Penn State University

Final Report

The HUB Addition

John C Keyes
4-8-2016

The Hetzel Union Building

John Keyes | L/E Option

Building Statistics

Location | University Park, State College, PA 16801

Size | 107,000 S.F.

Stories | Three stories above grade and two basement levels

Construction Dates | May 2013 – May 2015

Estimated Building Cost | $44,600,000

Project Delivery Method | Design-Bid-Build

Owner | Penn State University

Architect | Gund Partnership

Construction Manager | Gilbane Building Company

Landscape Architect | Andropogon Associates, Ltd.

MEP Engineer | Vanderweil Engineers

Civil Engineer | Sweetland Engineering and Assoc.

Structural Engineer | LeMessurier Consultants

Lighting Consultant | HLB Lighting Design

Interior of Atrium (*Credit to Gund Partnership for all renders)

Architectural

The HUB addition created an open gathering space for students and provided a gateway to the rest of the building from the east side of campus. The terracotta brick relates to the existing building, while still giving the addition its own identity. The roof top over the atrium creates an organic form that adds interest to the space.

The HUB will also be the first building on the campus to feature an occupiable green roof. Other green building practices were implemented, such as using recycled and local materials.

Structural

Composite decking consists of light weight concrete on top of 1.5”-3” galvanized steel deck. These are supported by wide-flange steel beams. Normal weight concrete makes up the footings, columns, and floor slabs on grade. 10 exposed HSS trusses support the steel deck roof in the main atrium.

Lighting/Electrical

The lighting consists almost entirely of LED fixtures. The overall impression created is a public, spacious, and visually clear space. Occupancy sensors, solar cells, and time clocks control the lighting to ensure that the maximum energy savings is achieved. Large glazing allows for daylight harvesting throughout most of the space, while shading devices ensure minimal glare.

The building receives power at medium voltage from the campus and a transformer steps the voltage down to 480Y/277V. A 1600A switch gear, located in the basement, feeds two 600A and two 800A panel boards. A second connection from campus provides emergency power for the building..

Mechanical

7 air handling units supply the building with conditioned air. AHU-1 and 2 supply the bookstore at 16,000 CFM each. AHU-3 and 4 supply the atrium areas at 18,000 CFM each. The campus loop provides the chilled water for cooling and steam for heating throughout the building.

EXECUTIVE SUMMARY

The following report is a detailed record of the work and analysis performed for AE senior thesis AE897G. This thesis contains redesigned lighting schemes for four spaces, an electrical depth, and an integrated study combining a MAE daylighting depth, mechanical breadth, and a construction management breadth. The main purpose of senior thesis is to show an understanding of topics taught in the various AE disciples, as well as an advanced knowledge of the students chosen option.

The four spaces that were subject to a lighting redesign were the outdoor entryways, atrium, bookstore, and flex theater. The details of each solution can be found in the lighting section of the report.

To reflect the new lighting designs, branch circuits were changed and eliminated accordingly. A panelboard resizing study was also performed on eight panelboards. More appropriate demand factors were applied to each panelboard to see if it was able to be downsized. In the end, five of the eight were able to be downsized, leading to a cost savings of $18,000 with materials and labor included.

The integrated study first looked at daylighting within the atrium space. An initial illuminance study was performed and 16 potential daylighting solutions were narrowed down to 4 for a more in-depth study. These four went through an annual daylighting study, as well as an annual mechanical study to assess the daylighting and mechanical performance of each option. A cost analysis was then done to provide the final metric for each design. Based on the metrics of the three disciples, one solution was found to be the optimal case. This would add $100,000 to the project, but this cost is offset by the $300 a year savings in energy loads and provide a more comfortable space year round.

| TABLE OF CONTENTS

Unless otherwise noted, all building drawings were provided by Penn State OPP as prepared by Gund Partnership. Fixture pictures were found on the respective manufacturer's website and cutsheets. All design renders and figures were created by John C Keyes.

BUILDING OVERVIEW

Name | The Hetzel Union Building (HUB)

Location | University Park, State College, PA 16801

Occupant Type | Something

Size | 107,000 S.F.

Number of Stories | Three stories above grade and two basement levels

Construction Dates | May 2013 – May 2015

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PROJECT TEAM

Owner: Penn State University

Construction Manager: Gilbane Building Company

Architect: Gund Partnership

Landscape Architect: Andropogon Associates, Ltd.

MEP Engineer: Vanderweil Engineers

Civil Engineer: Sweetland Engineering and Assoc.

Structural Engineer: LeMessurier Consultants

Acoustic Consultant: Acentech Incorporated

AV/IT Consultant: Vantage Technology Group

Lighting Consultant: Horton Lees Brogden Lighting Design

GENERAL BUILDING INFORMATION

The design of the HUB addition both compliments and stands apart from the rest of the HUB. The terra cotta shell is reminiscent of the masonry brick façade on the older portions of the building, but maintains a strong identity as a newer and improved space. The large use of glass helps to create a lighter feel both visually and structurally to the addition as a whole.

There are a variety of spaces within the HUB, including the campus bookstore, various food vendors, THON offices, and various gathering spaces. The bookstore features a design that is both inviting and open. The first story acts as the main store, while the mezzanine level connects to the main floor of the HUB and is more of a study space and casual reading area. The main atrium is the main pathway through the building, connecting the new addition to the old HUB. The main floor also functions as a seating area for the food court. A main stair is positioned in the center of the space that is both for bleacher style seating and a means of getting onto the mezzanine level. The mezzanine is a ring that spans the perimeter of the atrium and is lined with conference rooms and offices that take advantage of the abundance of daylighting with curtain wall like glazing.

FACADES

The three main building facades for the building are terra cotta, curtain wall, and masonry brick. A large portion of the atrium and attached spaces is clad in terra cotta panels, which vary in texture from smooth to corrugate. The masonry brick is the main façade of the bookstore. These bricks vary in color considerably, from a rich crimson to a much lighter rose color. Behind the masonry is 2.5" cavity wool insulation and 8" metal studs that are 16" on center to hold everything up.

The two main curtain wall facades, made up of low-e reflective glazing, provide daylight to the bookstore and to the main atrium space. The upper panels of glass in the atrium space also have frit to help control the amount of direct sunlight that enters the space. In addition to the curtain wall there is also a skylight like system in the atrium space with a metal scrim over top of triangular glass panels.

Lighting Design Depth

LIGHTING DESIGN DEPTH

In this section the final lighting design solutions for the HUB Addition are explained. Each subsection will describe one of the four spaces chosen for redesign. The four spaces include:

Flex Theater

Atrium

Site

Bookstore

CONCEPT – CONNECTIONS

The HUB addition is an appropriate name as it fits the function of the building perfectly. People come in and out filtering through the space to their destinations. The building serves many purposes and house a variety of spaces such as eating areas, gather and study spaces, conference rooms, and concert halls, to name a few. The new addition shares many of these uses and provides both large and small spaces for the student body to use for whatever they'd like. One of the main reasons behind the renovation was to provide better access to the building from the HUB parking deck, to the east, and the east and south sides of campus.

Each of the spaces within the HUB was meant to connect people to something. This could be to the building itself or a specific function of the space. This led me to the concept of connections and using lighting to help promote these connections.

OUTDOOR SPACE | SURROUNDING AREA

EXISTING CONDITIONS

The HUB addition has two main access points, one to the East and South. These are connected to campus through various pedestrian walkways. A 50' elevation change occurs between the two entrances and stairs are needed to get from one elevation to the next. The south façade of the bookstore frames the southern entrance, adding some architectural interest to the area through materials and forms.

DIMENSIONS

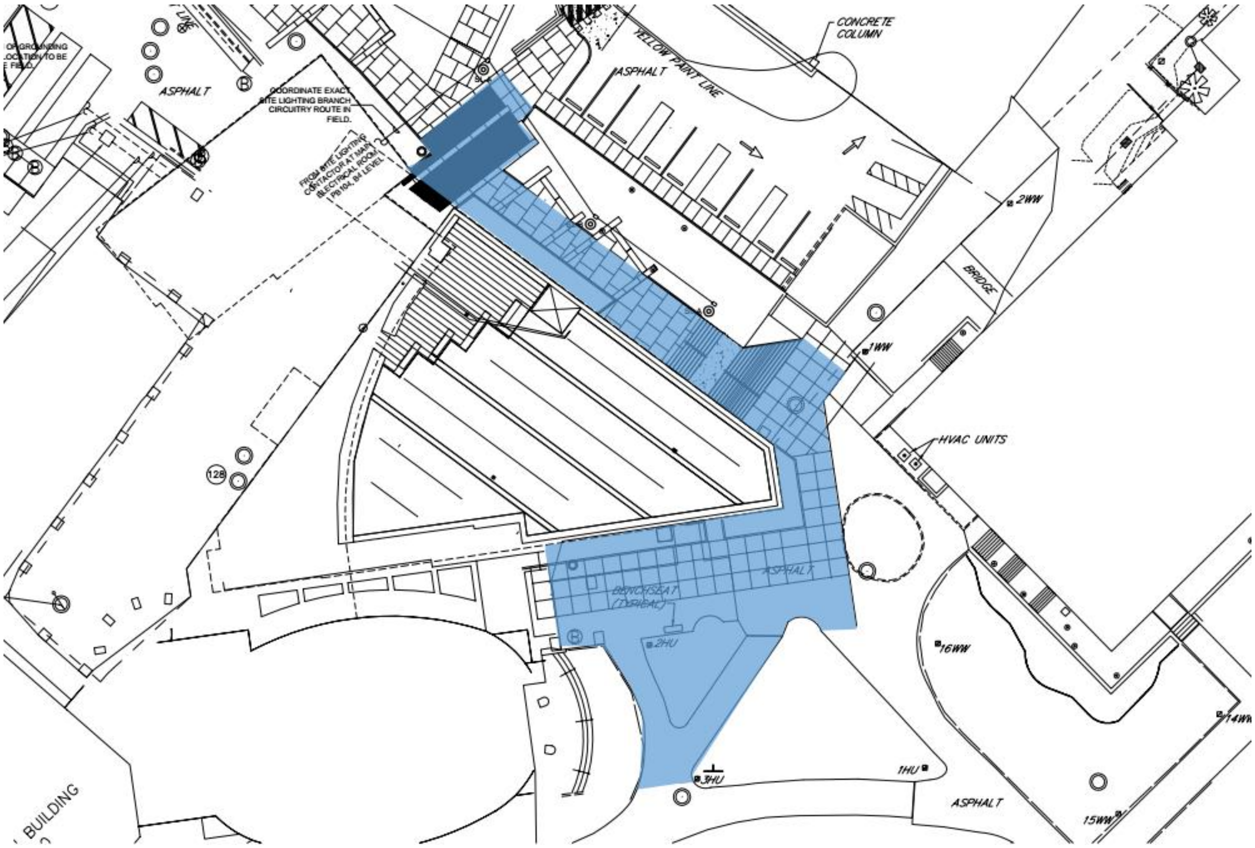
Area of grounds – 7000 ft^2

FINISHES AND GLAZING

The façade consists of two materials, terracotta bricks and aluminum curtain wall. The terracotta bricks are one of two kinds, smooth or grooved. The pavers that make up the occupiable area are made of granite and the sitting walls are poured concrete. The curtain wall glazing is the same low-e glass as the atrium space (see atrium finishes). The pedestrian walkways are also made of concrete.

Site Materials				
Surface	Material	Descrption	Color	Reflectance
Exterior Walls	Terra/ACW	Terracotta panels and aluminum curtain wall	Red	0.41
Site	Concrete	Poured concrete	Gray	0.4

SITE PLAN



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PLANTINGS

There are a variety of plantings that will be used throughout the site and on the green roof. The main types of trees that will be planted are the blackgum, eastern redbud, and pagoda dogwood trees. The green roof will be home to stonecrop, gold sedum, dragon's blood sedum, and southern stonecrop to name a few.

TASKS

Way-finding and security in the evening hours are very important on the pathways. The outdoor lighting should ensure that pedestrians can not only navigate the area, but feel safe while doing so. The entrances into the space should also be made apparent through lighting.

DESIGN CRITERIA/CONSIDERATIONS

QUALITATIVE CRITERIA

Very Important

- Adequate lighting of area
  - Lighting the area to appropriate levels to ensure safety and security of the building and pedestrians

Important

- Provide interest to the space
  - Lighting some of the architectural features on the façade may add interest to the area and enhance the visual experience of bystanders
- Continuity of existing lighting
  - To ensure a smooth transition from outside areas fixtures specified should comply with campus codes and design practices

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance

- Classification – Common Applications
  - Building Entries, Canopied entries/exit, medium activity, LZ2
    - Category F: 10 lux at ground
    - Avg/Min: 2:1

Recommended Vertical Illuminance

- Classification – Common Applications
  - Building Entries, Canopied entries/exit, medium activity, LZ2
    - Category D: 6 lux

LEED

SSC: Light Pollution Reduction

- Meet uplight and light trespass requirements, using either the backlight-uplight-glare (BUG) method (Option 1) or the calculation method (Option 2). Projects may use different options for uplight and light trespass

Meet these requirements for all exterior luminaires located inside the project boundary (except those listed under "Exemptions"), based on the following:

- the photometric characteristics of each luminaire when mounted in the same orientation and tilt as specified in the project design; and
- the lighting zone of the project property (at the time construction begins). Classify the project under one lighting zone using the lighting zones definitions provided in the Illuminating Engineering Society and International Dark Sky Association (IES/IDA) Model Lighting Ordinance (MLO) User Guide.

EAP: Minimum Energy Performance Required

- ❖ Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.1–2010, with errata (or a USGBC-approved equivalent standard for projects outside the U.S.).

EAC: Optimize Energy Performance (Major Renovation)

- ❖ Reduce overall energy consumption by 4% - 40% for 1 – 16 points.

Model Lighting Ordinance

Energy Allowances

The following table shows the energy allowance for the outdoor space according to ASHRAE 2013 Table 9.4.2-2.

Energy Allowance			
Space	Area (SF)	W/SF	Allowable Wattage
Site	7000	0.16	1120

ASHRAE 2013 Standards

9.4.1.4

DESIGN CRITERIA SELECTED

1) Create a safe outdoor environment with proper lighting
2) Meet ASHRAE energy code requirements
3) Limit uplight to comply with MLO and limit light pollution
4) Meet LEED requirements

DESIGN DEVELOPMENT

SUMMARY

Pole mounted fixtures are used to provide the general area illumination away from the building and along the pathways. These fixtures follow the campus standard to match the surrounding areas. Within the immediate vicinity of the building, these are replaced with wall-mounted flood lights. This is to create a shift in how the area is being lit that marks the transition from outside to inside. The goal is to provide light without the sources being apparent. This also helps to draw more attention to the Light Tape ™ that is placed in the joints between the terracotta panels on the bookstore's southern façade. This subtle decorative layer of light not only draws attention and provides visual interest to the area, but also mimics the atrium terracotta wall. The layout of the Light Tape ™ represents nature reaching into the building through the many curtain walls of the addition, forming a connection between the interior and exterior and breaking the barrier between nature and the built environment.

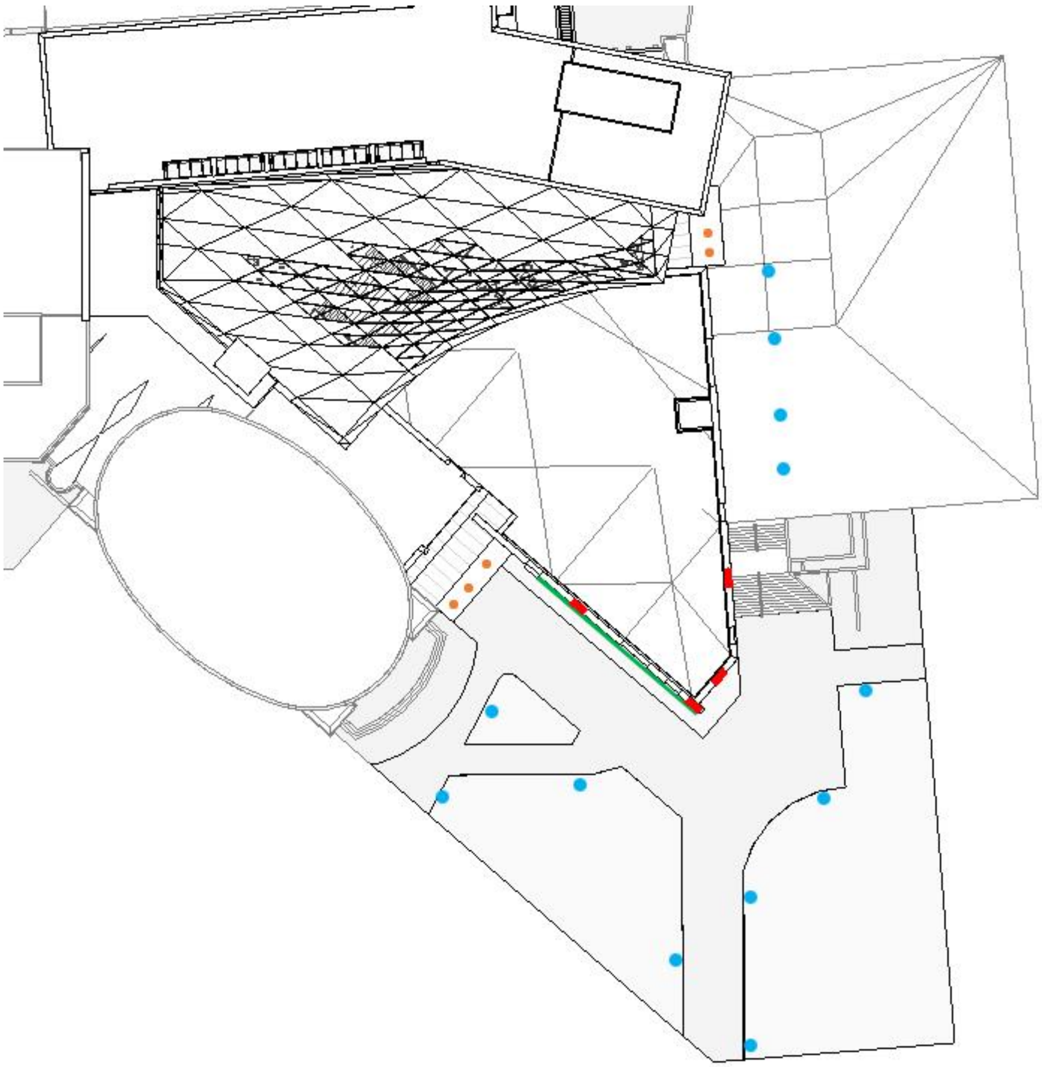
Southern Entrance

The final layer of light is provided by recessed downlights in the overhangs above the entryways. This provides adequate light to the area, while also acting as a beacon of light drawing people inside the building.

