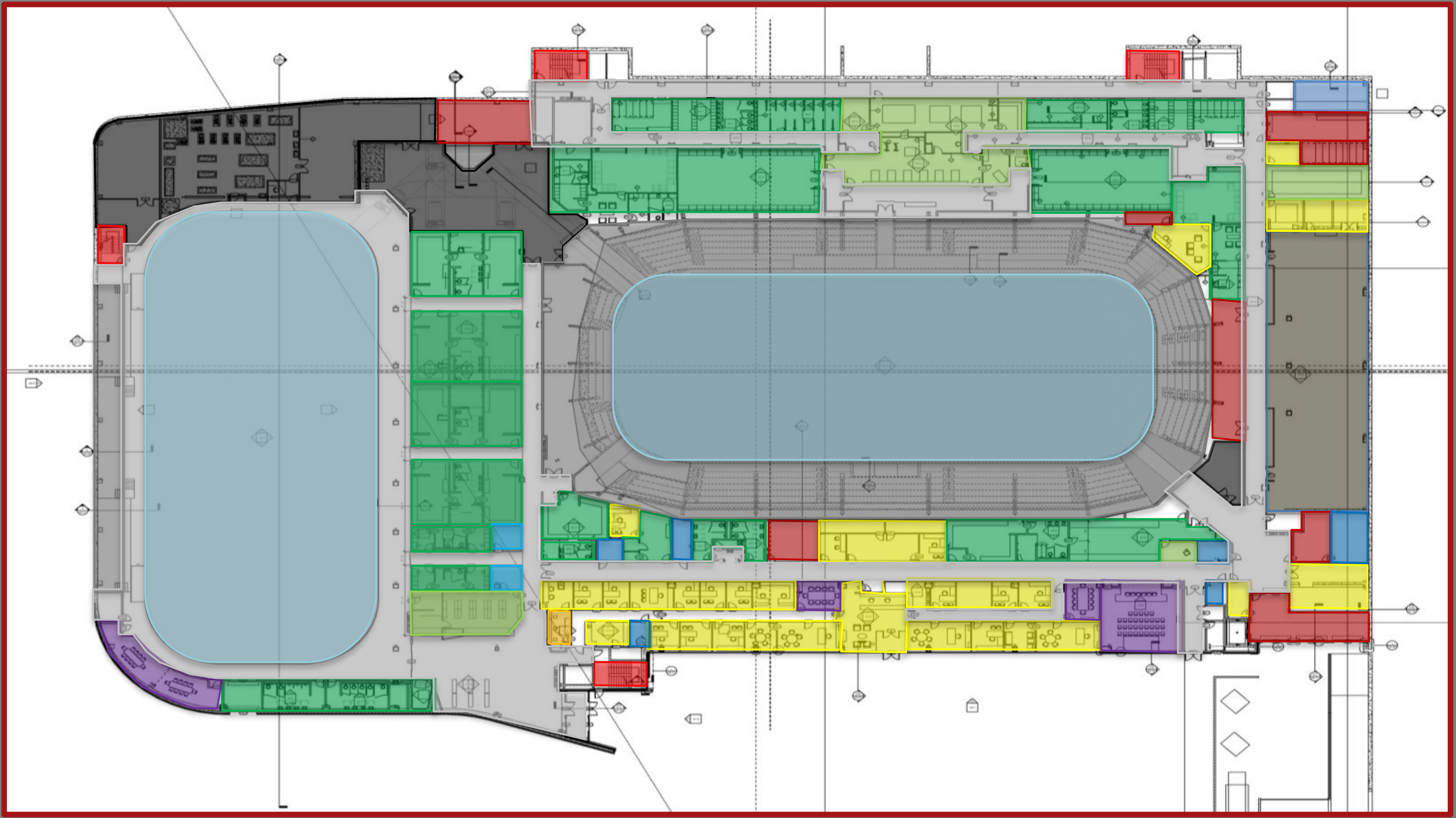
Zones & Loads – Event Level

Conference – 1.23 [w/sf]

Exam Room – 1.66 [w/sf]