South Eastern View

FIXTURE & EQUIPMENT SELECTION

The light fixtures used to light the outdoor space are comprised entirely of LEDs. Cut sheets can be found in appendix A and detailed fixture schedules can be found in appendix B.



Site Plan

Fixture Schedule				
Type	Symbol	Image	Description	Manufacturer
L7			Electroluminescent thin strip light	Light Tape
L12			LED area conical pole light	Louis Poulson
L13			Recangular LED 150W CMH replacment	RAB
L14			2" recessed wet rated outdoor LED downlight	Juno

Fixture Calculations							Lightloss Factors			
Type	Quantity	W/fixture	Total Wattage	PF	Va/fixture	Total VA		LLD	LDD	Total
L7	5352 in^2	0.016 W/in^2	86	1	0.016 W/in^2	86	L7	0.8	0.96	0.77
L12	12	44	528	1	44	528	L12	0.8	0.96	0.77
L13	4	39	156	1	39	156	L13	0.8	0.96	0.77
L14	5	5	25	1	5	25	L14	0.8	0.96	0.77

CONTROLS STRATEGY

All lighting will be on a time clock and photo sensor to ensure that fixtures won't be placed on when not needed, but would provide light when there is insufficient daylight. The time clock would ensure that all decorative lighting would be extinguished by 12:00 AM to conform to MLO 2011 standards.

CALCULATION SUMMARY

The table below summarizes the calculations for the space. For more in-depth analysis, refer to the pseudo color renderings.

Outdoor Illuminance Criteria					
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)	
Space	Metric	Recommended	Achieved	Recommended	Achieved
Site	Average	10	13	6	9
	Avg/Min	2:1	5:1	--	--
Entry	Average	10	29	6	19
	Avg/Min	2:1	1.4:1	--	--

EVALUATION

SUMMARY

The new site lighting design provides an even amount of light throughout the site. Some hot spots exist under the pole lights, but they are unavoidable and due to the spacing aren't an issue. The flood lighting on top of the southern bookstore wall help fill in the surrounding area with light, as well as light the pathway near the building evenly. The downlights under the entrance canopies give light levels three times the surrounding to ensure that they add emphasis and draw people toward the entrances to the building. Finally, the Light Tape ™ provides a nice glow on the southern bookstore wall, drawing people's attention without being overbearing. Although the decorative lighting isn't normal for Penn State, I feel that it adds to the architecture, while not using a considerable amount of wattage. Due to the mounting location between the joints of the brick along with the color of the tape, it should be undetectable to anyone not actively looking for it during the day. This is important, as it doesn't change the daytime aesthetic of the building.

This design fulfilled the design goals set for the area. The required light levels were met, visual interest and emphasis was added, and energy codes were met. Additionally, a safe and secure feeling area was established through uniform light levels and adequate vertical illuminances.

ASHRAE/IESNA

The proposed design is 29% better than the ASHRAE standards. The system uses 795 watts at full brightness giving an overall power density of 0.11 W/SF. The decorative portion of the lighting only uses 86 watts of power as well, which accounts for less than a tenth of the total wattage. The use of LEDs and flood lighting allowed for a modest power usage that complies with Penn States rule of thumb to be at least 25% better than ASHRAE standards.

Energy Usage (ASHRAE/IESNA) - Outdoor		
Category	Allowable	Calculated
Area (SF)	--	7000
Input Wattage	1120	795
Power Density (W/SF)	0.16	0.11

CIRCULATION SPACE | LARGE ATRIUM

EXISTING CONDITIONS


Provided by Gund Partnership

The atriums primary use is seating, for the food area, and circulation. This space connects the east entrances as well as the parking deck traffic to the rest of the HUB. There is also a gathering space that connects the 1st floor to the mezzanine level, which features both stairs and bleacher style seating. At times of lower traffic, it could act as a gathering space as well for various clubs or other student activities. There is an abundance of daylight through the exterior gazing and skylight aperture.

DIMENSIONS

Area – 9300 ft^2

Approximate width – 78 ft.

Approximate length – 165 ft.

Approximate ceiling height – 38 ft.

1ST FLOOR PLAN

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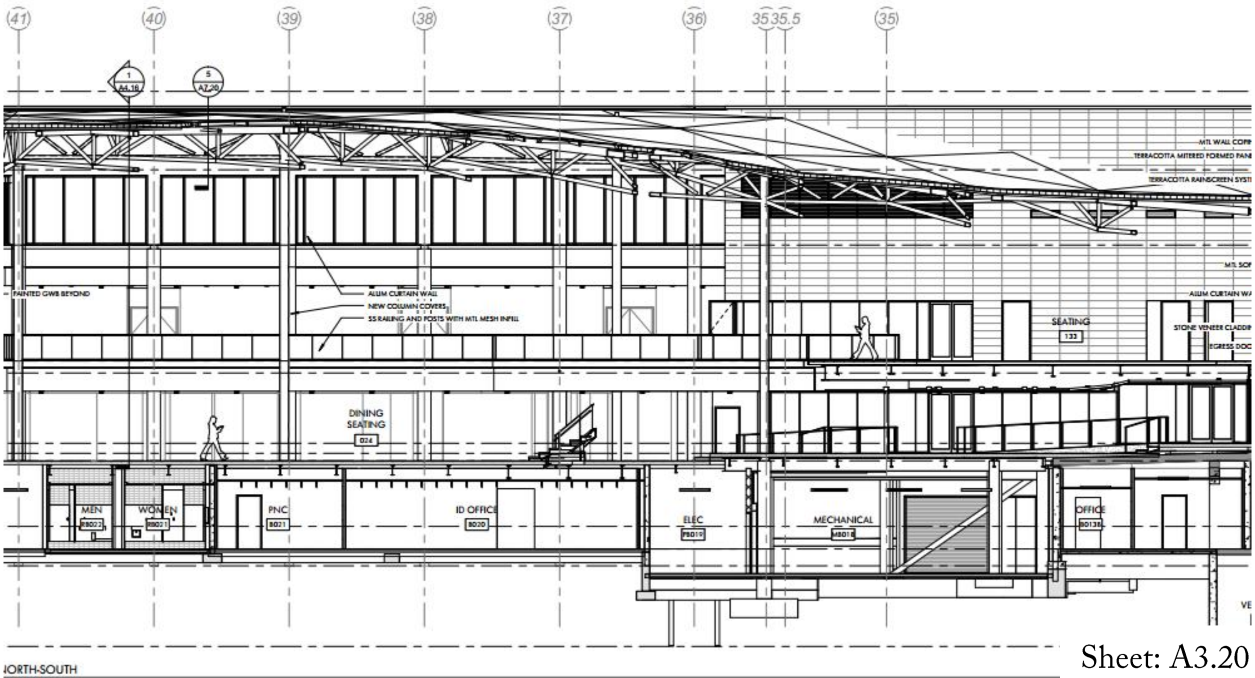
2ND FLOOR PLAN

NORTH SOUTH SECTION



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FINISHES

The floors are made up of terrazzo tiles that have a high reflectance to aid daylights contribution deep in the space. The walls are primarily painted gypsum wall board, but also consist of terracotta and glazing. The terracotta blocks vary from smooth to grooved at a ratio of 4:1. The curtain walls range in opacity from completely clear to partially obscured due to the presence of frit on the upper panels. The ceiling is exposed steel panels mixed with glass skylight panels, which also contain frit.

Atrium Materials				
Surface	Material	Descrption	Color	Reflectance
Ceiling	GSRD	3" Galvanized steel roof deck	Eggshell	0.85
Wall	GWB/PTD, GCW	Painted gypsum and aluminum fromed curtain wall	Eggshell	0.9
Floor	Terr	Terrazzo Flooring	Eggshell	0.85

GLAZING

The glazing spanning the north, west, and south side is comprised of low-E glass. Frit is introduced in the panels on the mezzanine floor and increases in density as they get closer to the ceiling. The visibility ranges from roughly 70% to 50% transmittance.

FURNITURE & EQUIPMENT

This area needs to accommodate a wide variety of uses, from collaboration space to dining areas. The solution was to have mobile furniture to allow this to be a dynamic space, shaped by its occupants. Most of the tables and chairs are free to move about the space with the exception of a few fixed raised restaurant style benches. On the north western end of the space is a line of fixed benches that act to separate this space from the food court area.

TASKS

The atrium's main purpose is a transition space and entrance to the building, linking several entrances to the main portion of the building. Because of this way-finding is paramount in this area. Reading and eating will also be occurring within the atrium, as well as general conversation.

DESIGN CONCEPT & GOALS

Within the atrium, there are a lot of different activities that happen. These range from eating and conversation to studying or watching a demonstration. These activities share a common thread of being centered on people their interactions. This is where I drew the inspiration for the lighting, connecting people to people. The lighting in the space should promote and reinforce making these connections by highlighting areas of interest and adding some visual interest to the space.

Navigation| The atrium is a large junction connecting different areas of the old and new HUB. It is likely that this will be one of the first spaces that people come to upon entering the building. The lighting should help limit confusion and guide people to areas of interest, as well as the different paths they can take to other areas.

Promote Interaction| This space is all about interpersonal connections and reinforcing them. The lighting should highlight areas that house these interactions and draw people to them.

Daylighting| There is an extensive use of curtain walls and skylights in the atrium, as such daylighting controls need to be put into place to react to the dynamic nature of the sun. The controls would regulate the amount of incoming daylight and dim electric lighting according to current conditions.

DESIGN CRITERIA

QUALITATIVE CRITERIA

Most Important

- Way-Finding
  - Since this is a major entrance area to the building it might be difficult for occupants to orient themselves at first. The lighting should help alleviate this as much as possible.
- Daylighting Controls
  - Since daylighting is so abundant throughout the space, the lighting within the space should respond accordingly, allowing for increased energy savings.
- Overall Appearance of Space
  - The lighting should enhance the architecture and provide a nice environment for occupants to come into as they enter the building.
- Glare Control
  - Due to the extensive use of glass in the space, it is imperative that glare from the sun be controlled. This is especially important for the southern and southwestern facades.

Important

- Color Rendering
  - The light sources in the space should render colors in a natural and pleasing manner.

PSYCHOLOGICAL IMPRESSION

The Flynn mode that I feel is most appropriate for a redesign of this space would be one of spaciousness and clarity.

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance

- Classification – Common Applications
  - Reading / Writing HB Pencil
    - Category P: 300 lux at work plane
    - Avg/Min: 2:1

Recommended Vertical Illuminance

- Classification – Common Applications
  - Reading / Writing HB Pencil
    - Category L: 75 lux at work plane

LEED

EAP: Minimum Energy Performance Required

- Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.1–2010, with errata (or a USGBC-approved equivalent standard for projects outside the U.S.).

EAC: Optimize Energy Performance (Major Renovation)

- Reduce overall energy consumption by 4% - 40% for 1 – 16 points.

EQC: Interior Lighting

- For at least 90% of individual occupant spaces, provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences, with at least three lighting levels or scenes (on, off, midlevel). Midlevel is 30% to 70% of the maximum illumination level (not including daylight contributions). For all shared multi-occupant spaces, meet all of the following requirements.

- Have in place multizone control systems that enable occupants to adjust the lighting to meet group needs and preferences, with at least three lighting levels or scenes (on, off, midlevel).
- Lighting for any presentation or projection wall must be separately controlled.
- Switches or manual controls must be located in the same space as the controlled luminaires. A person operating the controls must have a direct line of sight to the controlled luminaires.

EQC: Daylight

- ❖ Demonstrate through annual computer simulations that spatial daylight autonomy300/50% (sDA300/50%) of at least 55%, 75%, or 90% is achieved. Use regularly occupied floor area. Healthcare projects should use the perimeter area determined under EQ Credit Quality Views.

EQC: Quality Views

- ❖ Achieve a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area. View glazing in the contributing area must provide a clear image of the exterior, not obstructed by frits, fibers, patterned glazing, or added tints that distort color balance.

Additionally, 75% of all regularly occupied floor area must have at least two of the following four kinds of views:

- multiple lines of sight to vision glazing in different directions at least 90 degrees apart;
- views that include at least two of the following: (1) flora, fauna, or sky; (2) movement; and (3) objects at least 25 feet (7.5 meters) from the exterior of the glazing;
- unobstructed views located within the distance of three times the head height of the vision glazing; and
- views with a view factor of 3 or greater, as defined in “Windows and Offices; A Study of Office Worker Performance and the Indoor Environment.”

Energy Allowances

The following table shows the energy allowance for the atrium according to ASHRAE 2013 space by space method.

Energy Allowance			
Space	Area (SF)	W/SF	Allowable Wattage
Atrium	9300	1.8	16740

ASHRAE 2013 Standards

9.4.1.1(a),(b),(d),(e),(f),(h)

DESIGN CRITERIA SELECTED

1) Meet ASHRAE Standards
2) Implement daylighting controls
3) Control glare
4) Create a visually pleasing environment

DESIGN DEVELOPMENT

SUMMARY

The fixtures within the atrium are all 3500K to create a space that was neither cool nor warm. The ambient layer of light is provided by a series of high output pendants mounted on the ceiling. Most of the fixtures were mounted below the structural trusses to avoid scalloping. These provide a uniform base layer of light on the main floor and the mezzanine level, with the exception of the main stair were a slightly higher light level was used to provide emphasis.

Main Stair from Mezzanine Balcony

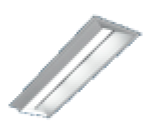
Several layers of light serve to highlight four areas within the space. The first are linear wall washers used to wash the wall north of the old HUB junction. This was to provide a beacon to that path, as well as add visual interest to the space and promote the use of the adjacent seating areas. The next are decorative pendants above the main seating area on the main floor. They serve to provide a decorative glow and mark the seating area. The cascading circular forms of the pendant itself represents the many personal connections that we make. The final layer is also Light Tape ™ that is placed within the horizontal grooves of the terra cotta wall.