Restrooms – *0.98 [w/sf]*

Stairs/storage – *0.63 [w/sf]*



Seating – *0.43 [w/sf]*

MEP – *0.95 [w/sf]*

Ice – *3.01 [w/sf]*

Office – *1.11 [w/sf]*

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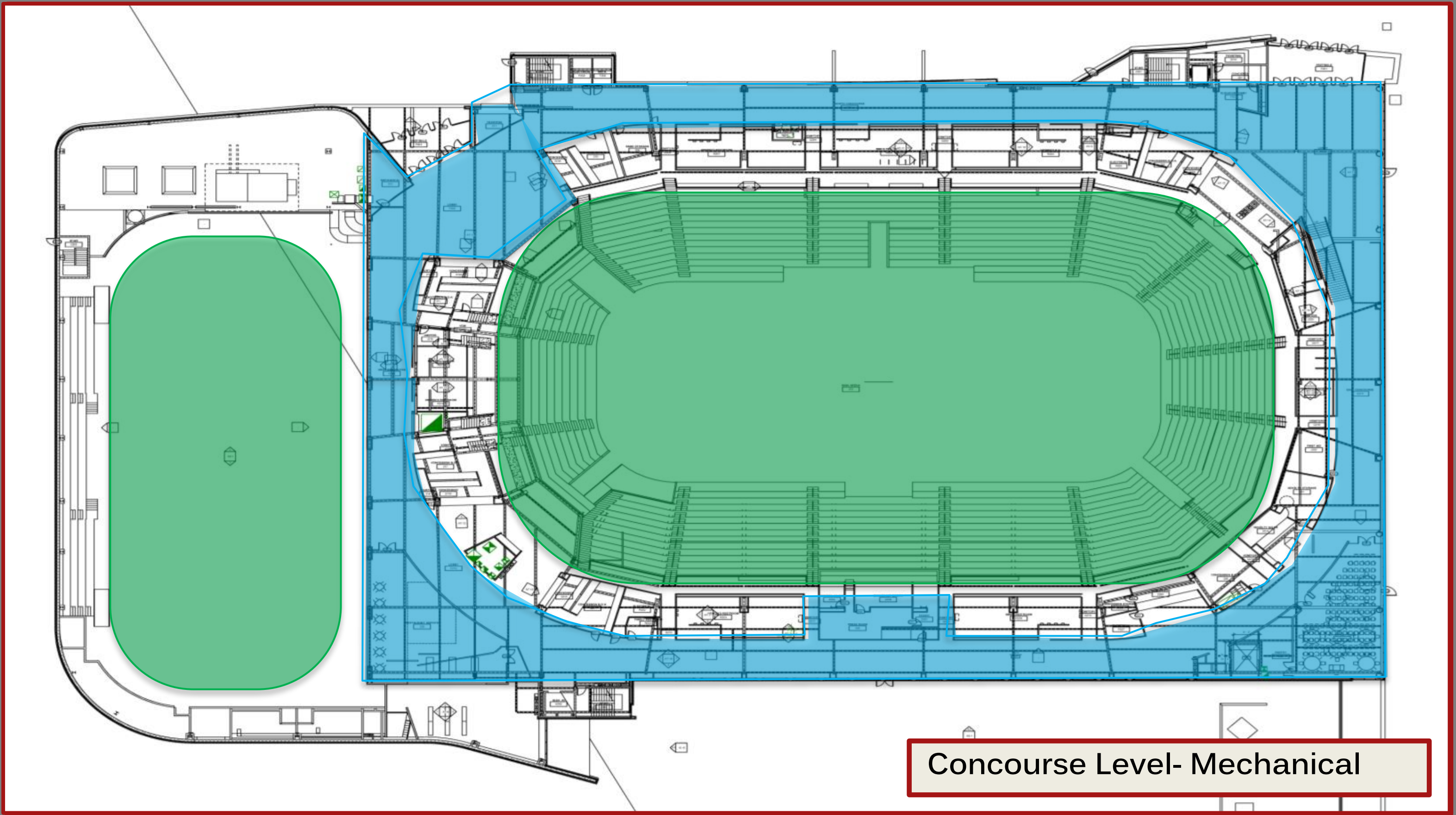
Zones & Loads – Concourse Level