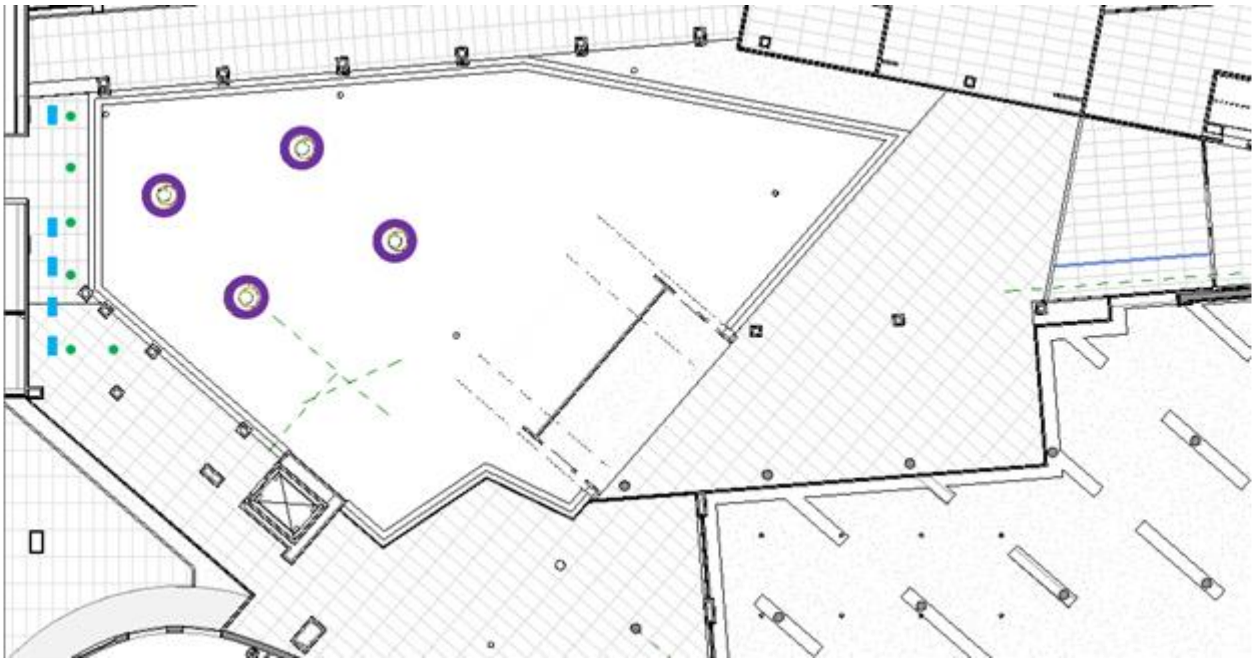
East Mezzanine Seating Toward Theater

East Entrance to Old HUB

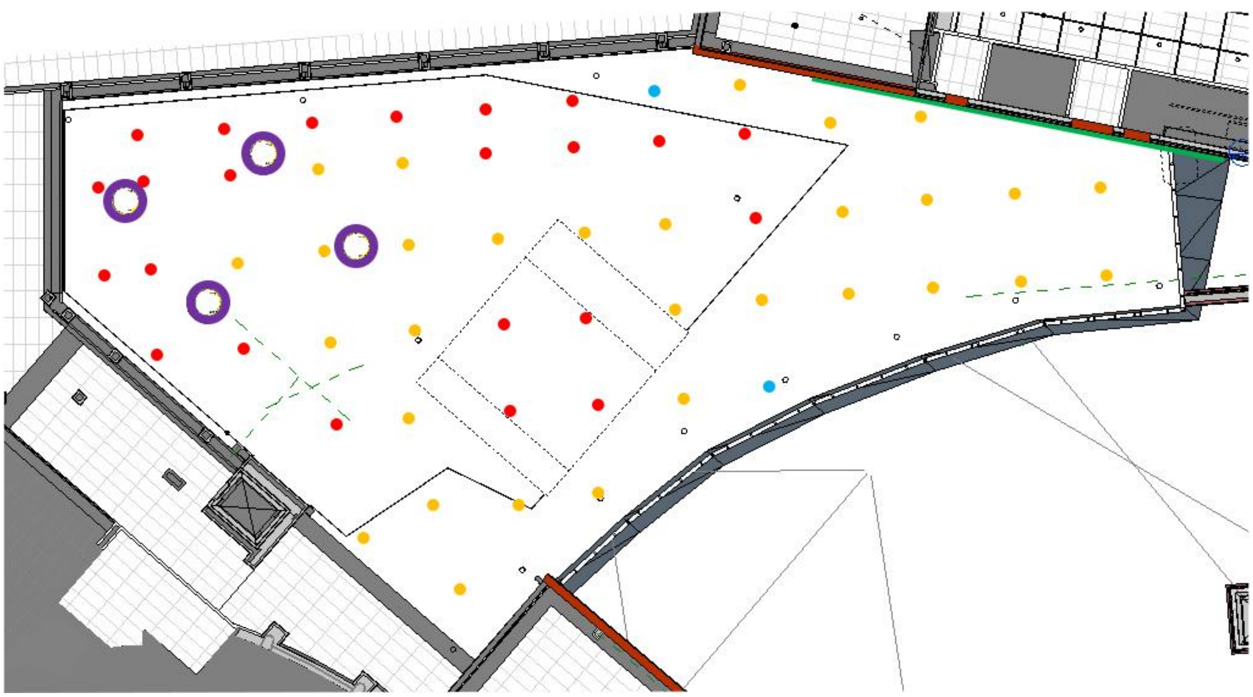
FIXTURE & EQUIPMENT SELECTION

The lighting with the atrium is entirely LED. Cut sheets can be found in appendix A and detailed fixture schedules can be found in appendix B.

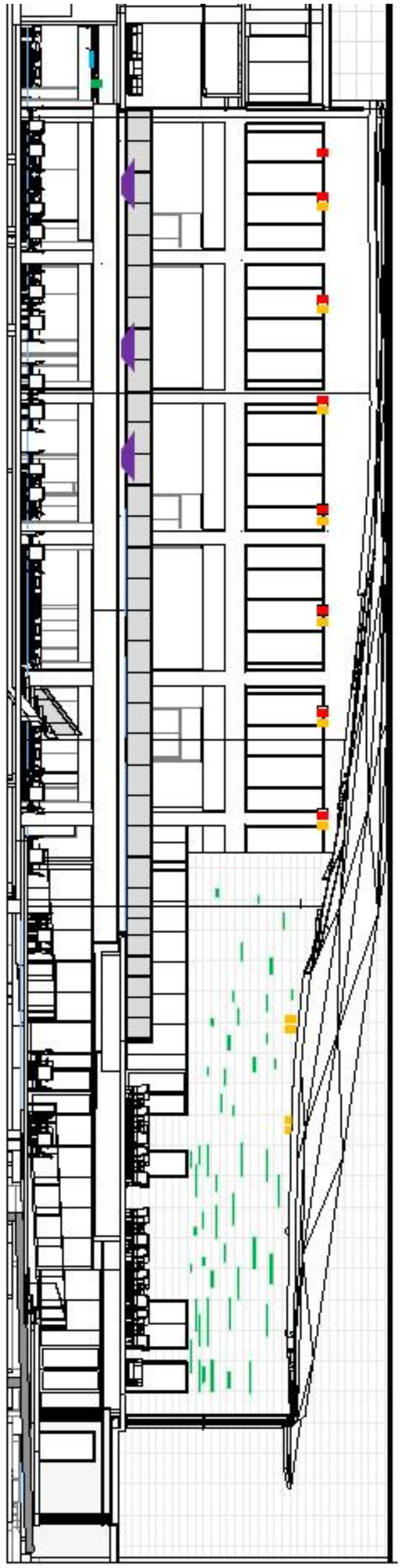
Fixture Schedule				
Type	Symbol	Image	Description	Manufacturer
L1			9000 lumen 45° HO LED pendant	Prescolite
L2			6000 lumen 45° HO LED pendant	Prescolite
L3			3000 lumen 45° HO LED pendant	Prescolite
L4			6" 1100 lumen 45° recessed LED downlight	Prescolite
L5			Recessed 2' LED linear wall washer	Lighting Quotient
L6			LED circular decorative pendant	Sattler
L7			Electroluminescent thin strip light	Light Tape



1st Story RCP



2nd Story RCP



East West Elevation

Fixture Calculations							Lightloss Factors			
Type	Quantity	W/fixture	Total Wattage	PF	Va/fixture	Total VA		LLD	LDD	Total
L1	22	99	2178	1	99	2178	L1	0.8	0.96	0.77
L2	30	66.5	1995	1	66.5	1995	L2	0.8	0.96	0.77
L3	2	33.9	67.8	1	33.9	67.8	L3	0.8	0.96	0.77
L4	6	14	84	1	14	84	L4	0.8	0.96	0.77
L5	5	48	240	1	48	240	L5	0.8	0.96	0.77
L6	4	255	1020	1	255	1020	L6	0.8	0.96	0.77
L7	1572.5 in^2	0.016 W/in^2	25.2	1	0.016 VA/in^2	25.2	L7	0.8	0.96	0.77

CONTROLS STRATEGY

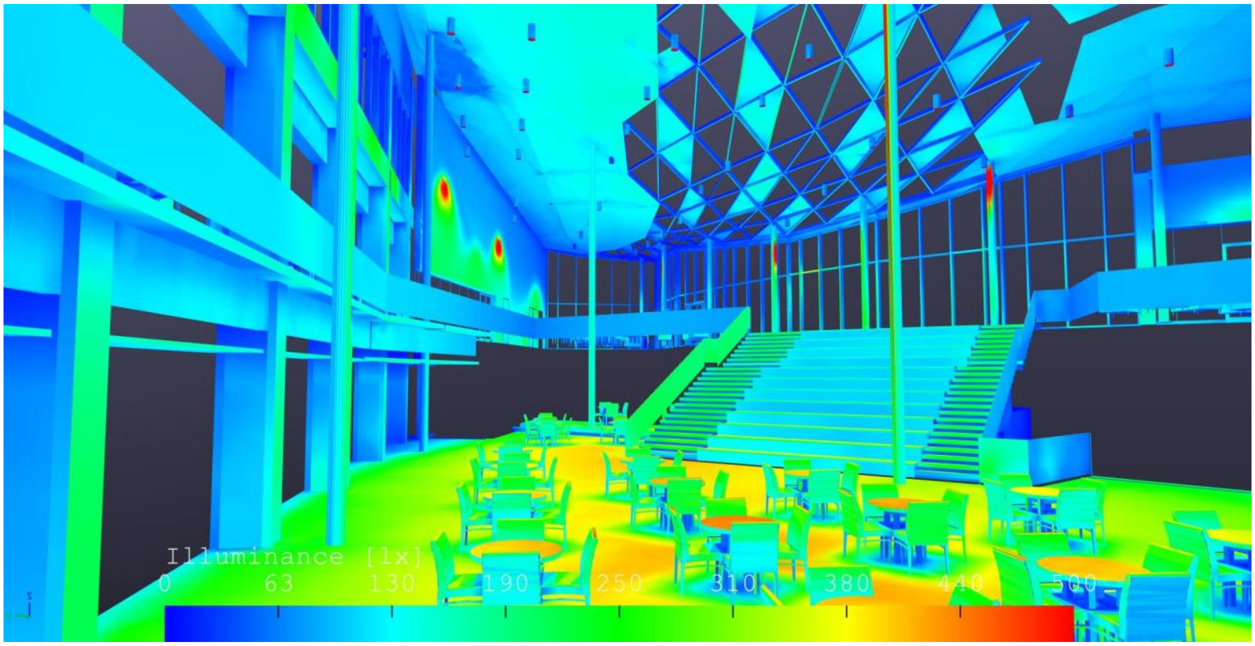
All lighting within the atrium space are on a time clock that dims the entire system during the evening hours. L1–L3 are also controlled by daylight sensors, dimming them when there is sufficient daylight. Lighting is keyed from the public to prevent tampering.

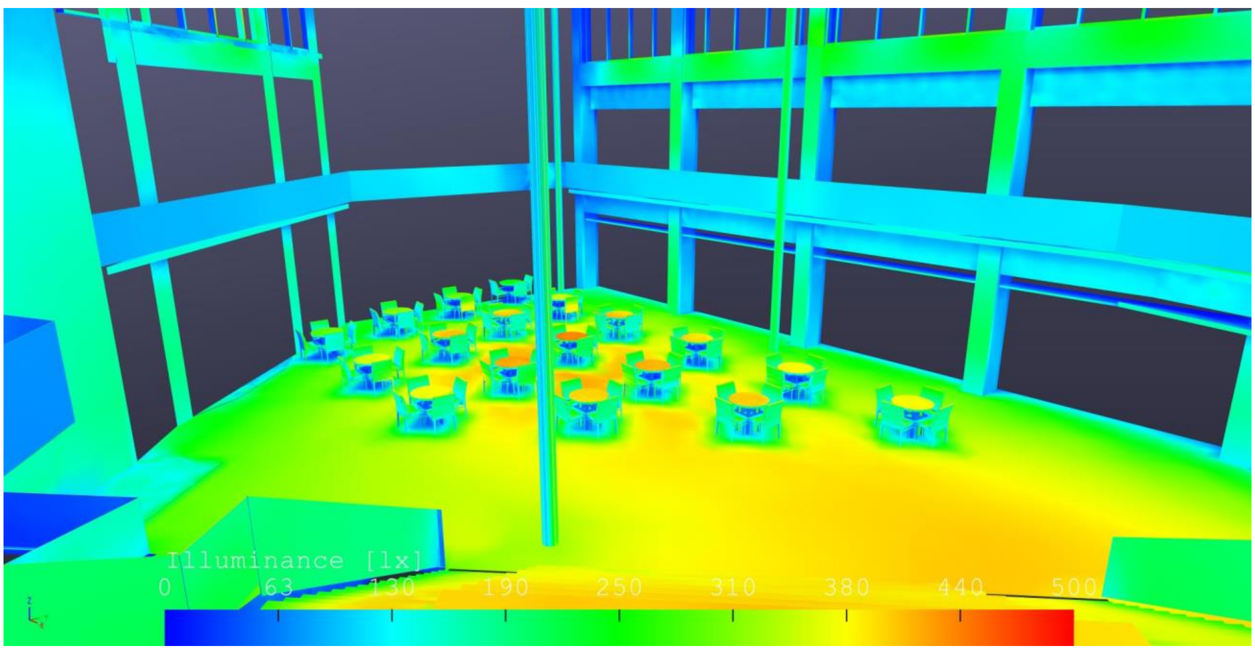
CALCULATION SUMMARY

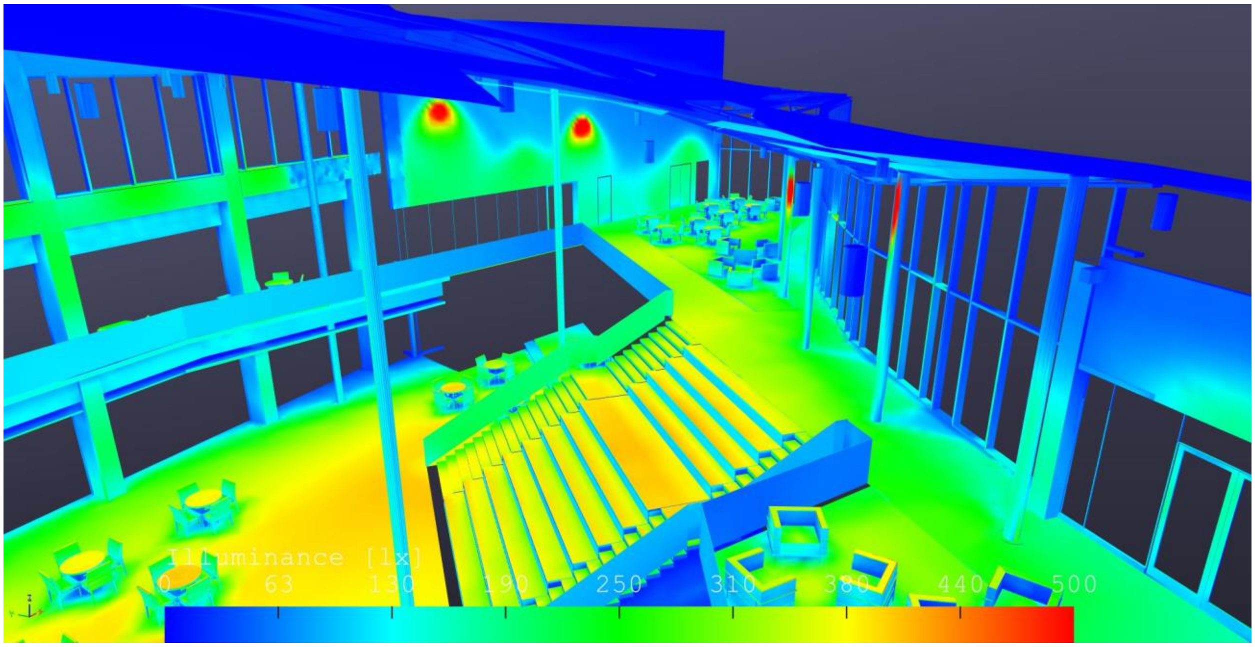
The table below summarizes the calculations for the space. For more in-depth analysis, refer to the pseudo color renderings.

Atrium Illuminance Criteria					
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)	
Space	Metric	Recommended	Achieved	Recommended	Achieved
Main Floor	Average	300	346	150	190
	Avg/Min	2:1	1.7:1	--	--
West Seating	Average	300	332	150	313
	Avg/Min	4:1	1.6:1	--	--
Main Stair	Average	300	375	150	120
	Avg/Min	4:1	1.6:1	--	--
West Mezz Seating	Average	300	319	150	100
	Avg/Min	4:1	1.7:1	--	--
East Mezz Seating	Average	300	281	150	120
	Avg/Min	4:1	2.4:1	--	--
Mezz Corridor	Average	50	268	30	110
	Avg/Min	2:1	2:1	--	--

KEY (LUX)							
0-60	60-120	120-180	180-240	240-300	300-370	370-440	440-500







EVALUATION

SUMMARY

The lighting provides a uniform light level throughout the space, providing a sense of spaciousness and clarity. Spots of emphasis are used to attract occupants to social areas, such as the main seating and main stair. These spots are created mainly by the decorative lighting .These also help to create a visual hierarchy, helping to separate transition areas from gathering spots and navigate the space. These highlights add a level of visual interest to the space beyond the general lighting.

This design fulfilled the design goals set for the space. The required light levels were met, visual interest was created, daylight works in tandem with electric lighting, and energy codes were met.

ASHRAE/IESNA

The proposed design is currently 66% better than the ASHRAE requirements. The system as a whole is using 5610 watts when at full brightness. Due to the daylighting controls and the dimmed state that the decorative lighting will be in, this number will actually be lower, further increasing the energy savings. The extensive use of LED lighting is responsible for the substantial energy reduction.

Energy Usage (ASHRAE/IESNA) - Atrium		
Category	Allowable	Calculated
Area (SF)	--	9300
Input Wattage	16740	5610
Power Density (W/SF)	1.80	0.60

LARGE WORK SPACE | BOOKSTORE

EXISTING CONDITIONS

The bookstore is a large open retail area. The entrance is open to the second story, creating a clear entryway into the space. Most of the products are on the first floor with the book section in a separate space in the back. The mezzanine level has a small library and reading area. The southern façade sports floor to ceiling windows that have solar shading louvers attached to the outside.

DIMENSIONS

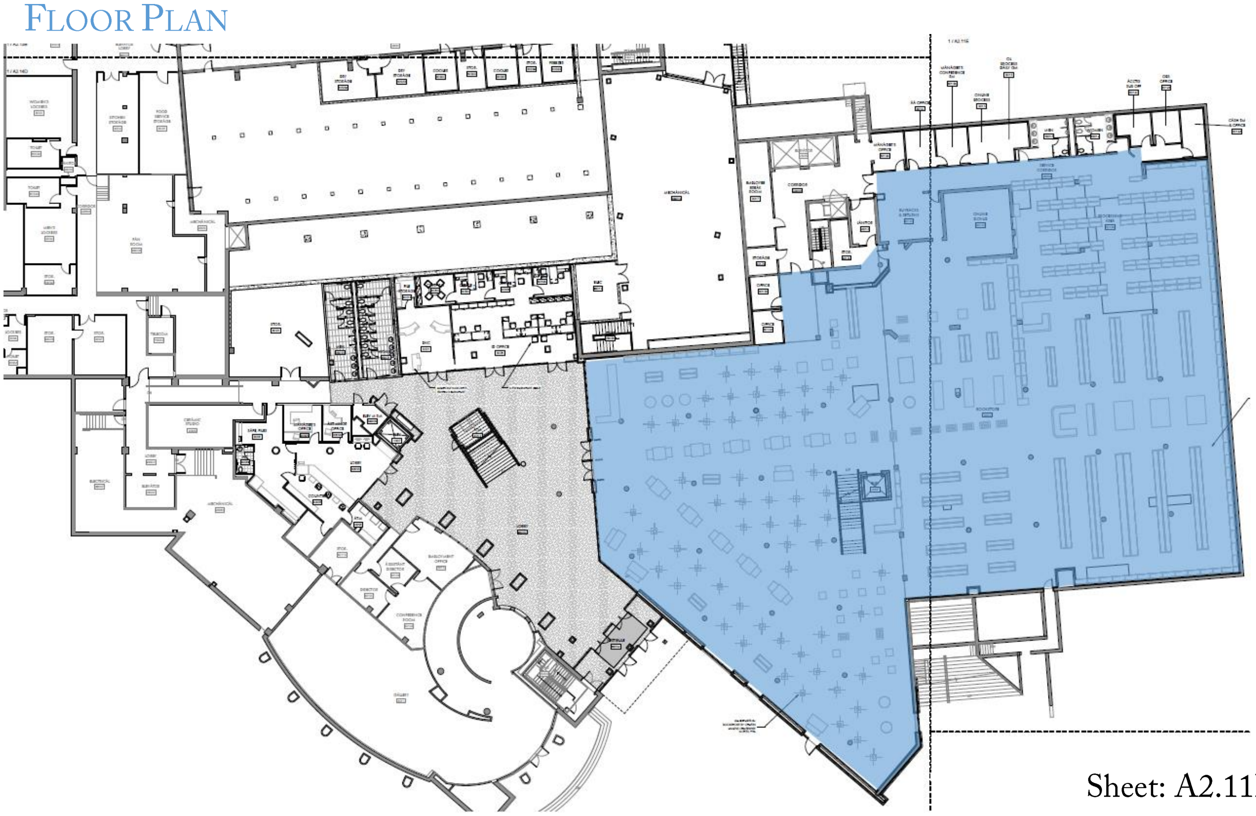
Area – 22000 ft^2

Approximate width – 136 ft.

Approximate length – 200 ft.

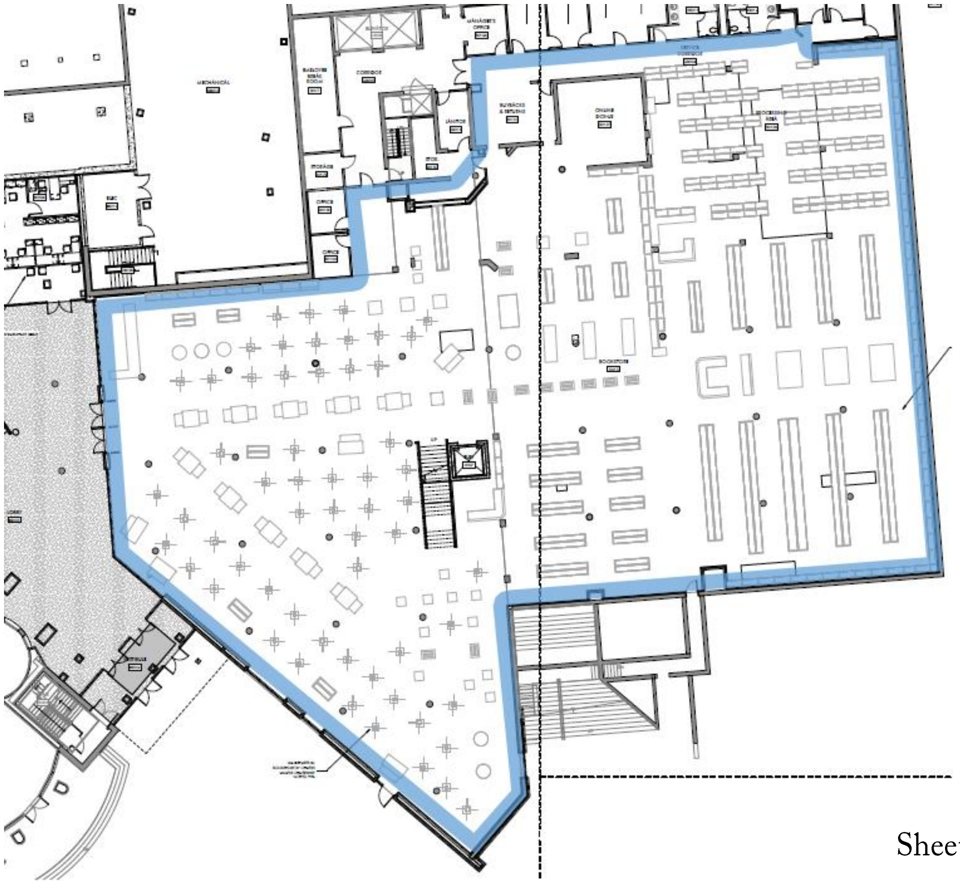
Approximate height – 20 ft. from 1^{st} to ceiling and 9 ft. from 1^{st} to mezzanine

FLOOR PLAN



Sheet: A2.11D

ENLARGED FLOOR/FURNITURE PLAN



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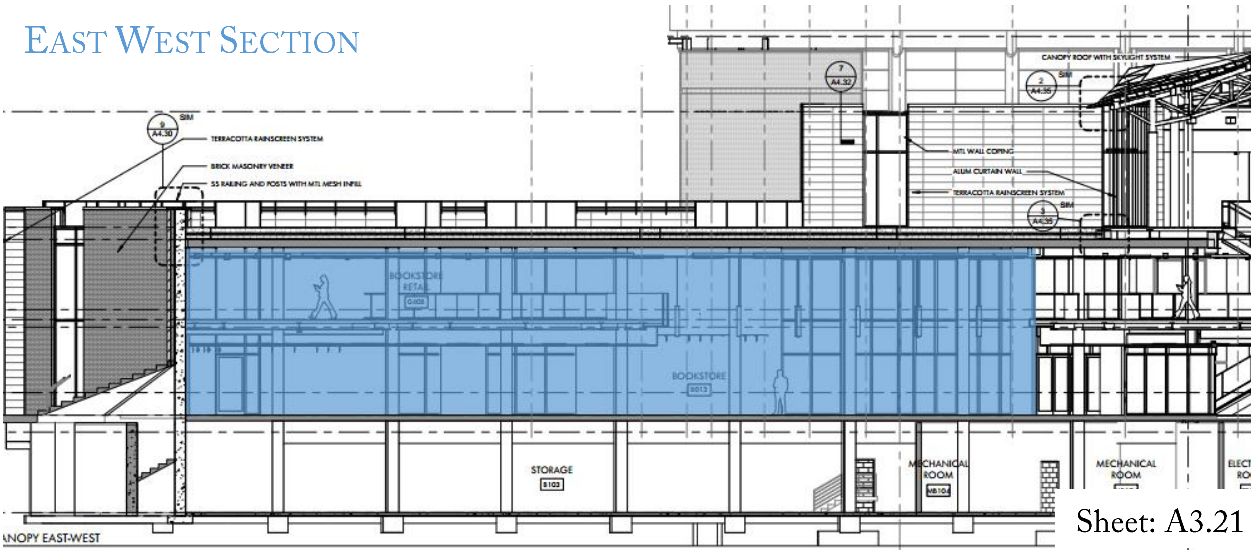
EAST WEST SECTION



Sheet: A3.21

FINISHES

The bookstore has two levels, the main level and mezzanine. Both floors have a mix of carpet, wood, and tile flooring. The walls are a grey painted GWB and glazing. The ceiling is made up entirely of acoustic ceiling tile for both the main and mezzanine floor.

Bookstore Materials				
Surface	Material	Descrption	Color	Reflectance
Ceiling	ACT-1	2' x 4' Acoustic ceiling tile	Eggshell	0.8
Wall	GWB/PTD	Painted gypsum wallboard	Eggshell	0.9
Floor	CPT TILE, WD, LIN	Carpet tile, wood, and linoleum	Grey, white	0.19*

*This is a combination of all floor materials

GLAZING

The glazing consists of floor to ceiling low-e clear insulated glass. These units have a visibility of 74%. The upper third of the windows have solar shading louvers that help project light deeper into the space, while preventing direct glare.

FURNITURE/EQUIPMENT

The majority of furniture in the main retail area are racks and shelves for apparel, supplies, and other Penn State merchandise. The bookstore portion has a main counter and shelves for books. The mezzanine level furniture is similar to the bookstore.

TASKS

The bookstore is primarily a retail space, so browsing and shopping will be the two major tasks in the space. The clerks will need to be able to read and write, as well as use computers.

DESIGN CONCEPT AND GOALS

The bookstore is mainly devoted to retail of various Penn State merchandise, school supplies, and, of course, books. The layout of the store creates a pathway through all the other wares to the books. This was most likely a strategy used by Barnes and Noble to get customers to buy more than the books that they ultimately needed. I saw an opportunity to play on this by treating it as a pathway to knowledge. Based on the Blooms Taxonomy, the steps would include remembering, comprehension and analysis, and end with synthesis and evaluation.

Encourage Movement| People won't buy anything if they don't know what's there. The lighting should reinforce movement through all areas of the space. By highlighting key displays on the sales floor, occupants would be drawn off of the main path to the back of the store.

Visual interest| In addition to providing adequate light levels, the lighting should also add a layer of interest to the space. Possibly through patterns, forms, and layouts of the fixtures themselves.

DESIGN CRITERIA

QUALITATIVE CRITERIA

Important

- Aesthetics
  - The fixtures in the space should add to and enhance the architecture, rather than take away from it. Clutter should be avoided and overall fixture appearance should be considered.
- Hierarchy
  - It may be desired to highlight merchandise using light, making it stand out from the surroundings.

PSYCHOLOGICAL IMPRESSION

The bookstore is a public space and the psychological impression should reflect that. The lighting redesign will focus on making this space feel spacious by providing uniform high levels of general illumination.

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance

- Classification – Retail
  - General Retail
    - Category R: 500 lux (50 fc) at 2.5'
    - Avg/Min: 3:1

Recommended Vertical Illuminance

- Classification – Retail
  - General Retail
    - Category M: 100 lux (10 fc)
    - Avg/Min: 6:1

LEED

EAP: Minimum Energy Performance Required

- Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.1–2010, with errata (or a USGBC-approved equivalent standard for projects outside the U.S.).

EAC: Optimize Energy Performance (Major Renovation)

- Reduce overall energy consumption by 4% - 40% for 1 – 16 points.

EQC: Interior Lighting

- For at least 90% of individual occupant spaces, provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences, with at least three lighting levels or scenes (on, off, midlevel). Midlevel is 30% to 70% of the maximum illumination level (not including daylight contributions). For all shared multioccupant spaces, meet all of the following requirements.

- Have in place multizone control systems that enable occupants to adjust the lighting to meet group needs and preferences, with at least three lighting levels or scenes (on, off, midlevel).
- Lighting for any presentation or projection wall must be separately controlled.
- Switches or manual controls must be located in the same space as the controlled luminaires. A person operating the controls must have a direct line of sight to the controlled luminaires.

EQC: Daylight

- ❖ Demonstrate through annual computer simulations that spatial daylight autonomy300/50% (sDA300/50%) of at least 55%, 75%, or 90% is achieved. Use regularly occupied floor area. Healthcare projects should use the perimeter area determined under EQ Credit Quality Views.

EQC: Quality Views

- ❖ Achieve a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area. View glazing in the contributing area must provide a clear image of the exterior, not obstructed by frits, fibers, patterned glazing, or added tints that distort color balance.

Additionally, 75% of all regularly occupied floor area must have at least two of the following four kinds of views:

- multiple lines of sight to vision glazing in different directions at least 90 degrees apart;
- views that include at least two of the following: (1) flora, fauna, or sky; (2) movement; and (3) objects at least 25 feet (7.5 meters) from the exterior of the glazing;
- unobstructed views located within the distance of three times the head height of the vision glazing; and

- views with a view factor of 3 or greater, as defined in "Windows and Offices; A Study of Office Worker Performance and the Indoor Environment."

Energy Allowances

The following table shows the energy allowance for the bookstore according to ASHRAE 2013 space by space method.

Energy Allowance			
Space	Area (SF)	W/SF	Allowable Wattage
Bookstore	22000	1.44	31680

ASHRAE 2010 Standards

9.4.1.1(a), (b), (d), (e), (f), (i)

DESIGN CRITERIA SELECTED

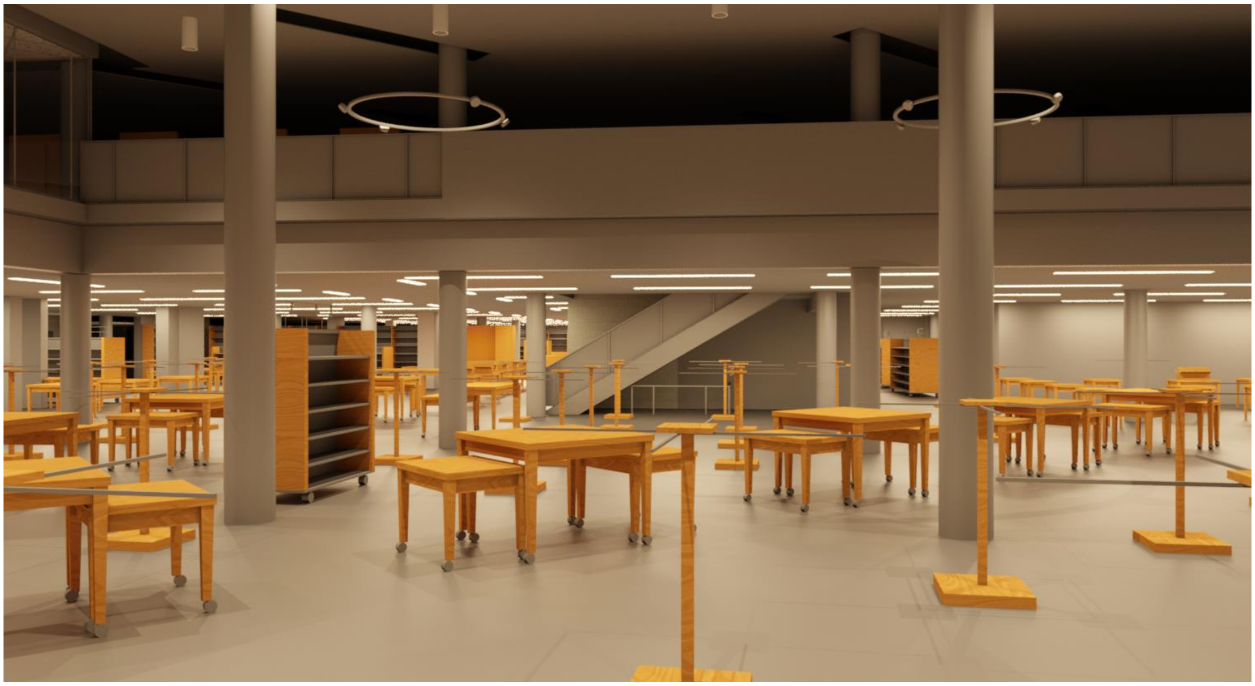
1) Meet ASHRAE Standards
2) Create a hierarchy within the space
3) Control glare and daylight
4) LEED credits

DESIGN DEVELOPMENT

SUMMARY

Following the previous spaces, the fixtures are a consistent 3500K. Starting at the front of the store, decorative circular pendants represent the base ideas and concepts we learn. These are mounted at a height so they are level with the bottom of the mezzanine floor and kept at a glow, rather than providing substantial light to the work plane. The spot light accents attached to the circular fixture, highlighting floor displays, embody the individual perceptions that make these experiences our own.