All Other Areas
100 psf

Mechanical Rooms
150 psf



Concourse Level- Mechanical

Event Floor/Truck Access
150 psf

Light Storage
125 psf

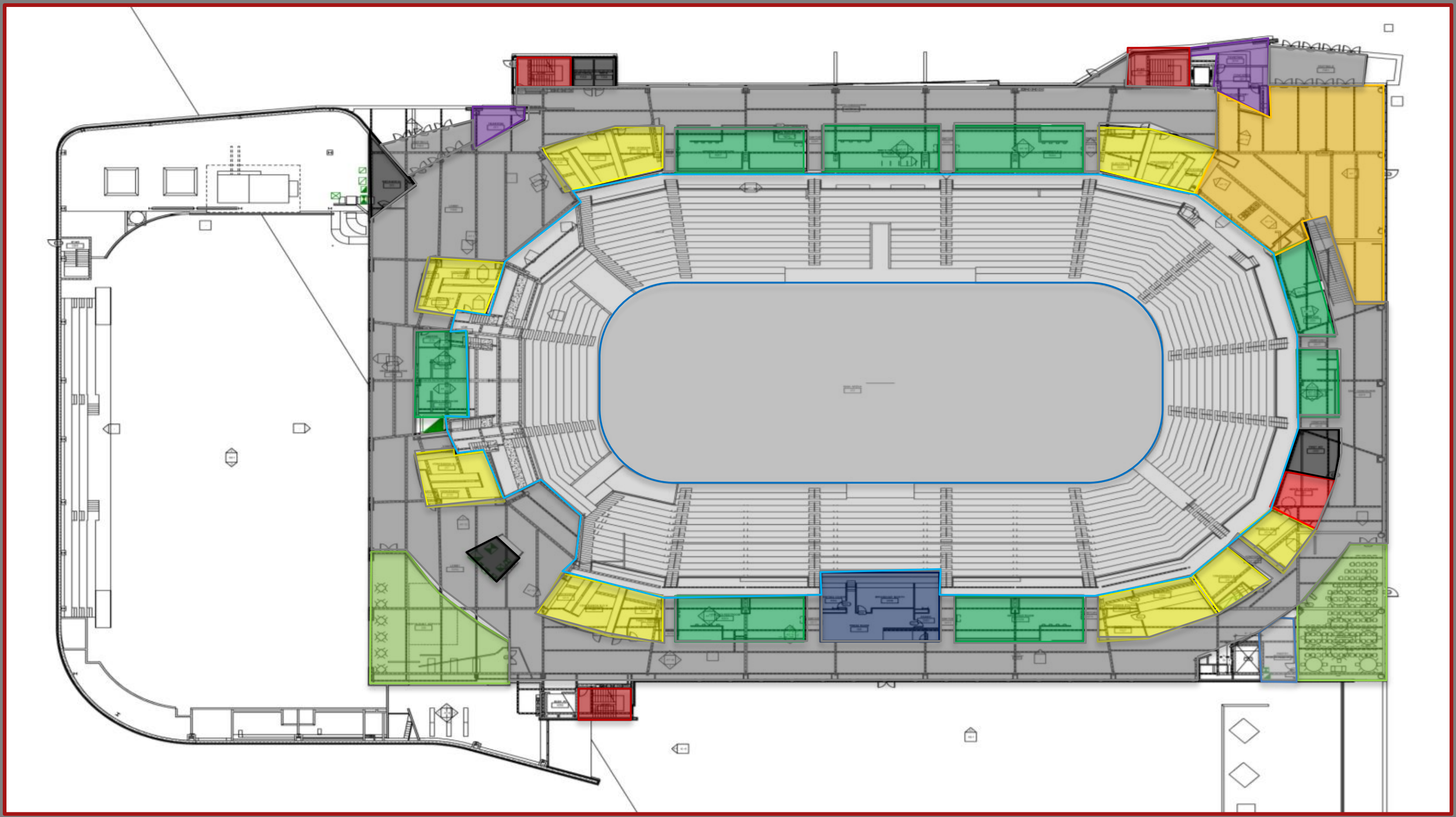
Zones & Loads – Concourse Level

Ticketting – 1.68[w/sf]

Dining– 1.23 [w/sf]