Bookstore Mezz to Sale Floor

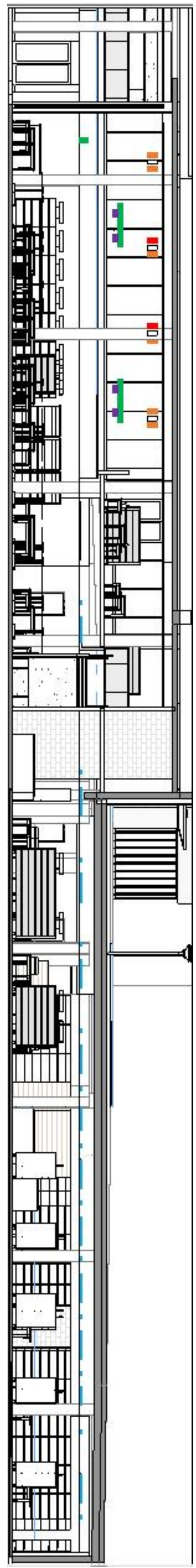


Main Sale Floor to Back of Store

The general lighting will be provided by LED downlights mounted on the ceiling. As you move through the store under the mezzanine level, the focus becomes more specialized on school related products. In this area the general lighting is created by linear fixtures that are placed to converge on the center path. This layer represents the comprehension of what you've learned by relating it to past knowledge and experiences. At the end of the path lies the book section which is illuminated by the same linear fixtures as under the mezzanine, but are arranged to circle back on themselves, representing synthesis of ideas and creation of new knowledge.

FIXTURE & EQUIPMENT SELECTION

Following the theme of previous spaces, the bookstore is lit entirely by LEDs. Cut sheets can be found in appendix A and detailed fixture schedules are in appendix B



Fixture Schedule				
Type	Symbol	Image	Description	Manufacturer
L2			9000 lumen 45° HO LED pendant	Prescolite
L8			12000 lumen 45° HO LED pendant	Prescolite
L4			6" 1100 lumen 45° recessed LED downlight	Prescolite
L9			10000 lumen 5' circular pendant	Sattler
L10			1000 lumen 36° LED spot connected to L8	Sattler
L11			8' linear 3500 lumen HO recessed LED fixture	LumenPulse

Fixture Calculations							Lightloss Factors			
Type	Quantity	W/fixture	Total Wattage	PF	Va/fixture	Total VA		LLD	LDD	Total
L1	5	99	495	1	99	495	L1	0.8	0.96	0.77
L4	4	14	56	2	14	56	L4	0.8	0.96	0.77
L8	15	132	1980	1	132	1980	L8	0.8	0.96	0.77
L9	4	110	440	1	110	440	L9	0.8	0.96	0.77
L10	16	15	240	1	15	240	L10	0.8	0.96	0.77
L11	268	48	12864	2	48	12864	L11	0.8	0.96	0.77

CONTROLS STRATEGY

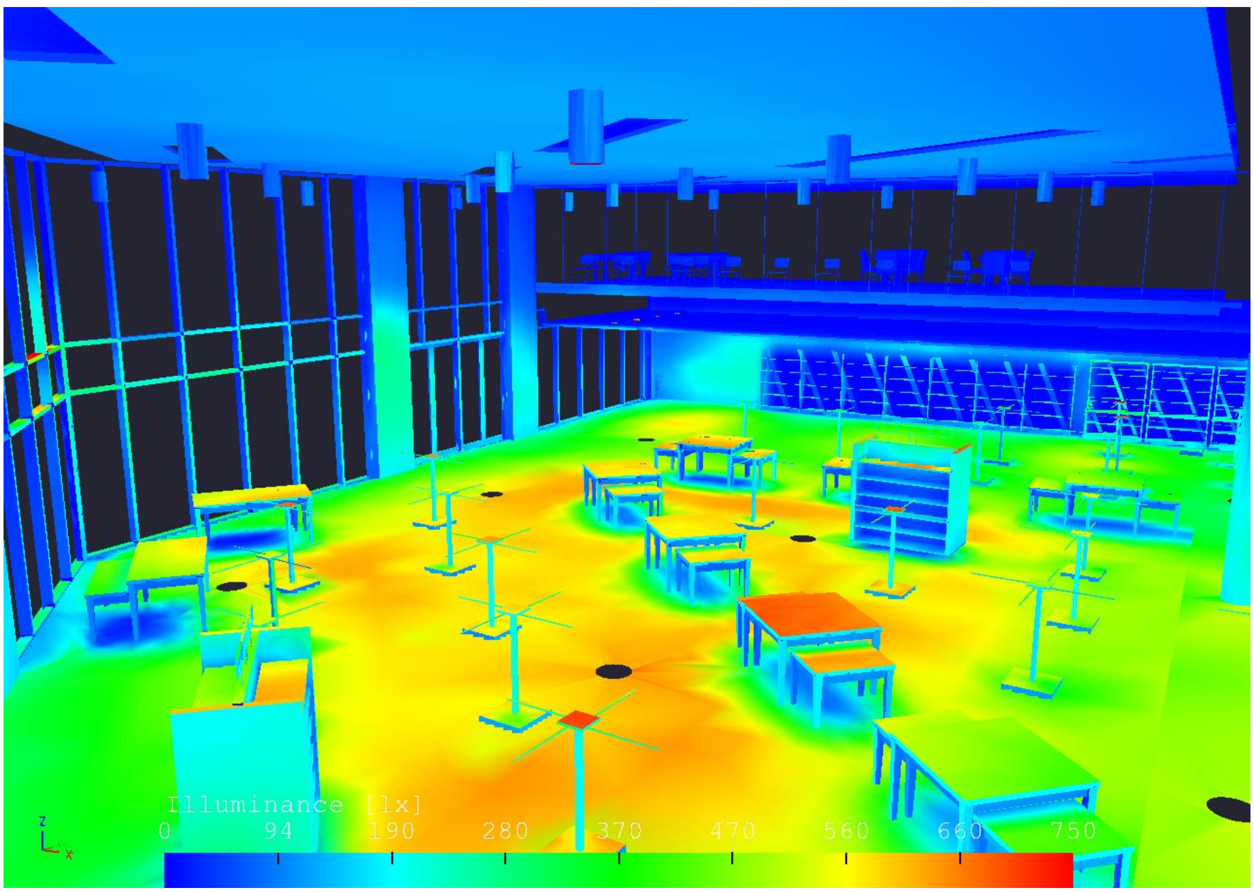
The L11 fixtures near the windows will be a dimmable and controlled by daylight sensors. This will allow part of the system to dim when adequate daylighting is present within the space.

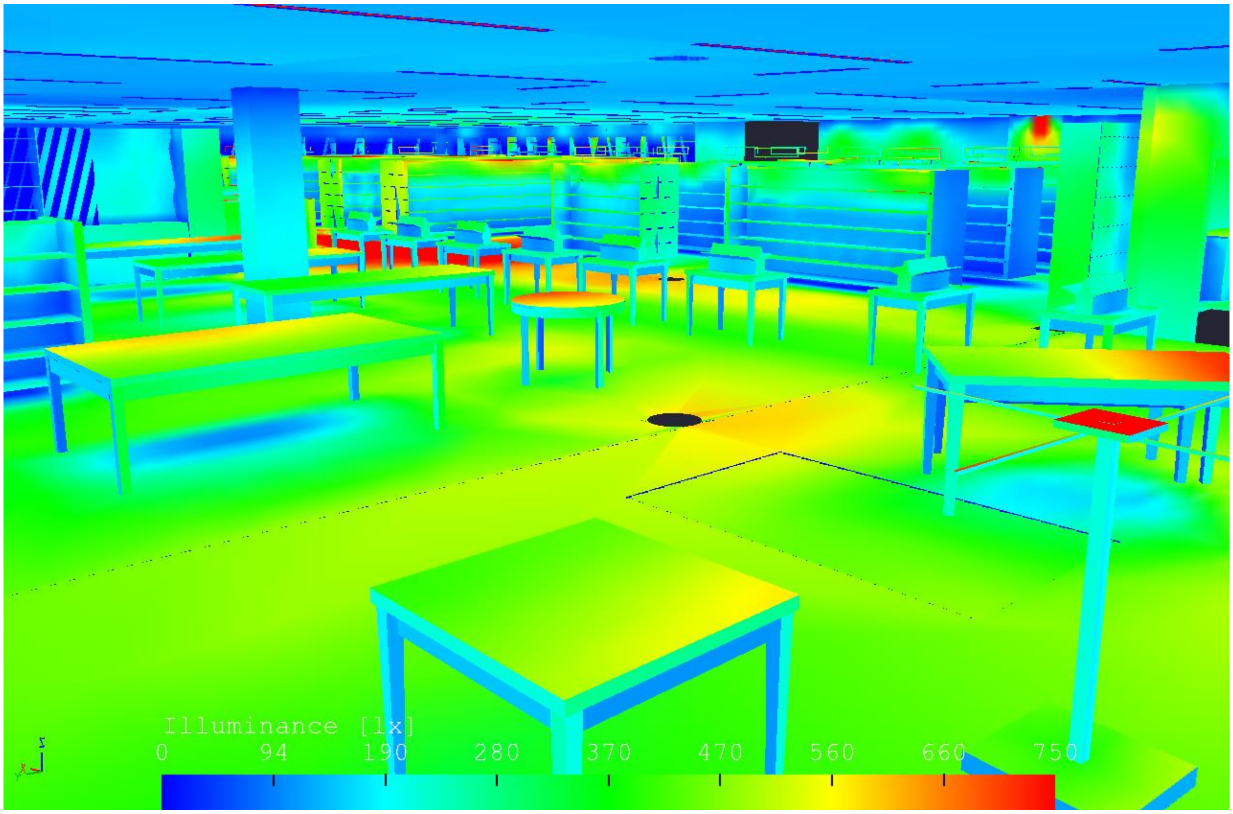
CALCULATION SUMMARY

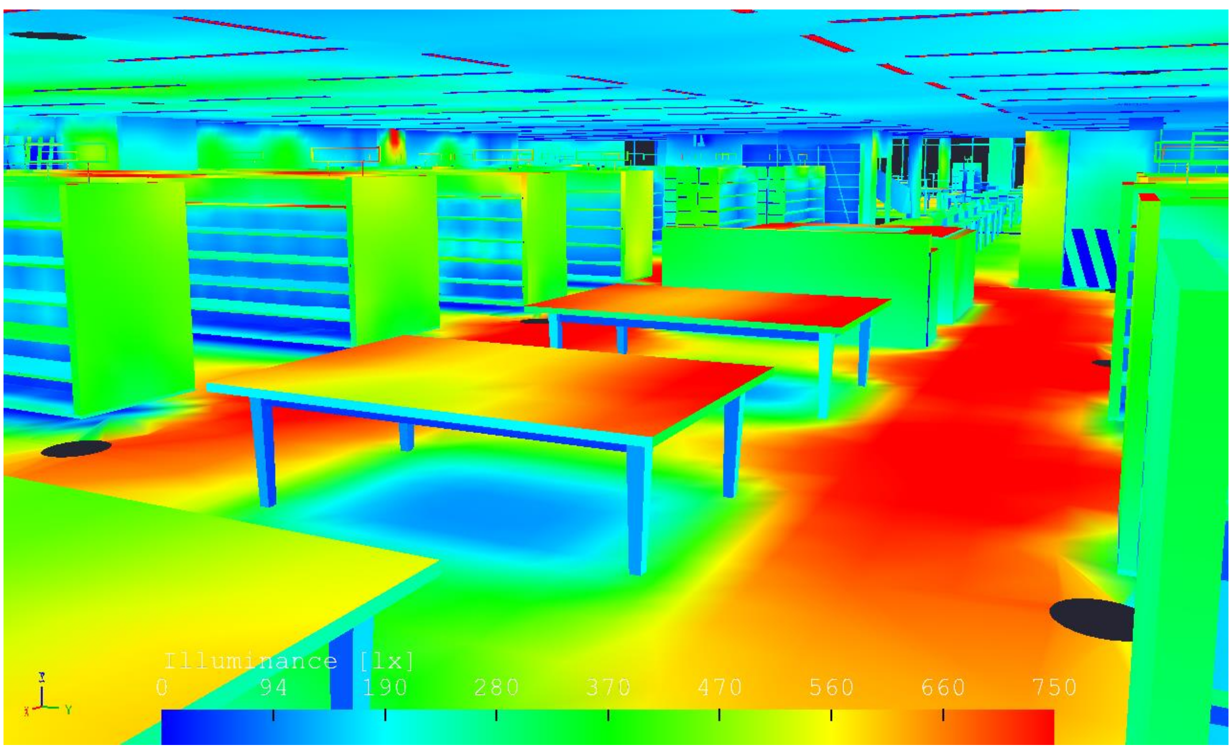
The table below summarizes the calculations for the space. For more in-depth analysis, refer to the pseudo color renderings.

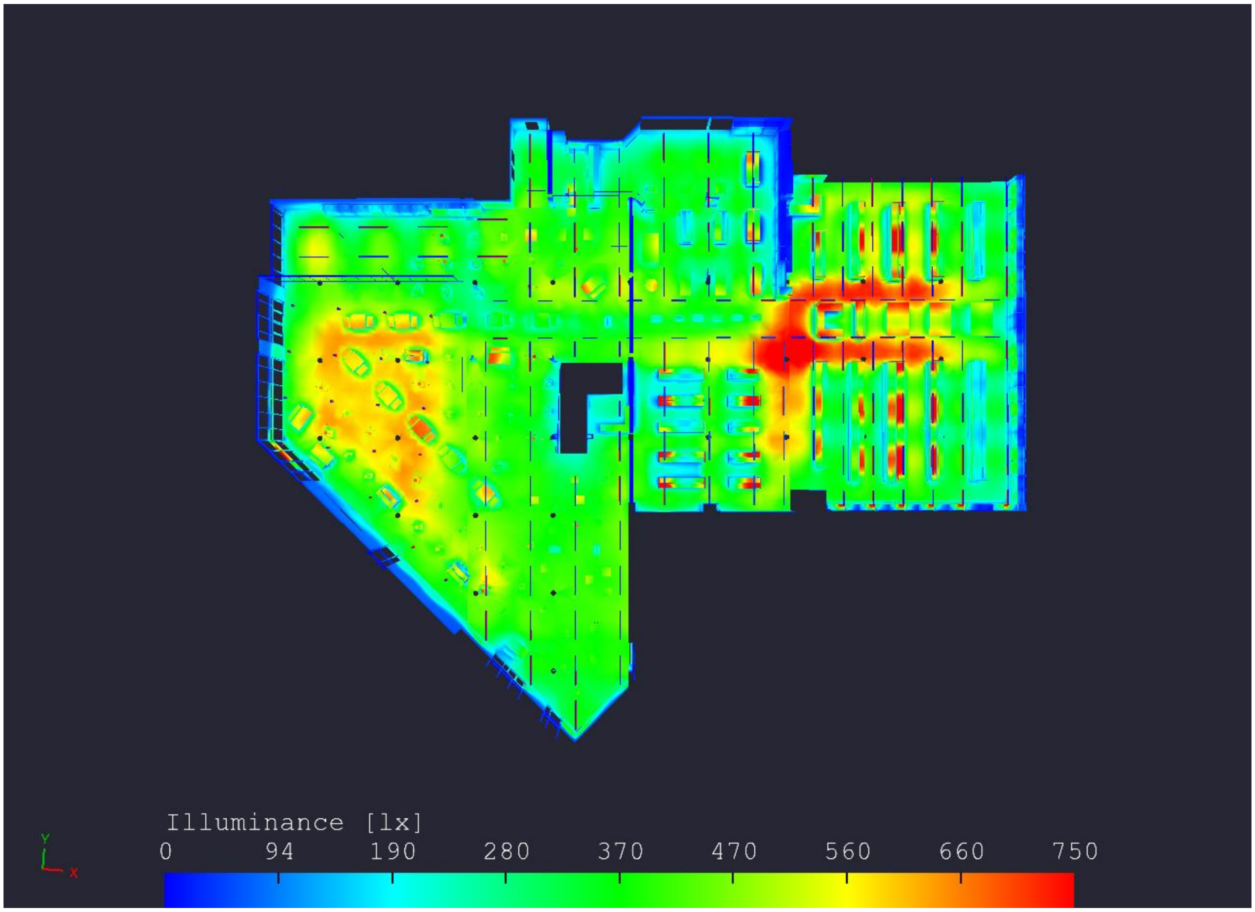
Bookstore Illuminance Criteria					
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)	
Space	Metric	Recommended	Achieved	Recommended	Achieved
Retail space	Average	500	499	100	200
	Avg/Min	3:1	1.7:1	--	--

KEY (LUX)							
0-100	100-190	190-280	280-370	370-470	470-560	560-660	660-750




Illuminance [lx]
0 94 190 280 370 470 560 660 750


Illuminance [lx]
0 94 190 280 370 470 560 660 750



EVALUATION

SUMMARY

The general lighting provides a consistent light level throughout the space, allowing for ample visibility and helps reinforce a feeling of spaciousness within the space. Using different fixtures and layouts allowed for variation within the space, signifying different areas and adding interest to the space. The layout of the linear fixtures encourages patrons to explore the space, while always drawing them back to the main pathway from the front of the store to the back.