Restrooms – *0.98 [w/sf]*

Stairs/storage – *0.63 [w/sf]*



Concourse – *0.66 [w/sf]*

MEP – *0.95 [w/sf]*

lobby – *0.9 [w/sf]*

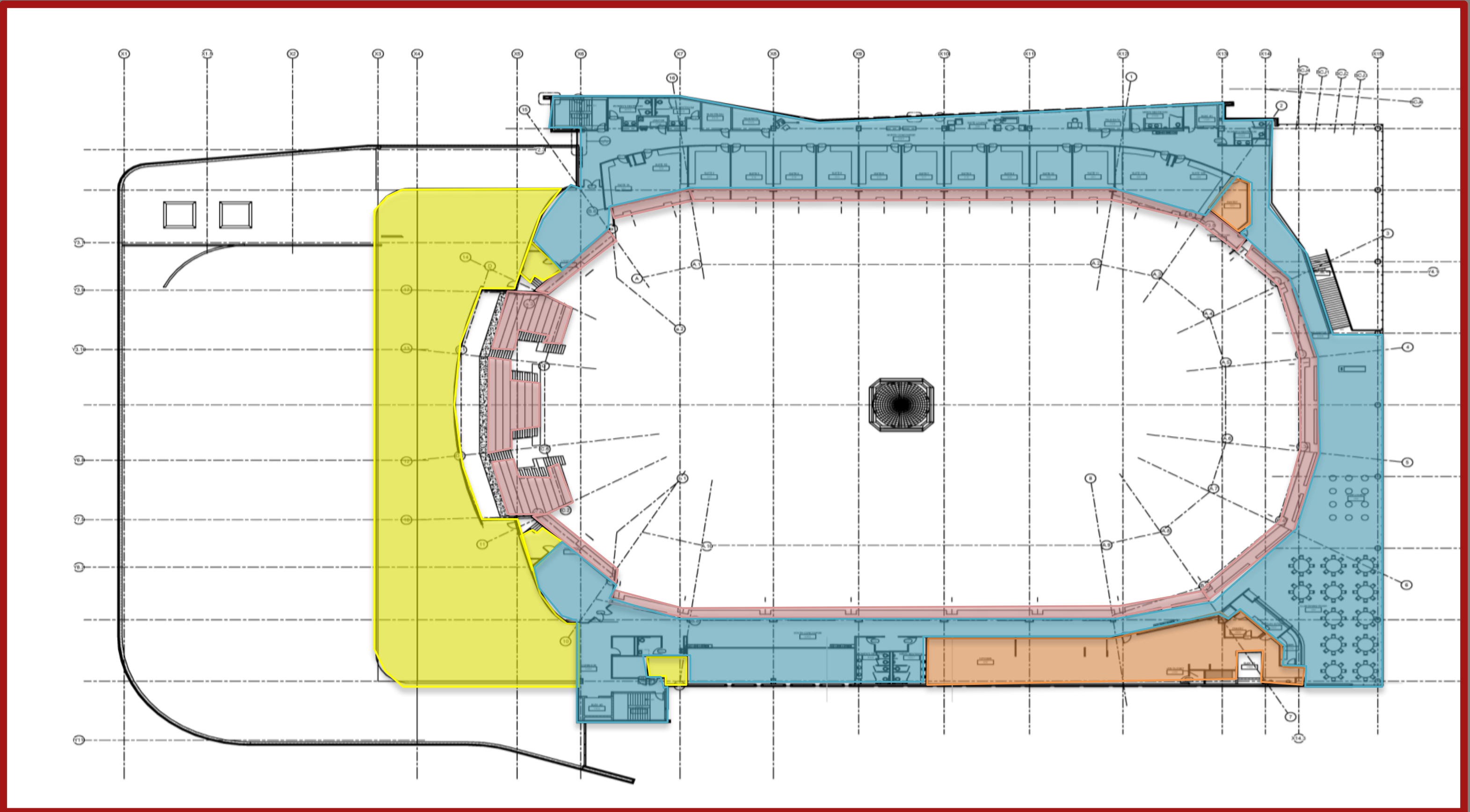
Concession – *1.68 [w/sf]*

Zones & Loads – Club Level

Contractual | Process | **Investigation** | Vision | Reflection

All Other Areas
100 psf

Mechanical Rooms
150 psf



Event Floor/Truck Access
150 psf

Light Storage
125 psf

Zones & Loads – Event Level

HPR Trailers

Site Deliveries & Storage

Site Layout

Building Footprint

Gate 1 / Delivery Entrance

Gate 2

Cranes

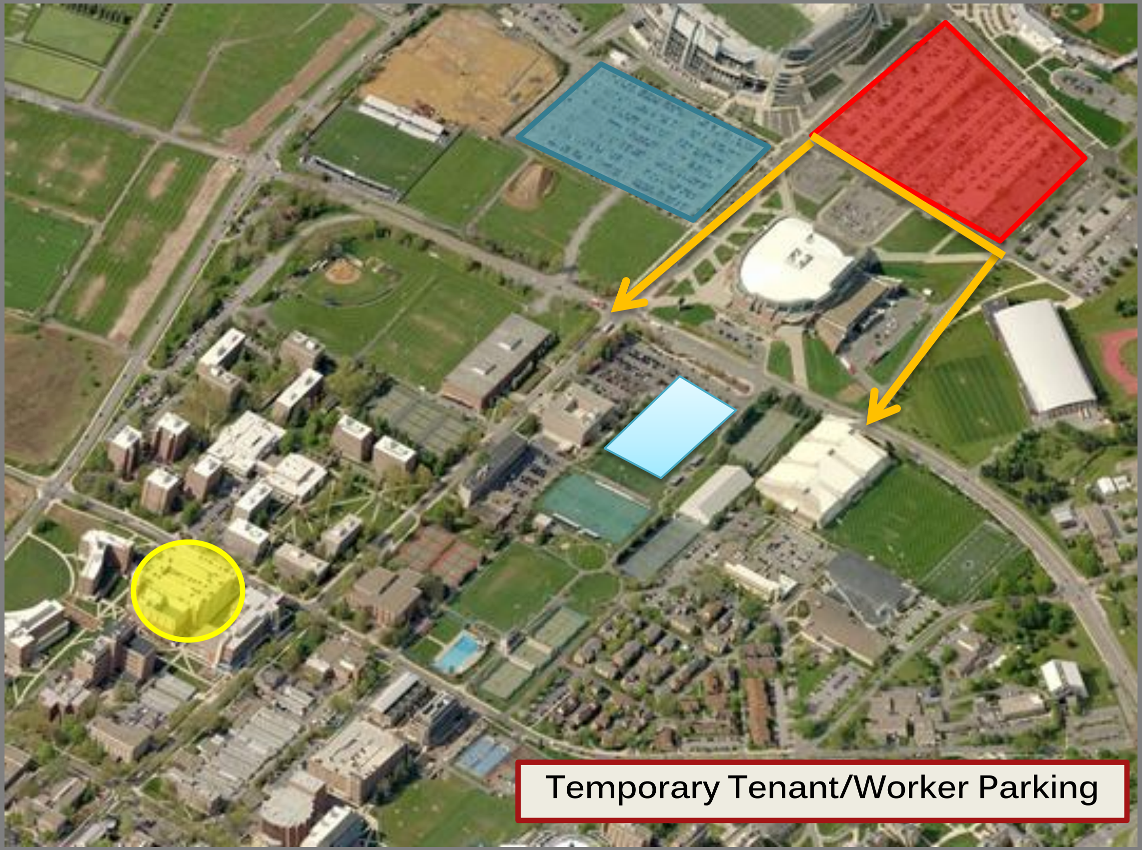
Subcontractor Trailers

Steel Temp Storage

Zones & Loads – Event Level

Beaver Stadium Parking

Site Deliveries & Storage



Temporary Tenant/Worker Parking

Building Footprint