This design fulfilled the design goals for the space. The required light levels were met with a visually interesting design. Daylighting controls allow energy savings, while natural light is allowed to supplement the electric lighting. Energy codes were met and exceeded as well.

ASHRAE/IESNA

This design is 49% better than the standards set by ASHRAE, using only 16000 of the 31680 allowable watts. Daylighting controls will help lower this number even further when the space is in use. In addition, the dimmed state that the decorative fixtures will be in will also decrease the total wattage used. The use of LED lighting is the main reason that such a low LPD was achieved.

Energy Usage (ASHRAE/IESNA) - Bookstore		
Category	Allowable	Calculated
Area (SF)	--	22000
Input Wattage	31680	16075
Power Density (W/SF)	1.44	0.73

SPECIAL PURPOSE SPACE | FLEX THEATER

EXISTING CONDITIONS

DIMENSIONS

Area – 2000 ft^2

Approximate width – 38 ft.

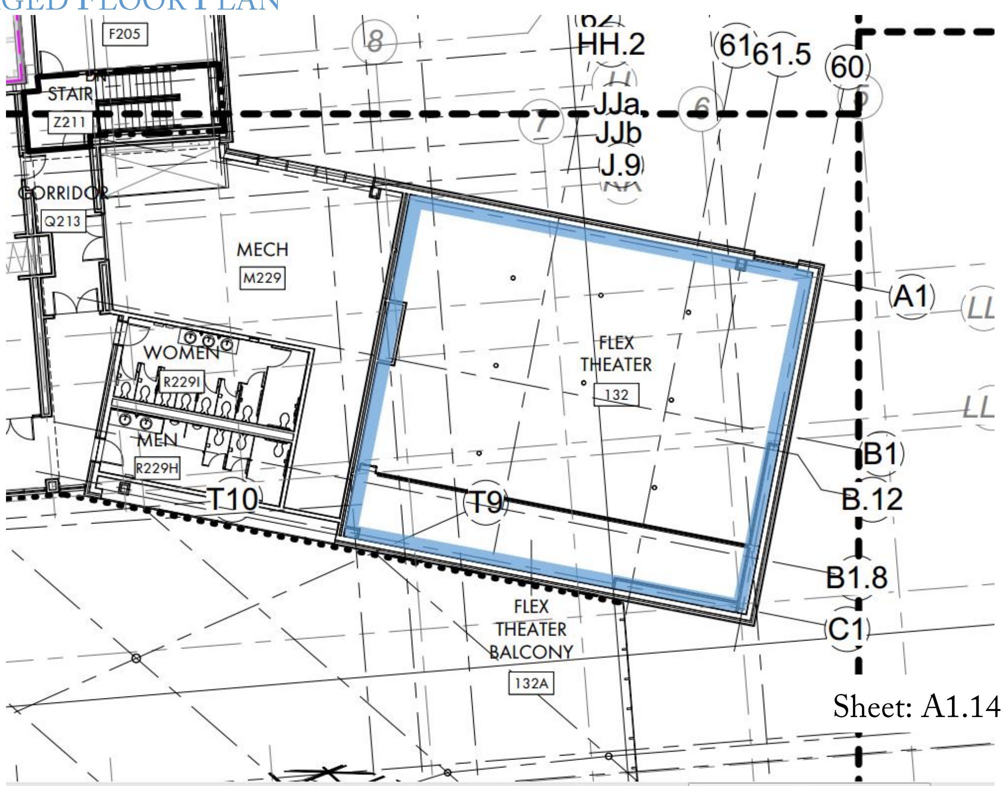
Approximate length – 55 ft.

Ceiling Height – 21 ft., 18 ft. to suspended ceiling

FLOOR PLAN

Sheet: A1.14

ENLARGED FLOOR PLAN



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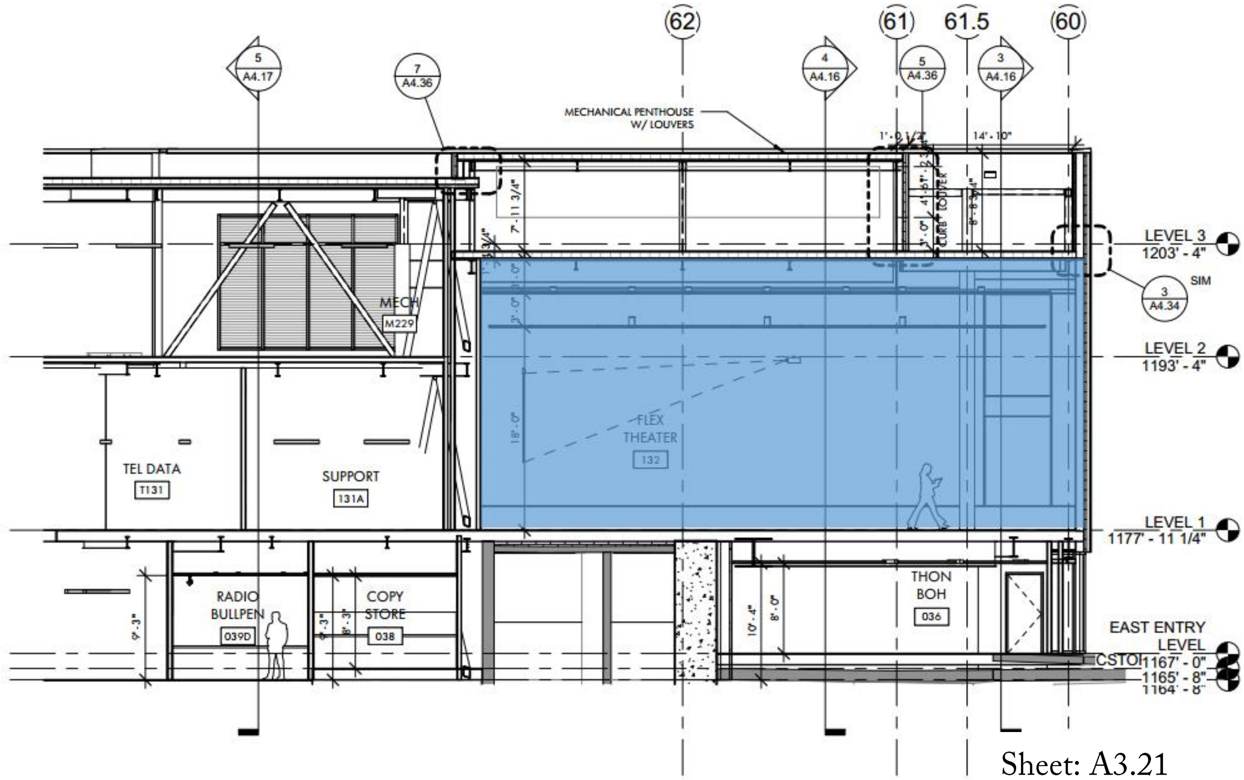
EAST WEST SECTION



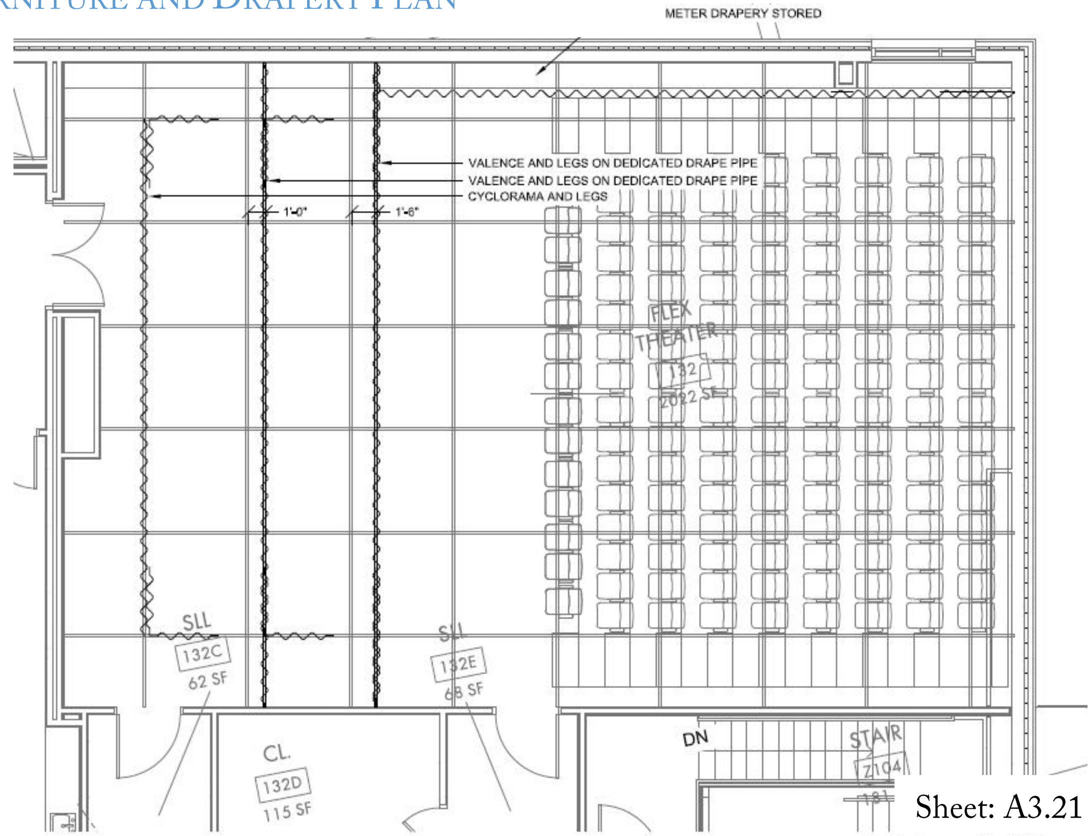
Sheet: A3.21

FINISHES

The floors are clad in ebony wood paneling which have a low reflectance. The walls are painted gypsum wall board. The ceiling is acoustic ceiling tile that is dyed black to absorb as much light as possible. The space as a whole is very absorptive to keep the audience portion of the theater dim and the focus on the stage.

Theater Materials				
Surface	Material	Descrption	Color	Reflectance
Ceiling	ACT-2	Fine fissured #1729 black 2x4, min NRC 0.55 & CAC35	Black	0.2
Wall	GWB/PTD	Painted gypsum wallboard	Grey	0.5
Floor	WD	Robbins bio-channel classic - white oak w/ ebony stain	Ebony	0.15

FURNITURE AND DRAPERY PLAN



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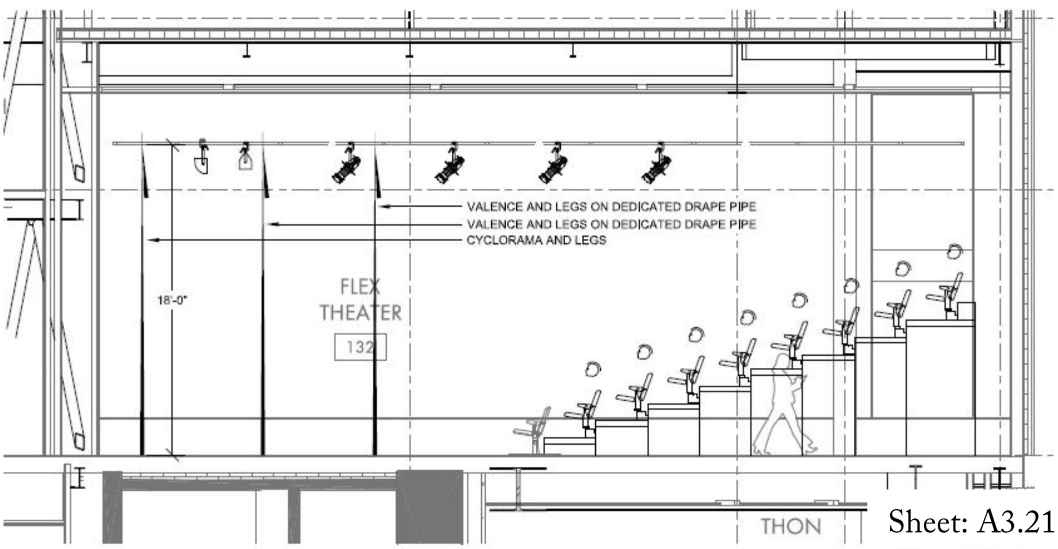
FURNITURE SECTION



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FURNITURE & EQUIPMENT

The theater has a capacity to seat 142 people in fixed theater seating. There is one projector that is placed on the centerline of the room. It can project on the projection screen located at the front of the room. There are also several layers of drapes to accommodate various stage areas and backdrops.

TASKS

The primary tasks in the space consist of acting and media viewing, as well as seeing the stage. This space could also be used to give presentations and the lighting redesign should account for that. In the case of presentations, it may be desired to take notes on what's being presented. The possibility of the projection screen being used as a presenting tool should also be considered and an effort to ensure adequate viewing of the speaker and screen during such time should be made.

DESIGN CONCEPT & GOALS

A theater is a space that was created to convey emotion through a variety of mediums. These performances connect people to emotions in ways that can even transcend words. For this space I've opted to layout the theatrical lighting rig that would be used to create these scenes of drama and passion, as well as the house lighting. The system itself should be flexible enough to be used for many different functions ranging from a performance to a gathering space for organizations on campus. The controls of the system should be advanced enough allow a theatrical designer to have the control they need, while also being simple enough for a student to operate part of the system if needed.

DESIGN CRITERIA

QUALITATIVE CRITERIA

Most Important

- Lighting the Stage
    - Actors should be adequately illuminated when on stage
    - Presenters faces should be lit so that they are seen from the back of the room
- Glare

Sheet: E2.24D

  - Occupants of the theater should not be exposed to glare from fixtures, since this would detract from the overall experience of a performance or presentation
- Controls
  - The control system should be advanced enough for a seasoned designer to make full use of the system
  - The control system should allow for limited functionality for any user of the space.
  - The controls should be able to communicate with the theatrical fixtures, to the point that various cues could be set and compiled into a production
- Dimming Levels
  - Specified fixtures should be able to provide adequate light levels for occupants to navigate through the space while a performance is ongoing, while not detracting from the show itself

Not Applicable

- Daylighting
  - There are no daylight portals in the space, therefore daylighting is a nonfactor.

QUANTITATIVE CRITERIA

Recommended Horizontal Illuminance

- Classification – Hospitality and Entertainment
  - During Production
    - Category B: 2 lux at floor
    - Avg/Min: 2:1
  - Pre/Post-show, Intermission
    - Category M: 100 lux at floor
    - Avg/Min: 2:1
  - Auditoria, Exhibition
    - Category P: 300 lux at 2’ 6”
    - Avg/Min: 3:1

Recommended Vertical Illuminance

- Classification – Hospitality and Entertainment
  - During Production
    - Category A: 1 lux at 5'
    - Avg/Min: 2:1
  - Pre/Post-show, Intermission
    - Category I: 30 lux at 5'
    - Avg/Min: 2:1
  - Auditoria, Exhibition
    - Category O: 200 lux at 5'
    - Avg/Min: 3:1

LEED

EAP: Minimum Energy Performance Required

- Comply with the mandatory and prescriptive provisions of ANSI/ASHRAE/IESNA Standard 90.1–2010, with errata (or a USGBC-approved equivalent standard for projects outside the U.S.).

EAC: Optimize Energy Performance (Major Renovation)

- Reduce overall energy consumption by 4% - 40% for 1 – 16 points.

EQC: Interior Lighting

- For at least 90% of individual occupant spaces, provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences, with at least three lighting levels or scenes (on, off, midlevel). Midlevel is 30% to 70% of the maximum illumination level (not including daylight contributions). For all shared multioccupant spaces, meet all of the following requirements.
  - Have in place multizone control systems that enable occupants to adjust the lighting to meet group needs and preferences, with at least three lighting levels or scenes (on, off, midlevel).
  - Lighting for any presentation or projection wall must be separately controlled.

- Switches or manual controls must be located in the same space as the controlled luminaires. A person operating the controls must have a direct line of sight to the controlled luminaires.

Energy Allowances

The following table shows the energy allowance for the flex theater space according to ASHRAE 2013 space by space method.

Energy Allowance			
Space	Area (SF)	W/SF	Allowable Wattage
Theater	2000	2.43	4860

ASHRAE 2013 Standards*

9.4.1.1(a),(b),(d),(e),(f),(h)

*See Appendix A for code description.

DESIGN CRITERIA SELECTED

1) Meet ASHRAE Energy Code requirements
2) Control light to meet various demands of the space
3) Provide adequate light on stage to illuminate actors and presenters
4) Meet LEED requirements

DESIGN DEVELOPMENT

SUMMARY

The house lighting consists of surface mounted LED downlights. Three outputs, 3000 lumens, 6000 lumens, and 9000 lumens were used to ensure uniformity and adequate light levels in the center and corners of the space.

The theatrical rig is made up of a nine by six pipe grid that has three types of fixtures. All fixtures mounted on rig would be approximately 18' off the ground. The first are 26° RGB-Lime LED spot lights, which light the front of the performers. The space itself was broken up into six zones, three wide by two deep. Each zone measures 11' in diameter, covering an area of 26' by 20'. The optimal angle for front lighting is 45° from vertical and 45° off the center of the zone on either side. This lights up a performer evenly, eliminating shadows on the face. Due to the size of the space some fixtures could not be placed at 45° from vertical, namely the fixtures on pipes 1 and 6. These were able to be placed 56°, which should still be adequate for the application. Additionally, those same fixtures were placed at 42° from the center of their respective zones. All other front fixtures were place 45° from the center of their zones and 50° from vertical.