Redirect of Traffic When Road is Blocked in Front of Site

East Parking Deck

BJC Parking

Jeremy Heilman ○ Josh Progar ○ Nico Pugliese ○ Jim Rodgers

Special Loads to Consider:

Loads	Considerations
Dynamic	Sudden application of brakes, deceleration of driving mechanism
Skew Effects	Linear moving panels on parallel tracks (push-pull problems)
Thermal	Thermal effects on rail systems
Inertial Forces	Accompanied by increasing or decreasing of speed of driving mechanism due to lateral movement
Lateral Force on Wheels	Horizontal force generated in direction perpendicular to progression of wheels and forced changed in direction due to accuracy in railing
Collision Load	Load generated by the driving mechanism bumping into a buffer.

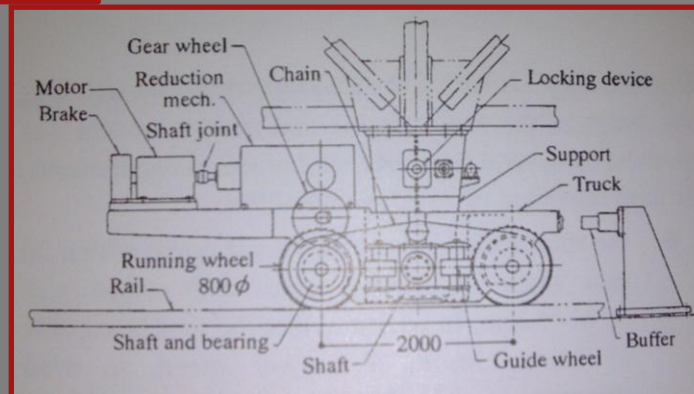
Special Issues to Consider:

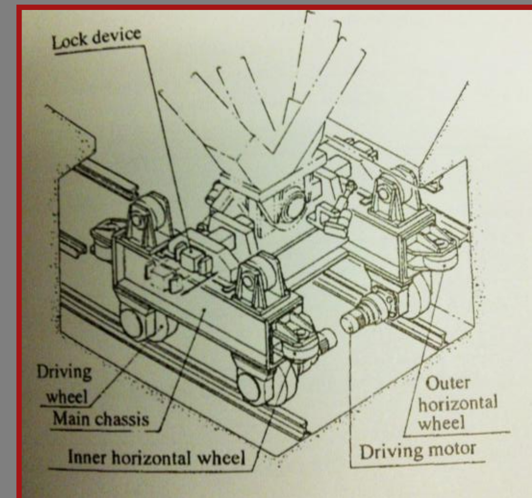
- **Waterproofing Considerations:** levels of flashing according to objectives of the building, panels do not meet up; usually a 3'-0" different between them.
- **Safety Concerns:** Marginal wind loads during opening/closing structure; redundancy within structure, adjustments in track system

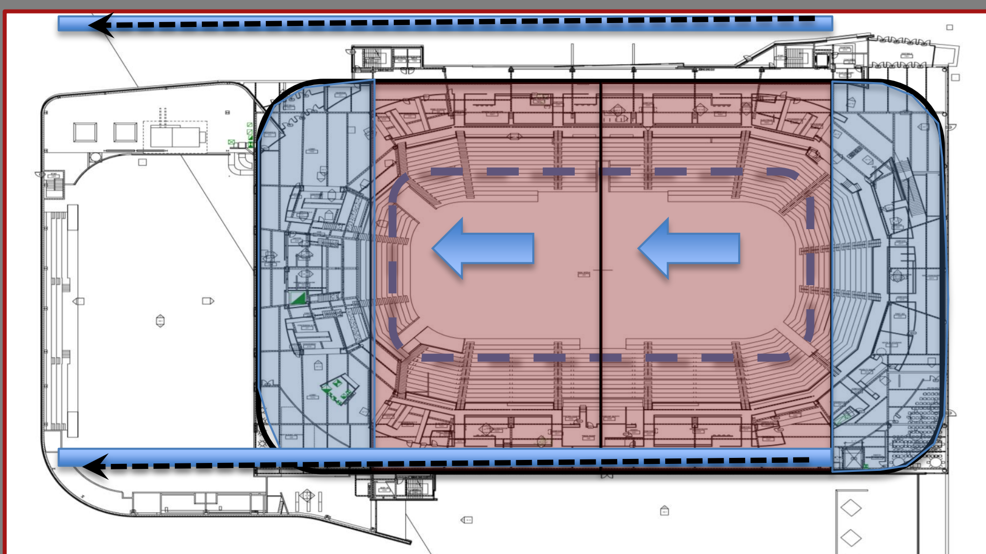
Alternative Driving Mechanisms

Self Running Wheel Method:

- Other Driving Mechanisms:
  - Rack and pinion method
  - Jack method

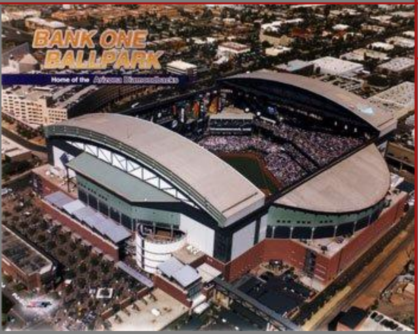






Advantages	Disadvantages
No alteration to architecture required.	Heavy roof function; not as economic
Closure speed is increased	Dynamic friction coefficient varies depending on railing system
Can be used on an inclined plane	Maintenance is more difficult