To supplement the front lights, back lighting is also needed. The back lighting was achieved using 25° RGB-Lime LED par lights. These zones split the space into 12 zones, four wide by three deep. Each zone is 9' in diameter, covering an area of 30' by 21'. To get a nice glow around a figures frame a vertical angle of no more than 65° is recommended. These fixtures were placed 9' 6" from the center of their zones, providing light at a vertical angle of 62°.

The next layer of light is provided by 7-color LED array linear fixtures. These allow the designer to wash the backdrop with colored or white light. A variety of different beam spreads could be applied to the fixtures, using lenses, to allow more area to be washed with light. These range from 20° to 80°.

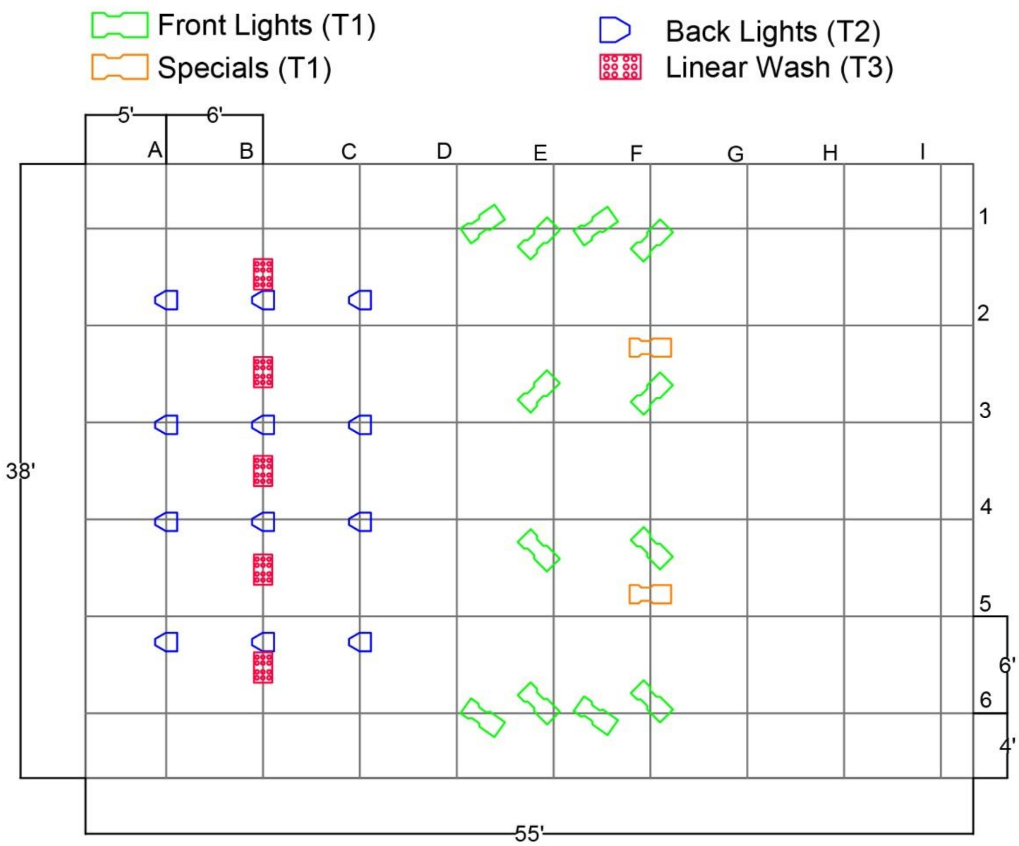
The final layer of light is provided by two 26° RGB-Lime LED spots mounted with the front lighting. These act as specials that can provide additional light where needed. This could be in the form of colored light or with a gobo installed a pattern.

Check appendix C for theatrical layout and mounting

FIXTURE & EQUIPMENT SELECTION

All fixtures in the theater are LED fixtures. Cut sheets can be found in appendix A and detailed fixtures schedules can be found in appendix B.

1st Story RCP



Fixture Schedule				
Type	Symbol	Image	Description	Manufacturer
L1	● (red)		9000 lumen 45° HO LED pendant	Prescolite
L2	● (yellow)		6000 lumen 45° HO LED pendant	Prescolite
L3	● (blue)		3000 lumen 45° HO LED pendant	Prescolite

Fixture Calculations							Lightloss Factors			
Type	Quantity	W/fixture	Total Wattage	PF	Va/fixture	Total VA		LLD	LDD	Total
L1	1	99	99	1	99	99	L1	0.8	0.93	0.74
L2	11	66.5	731.5	1	66.5	731.5	L2	0.8	0.93	0.74
L3	4	33.9	135.6	1	33.9	135.6	L3	0.8	0.93	0.74
T1	14	148	2072	1	148	2072	T1	--	--	--
T2	12	90	1080	1	90	1080	T2	--	--	--
T3	5	250	1250	1	250	1250	T3	--	--	--

CONTROLS STRATEGY

Theatrical fixtures will be controlled primarily through an ETC Element 60-250 console. This allows up to 250 DMX channels to be addressed. With 31 DMX fixtures in the space, 26 will take up 4 channels each and five that take up seven channels each, for a total of 139 channels in use. This leaves plenty of room for additional fixtures to be added on the console if desired.

An ETC Inspire E1006 will act as an entry switch. This can handle up to four preset scenes in addition to basic on off functionality. This would allow anyone to be able to set the house lighting to the level desired. An additional wall switch would be located near the console to allow control of the house lights on the mezzanine level.

The final control device will be a Flow7 FHD wall-mounted touchscreen tablet with power over Ethernet. This could be hardwired into the system or connect via Wi-Fi. Using an EchoAccess interface, occupants could connect to the system using the EchoAccess app, giving more control over the system than a wall switch, without needing to know how to use a theatrical console. This would allow up to eight theatrical fixtures and all house lighting to be changed as desired, including hue and intensity. All presets present on the entry switch would also be accessible from the wall-mounted tablet. Specified personnel could also access the system using a smartphone or mobile device if desired.

To prevent unwanted tampering during a performance, the wall-mounted touchscreen would be under key access. A DMX input toggle switch would also be located at the console to cut off the DMX signal for the theatrical fixtures from the touchscreen panel while the console is in use.

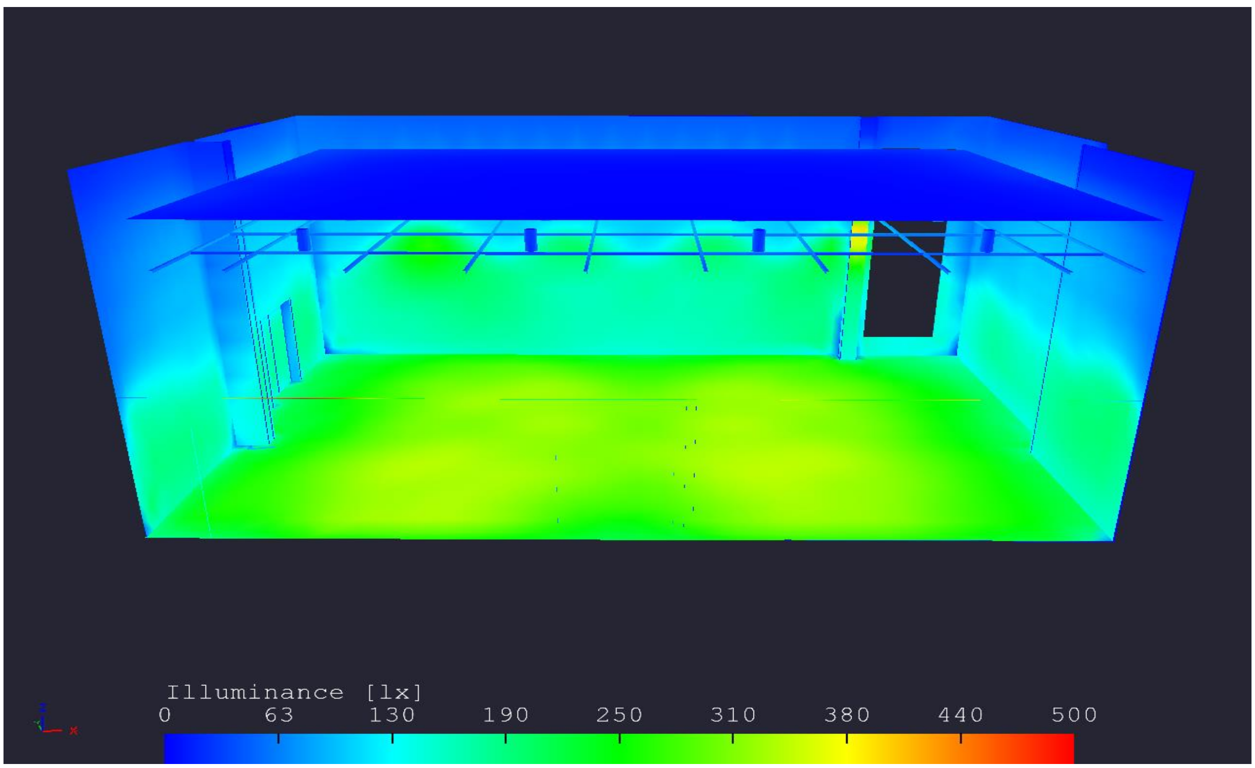
These three levels of control would allow any user to be able to access the system according to their needs and level of knowledge. This allows for the optimal usability and flexibility for the space.

For more information and one-line diagram, refer to appendix C.

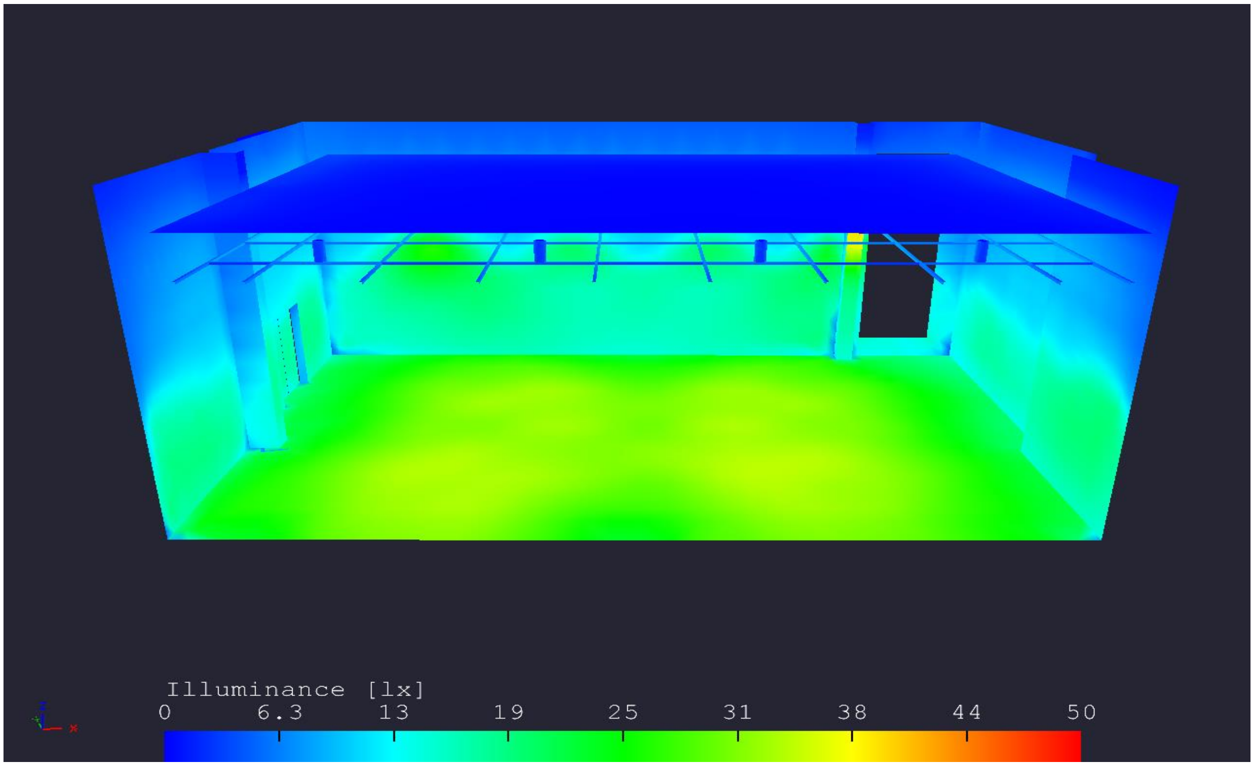
CALCULATION SUMMARY

The table below summarizes the calculations for the space. For more in-depth analysis, refer to the pseudo color renderings.

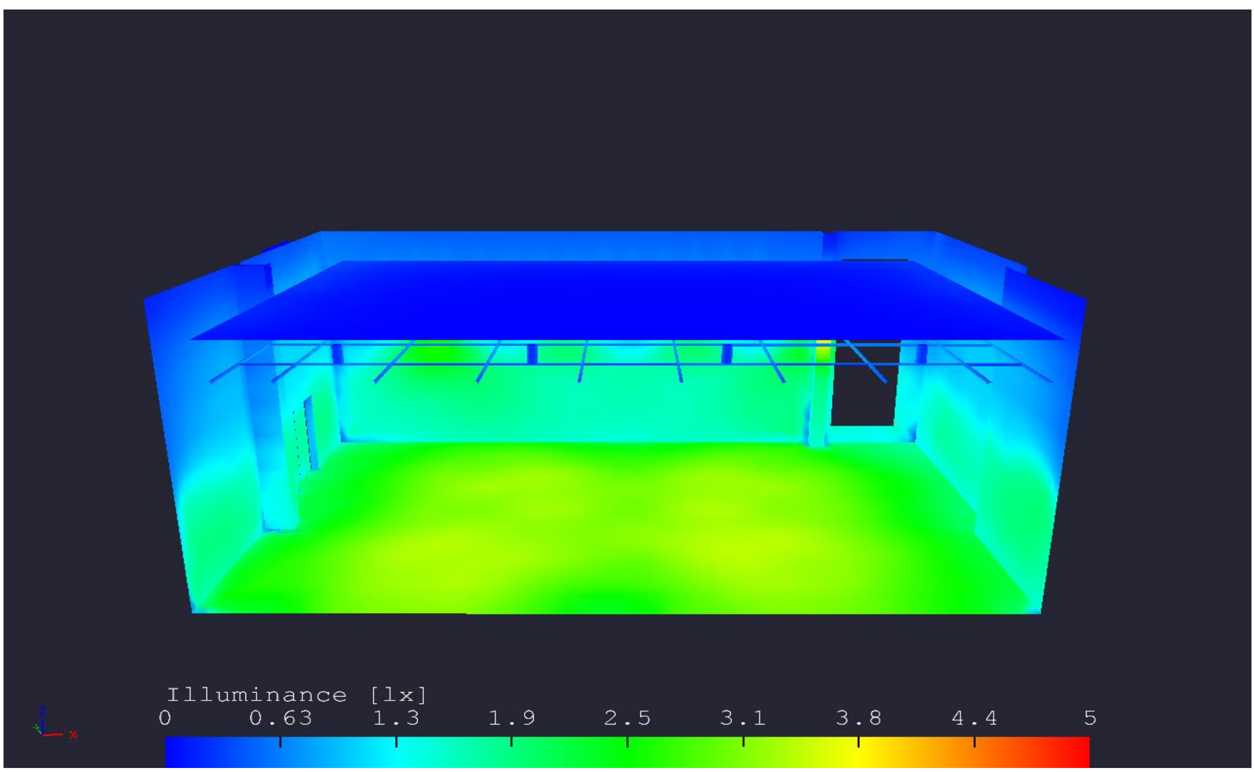
Theater Illuminance Criteria					
Category		Horizontal Illuminance (lux)		Vertical Illuminance (lux)	
Space	Metric	Recommended	Achieved	Recommended	Achieved
House Lighting Performance	Average	2	3	1	1.8
	Avg/Min	2:1	1.6:1	--	--
House Lighting Per/Post	Average	30	30	30	22
	Avg/Min	2:1	1.6:1	--	--
Genearl Use	Average	300	299	30	150
	Avg/Min	2:1	1.6:1	--	--



Exhibition Preset



Intermission Preset



During Show Preset

EVALUATION

SUMMARY

The house lighting achieves a uniform illuminance within the space. The use of dimming and presets allows for flexible scene control. The light levels are sufficient to accommodate general use, as well as lighting during a theatrical performance. The theatrical fixtures provide optimal stage lighting to 520 sqft of the space. Nearly all fixtures are within the ideal range for both vertical and horizontal angles for lighting a performer. With three levels of control, ranging from push button presets and touchscreen controls to a theatrical console, this space allows any user to get the most out of the fixtures within the space.

The design fulfilled the design goals set for the space. The required light levels were met, proper mounting angles allow for near-ideal stage lighting conditions, multiple levels of control maximize usability for any user of the space, and energy codes were met.