Case Studies



http://www.baseballchronology.com/baseball/Stadiums/

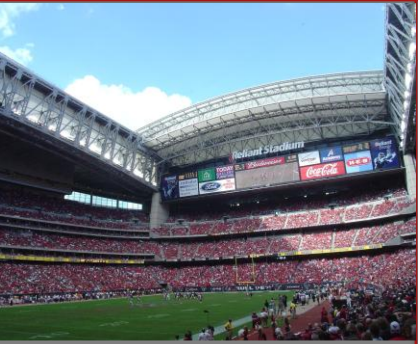
Bank One Ballpark — Phoenix, AZ

- **Total Cost:** $354,000,000
- **Roof Cost:** $70,000,000 (approx. 20%)
- **Roof Span:** 517'-0"
- **Weight of Roof:** 6,900 ton
- **Retractable System:** Two telescoping sections that bi-part at mid field.
- **Mechanism:** (8) 200 hp motors
- **Case Study:** *Good Design*

http://www.theticketking.com/tickets/miller-park-ticke

Miller Park — Milwaukee, WI

- **Total Cost:** $400,000,000
- **Roof Cost:** $133,000,000 (approx. 33.25%)
- **Roof Span:** Not noted
- **Weight of Roof:** Not noted
- **Retractable System:** 7 panel "fan" arrangement; 5 movable panels, 2 stationary
- **Mechanism:** Not noted
- **Case Study:** *Terrible Design, major litigation problems*



http://www.panoramio.com/photo/2412972

Reliant Stadium — Houston, TX

- **Total Cost:** $417,000,000
- **Roof Cost:** $48,000,000 (approx. 11.5%)
- **Roof Span:** 984'-0"
- **Weight of Roof:** Not noted
- **Retractable System:** Two panel system, bi parts at midfield
- **Mechanism:** 40 wheeled bogies, (80) 5 hp motors
- **Case Study:** *Very Successful Structure*

Retractable Roof Construction Case Studies

Amsterdam Arena — Amersterdam, Netherlands

http://wwww.amsterdamarena.nl/over_amsterdam_arena/historie/en/

Lucas Oil Stadium — Indianapolis, Indiana

http://www.frpinc.com/gallery/lucas-oil-stadium.jpg

- **Increase Cost of Retractable Roof:** Estimated 2.5% to 3% increase in budget
- **Sequence:** Built Trusses & Posts, Raise Trusses & Build Walls Around Them
- **Case Study:** *Great Development, Easier to Build, Easier for All Trades*

Embodied Energy

- **Embodied Energy:** total primary energy consumed during the extraction, transportation, manufacturing and fabrication of construction materials

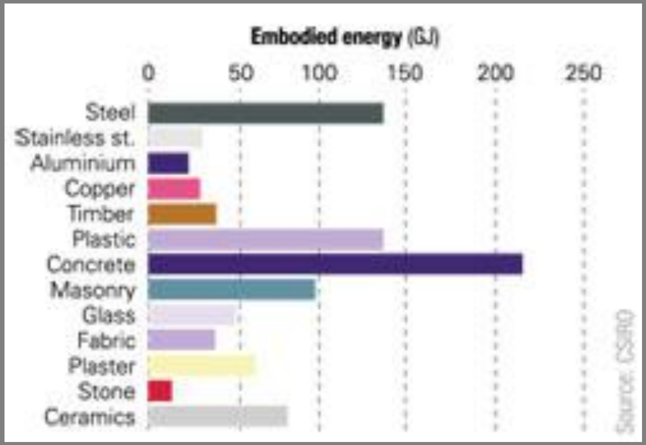


Figure: http://www.yourhome.gov.au/technical/fs52.html

http://www.aaronsenvironmental.com/

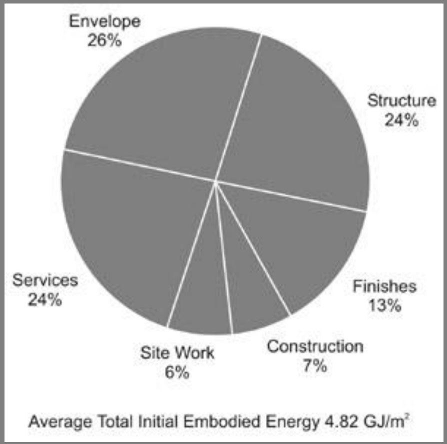


Figure: http://www.canadianarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_embodied.

- **Note: Structural systems account for roughly 1/4 of the total embodied energy in building construction.**
- **Carbon Dioxide Emissions:** roughly 10% of all manmade greenhouse gases are due to concrete/steel industries

Material	Embodied Energy	Carbon Dioxide Emissions
Steel	High	1.50 lb/lb
Concrete	Very High	1.00 lb/lb
Wood	Low	0.7 lb/lb