ASHRAE/IESNA

The proposed design is currently 78% better than the minimum ASHRAE requirements. This calculation only includes the house lighting and not the theatrical fixtures due to no NEC requirements for stage lighting

Energy Usage (ASHRAE/IESNA) - Theater		
Category	Allowable	Calculated
Area (SF)	--	2100
Input Wattage	4680	997
Power Density (W/SF)	2.46	0.47

Electrical Depth

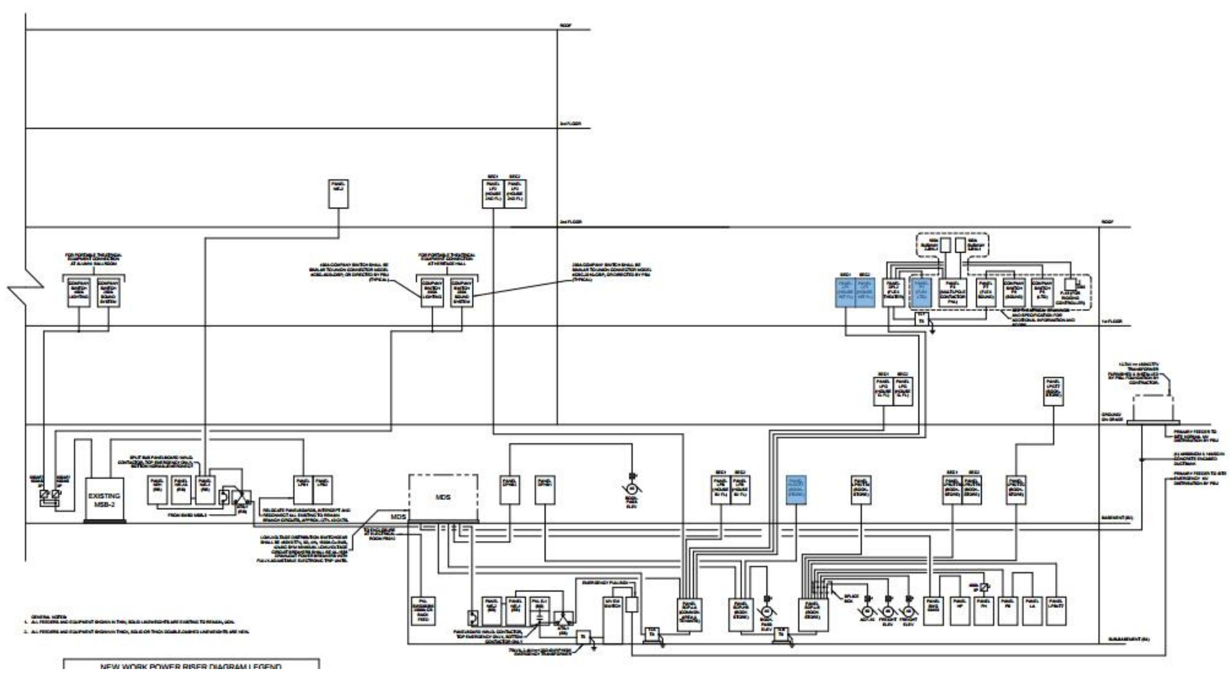
ELECTRICAL DEPTH

In this section the electrical system update is explained. This includes a branch circuit redesign in response to the new lighting designs for the four spaces described in the previous section. As an additional study, several panelboards and their respective feeder wiring were also resized in an effort to trim unnecessary extra capacity from the system.

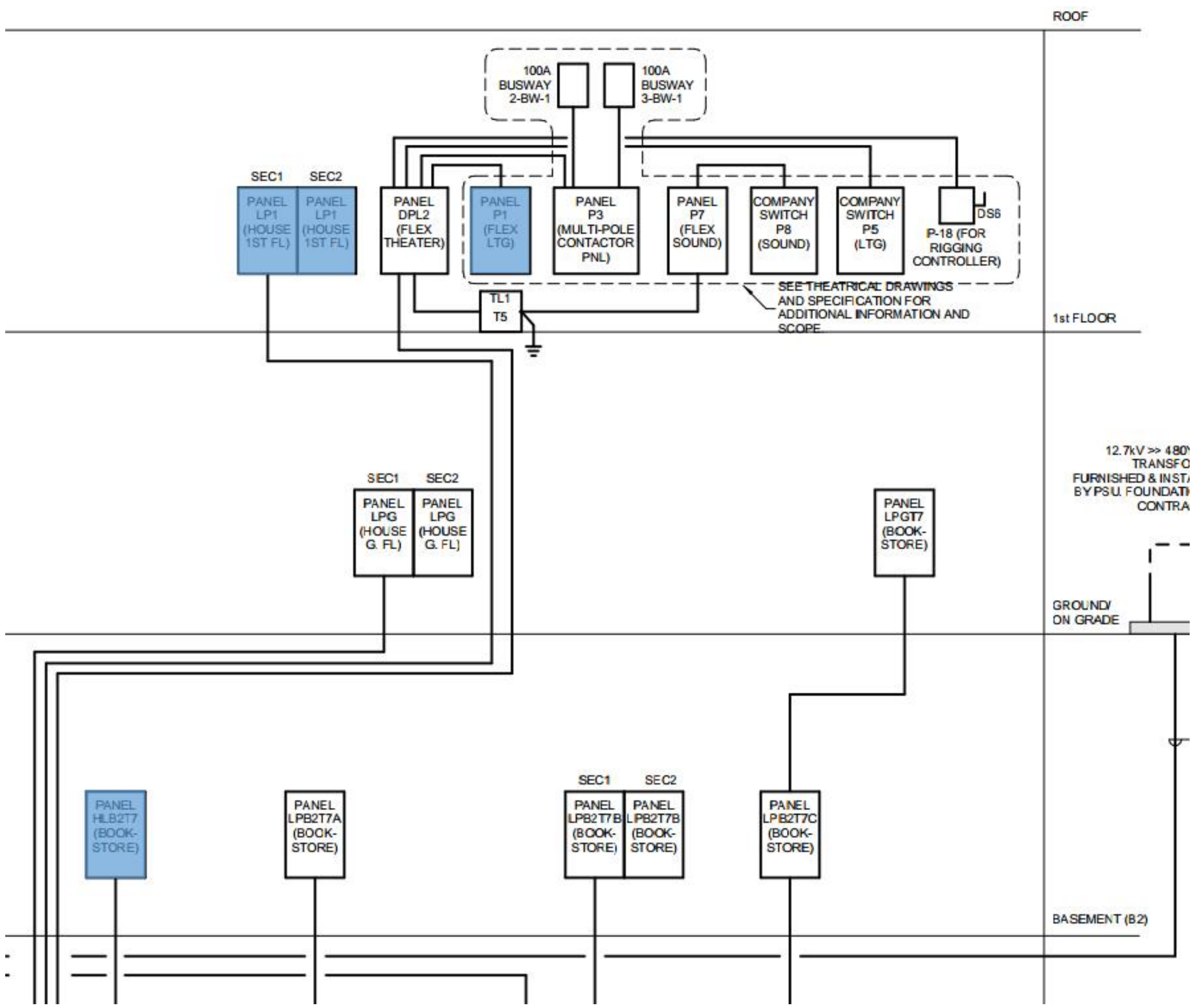
INTRODUCTION

BRANCH CIRCUIT REDESIGN

The new lighting design affects three panelboards in the HUB Addition: HLB2T7, LP1, and P3. Additionally, P3 was replaced with a new Echo relay panel to allow dimming of the house lights, power distribution to the theatrical fixtures, and power the two control systems within the flex theater space. These panels are all 208Y/120V, 3PH, 4 wire panelboards. Each of them are also MLO type panelboards.



HLB2T7 houses all of the bookstore lighting loads. LP1 is the main panelboard for the Atrium space lighting, receptacle, and telecom loads. P3 currently only services the flex theater lighting loads.



ELECTRICAL INFORMATION

FIXTURE LAYOUT

Refer to Appendix D for wiring diagrams.

EXISTING PANELBOARD LOADS

The panelboard schedules below show the existing lighting design loads. The highlighted circuits on panel LP1 are affected by the new lighting design and will be replaced to accurately depict the new loads on the electrical system. HLB2T7 and P3 were completely redesigned and P3 was replaced with a dimming capable panel relay. For details see lighting depth.

PANEL: HLB2T7 **BUS AMPS: 225**

SUPPLY FROM: SDP-HB

MAIN: MLO
MOUNTING: Surface
ST MAIN:
SUB-FEED LUGS:
FEED-THRU LUS:

DISTRIBUTION: 480Y/277
A.I.C. RATING: 42 kAIC
IG GND:
NEUTRAL: 100%

CKT	TYPE	DESCRIPTION	BKR TYPE	WIRE	TRIP	POLE	A (kVA)		B (kVA)		C (kVA)		POLE	TRIP	WIRE	BKR TYPE	DESCRIPTION	TYPE	CKT
1	L	LTG BOOKSTORE RELAY#1		2w20	20	1	2.87	2.8					1	20	2w20		LTG BOOKSTORE RELAY#2	L	2
3	L	LTG BOOKSTORE RELAY#3		2w20	20	1			2.66	3.22			1	20	2w20		LTG BOOKSTORE RELAY#4	L	4
5	L	LTG BOOKSTORE RELAY#5		2w20	20	1					1.82	1.89	1	20	2w20		LTG BOOKSTORE RELAY#6	L	6
7	L	LTG BOOKSTORE RELAY#7		2w20	20	1	1.5	3.22					1	20	2w20		LTG BOOKSTORE RELAY#8	L	8
9	L	LTG BOOKSTORE RELAY#9		2w20	20	1			2.29	1.96			1	20	2w20		LTG BOOKSTORE RELAY#10	L	10
11	L	DISP CASE LTG RELAY #11		2w20	20	1					0.72	0.9	1	20	2w20		DISP CASE LTG RELAY #12	L	12
13	L	DISP CASE LTG RELAY #13		2w20	20	1	0.54	0.72					1	20	2w20		DISP CASE LTG RELAY #14	L	14
15	L	LTG BOOKSTORE RELAY#15		2w20	20	1			2.17	0.56			1	20	2w20		LTG BOOKSTORE RELAY#16	L	16
17	L	LTG BKSTORE CORRIDOR		2w20	20	1					0.63	0	1	20	--	--	SPARE	--	18
19	L	LTG BOOKSTORE OFFICES		2w20	20	1	2.18	0					1	20	--	--	SPARE	--	20
21	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	22
23	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	24
25	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	26
27	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	28
29	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	30
31	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	32
33	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	34
35	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	36
37	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	38
39	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	40
41	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	42
			PHASE LOAD:				13.83		12.86		5.96								
			PHASE AMPS:				53.77		50.27		21.52								

LOAD TYPE	CONNECTED	DEMAND/ADJUSTED	LOAD TYPE KEY	BREAKER TYPE KEY	PANEL TOTALS	
L	32.65	32.65	R = RECEPTACLE	BLANK = STANDARD		
			L = LIGHTING	G3 = GROUND FAULT 30 Ma (EQUIP)	CONNECTED LOAD:	32.65
			M = MECH/EQUIP	G = GROUND FAULT 5 Ma (PERSONNEL)	DEMAND LOAD:	32.65
			K = KITCHEN	A = ARC FAULT	CONNECTED AMPS:	39.27
			C = CONTINUOUS	ST = SHUNT TRIP	DEMAND AMPS:	39.27
			N = NONCONTINUOUS	HT = HANDLE TIE		

Notes:

PANEL: P3 **BUS AMPS: 225**

SUPPLY FROM: DPL2

MAIN: 225A MCB
MOUNTING: Surface
ST MAIN: No
SUB-FEED LUGS: No
FEED-THRU LUS: No

DISTRIBUTION: 208Y/120
A.I.C. RATING: 10 kAIC
IG GND: No
NEUTRAL: 100%

CKT	TYPE	DESCRIPTION	BKR TYPE	WIRE	TRIP	POLE	A (kVA)		B (kVA)		C (kVA)		POLE	TRIP	WIRE	BKR TYPE	DESCRIPTION	TYPE	CKT
1	R	TLB BOX #4 - DMX1		2W20	20	1	1.8	1.8					1	20	2W20		TLB BOX #5 - DMX2	R	2
3	R	TLB BOX #6 - DMX3		2W20	20	1			1.8	1.8			1	20	2W20		TLB BOX #7 - DMX4	R	4
5	R	TLB BOX #8 - CKT #1 - DMX5		2W20	20	1					1.8	1.8	1	20	2W20		TLB BOX #8 - CKT #2 - DMX6	R	6
7	R	TLB BOX #9 - CKT #1 - DMX7		2W20	20	1	1.8	1.8					1	20	2W20		TLB BOX #9 - CKT #2 - DMX8	R	8
9	R	TLB BOX #10 - CKT #1-DMX9		2W20	20	1			1.8	1.8			1	20	2W20		TLB BOX #10 - CKT...	R	10
11	R	TLB BOX #11 - CKT...		2W20	20	1					1.8	1.8	1	20	2W20		TLB BOX #11 - CKT...	R	12
13	--	SPARE - DMX13	--	--	20	1	0	0					1	20	--	--	SPARE - DMX14	--	14
15	--	SPARE - DMX15	--	--	20	1			0	0			1	20	--	--	SPARE - DMX16	--	16
17	L	LTG FLEX THEATER		2w20	20	1					0.24	0.24	1	20	2w20		LTG FLEX THEATER	L	18
19	L	LTG FLEX THEATER		2w20	20	1	0.24	0.24					1	20	2w20		LTG FLEX THEATER	L	20
21	L	LTG FLEX THEATER		2w20	20	1			0.24	0.24			1	20	2w20		LTG FLEX THEATER	L	22
23	L	LTG FLEX THEATER		2w20	20	1					0.24	0.16	1	20	2w20		LTG FLEX BALCONY	L	24
25	L	LTG FLEX BALCONY		2w20	20	1	0.11	0					1	20	--	--	SPARE	--	26
27	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	28
29	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	30
31	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	32
33	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	34
35	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	36
37	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	38
39	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	40
41	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	42
			PHASE LOAD:				7.79		7.68		8.08								
			PHASE AMPS:				65.06		64		67.47								

LOAD TYPE	CONNECTED	DEMAND/ADJUSTED	LOAD TYPE KEY	BREAKER TYPE KEY	PANEL TOTALS	
R	21.6	15.8	R = RECEPTACLE	BLANK = STANDARD		
L	1.95	1.95	L = LIGHTING	G3 = GROUND FAULT 30 Ma (EQUIP)	CONNECTED LOAD:	23.55
			M = MECH/EQUIP	G = GROUND FAULT 5 Ma (PERSONNEL)	DEMAND LOAD:	17.75
			K = KITCHEN	A = ARC FAULT	CONNECTED AMPS:	65.37
			C = CONTINUOUS	ST = SHUNT TRIP	DEMAND AMPS:	49.27
			N = NONCONTINUOUS	HT = HANDLE TIE		

Notes: MOTORIZED BREAKER PANEL FURNISHED BY PERFORMANCE LIGHTING CONTRACTOR, INSTALLED BY THE ELECTRICAL CONTRACTOR

PANEL: LP1 | **BUS AMPS: 225**

SUPPLY FROM: SDP-LB

MAIN: MLO
MOUNTING: Surface
ST MAIN:
SUB-FEED LUGS: Yes
FEED-THRU LUS:

DISTRIBUTION: 208Y/120
A.I.C. RATING: 10 kAIC
IG GND:
NEUTRAL: 100%

CKT	TYPE	DESCRIPTION	BKR TYPE	WIRE	TRIP	POLE	A		B		C		POLE	TRIP	WIRE	BKR TYPE	DESCRIPTION	TYPE	CKT
1	R	RECS CORRIDOR		2w20	20	1	0.72	0.72					1	20	2w20		FL BOXES MTG RM 131	R	2
3	R	RECS MTG RM 131		2w20	20	1			0.72	0.36			1	20	2w20		RECS SUPPORT 131A	R	4
5	R	RECS SUPPORT 131A		2w20	20	1					0.36	0.36	1	20	2w20		RECS SUPPORT 131A	R	6
7	R	RECS TEL/DATA T131		2w20	20	1	0.72	0.72					1	20	2w20		RECS TEL/DATA T131	R	8
9	R	FLOOR BOX MPR 132		2w20	20	1			0.36	0.54			1	20	2w20		RECS MPR 132	R	10
11	R	RECS MPR 132		2w20	20	1					0.72	0.72	1	20	2w20		RECS MPR 132	R	12
13	L	LTG ZONE 1a SEATING 133		2w20	20	1	0.66	1.2					1	20	2w20		LTG MAIN STAIR ZONE 1b	L	14
15	L	LTG ZONE 1j SEATING 133		2w20	20	1			1.34	1.2			1	20	2w20		LTG SEATING 134 ZONE 1c	L	16
17	M	SSAC-1 T131		2w25	25	2					1.35	0.5	1	20	2w20		AV RACK MTG RM 131	R	18
19							1.35	0.8					1	20	2w20		PROJ. & SCREEN 131	R	20
21	L	LTG MEZZ CORR ZONE 1f		2w20	20	1			1.48	0.36			1	20	2w20		FLOOR BOX MPR 132	R	22
23	L	LTG MEZZ CORR ZONE 1e		2w20	20	1					0.8	0	1	20	--	--	SPARE	--	24
25	L	LTG MTG/STUDIO SUPPORT		2w20	20	1	0.66	1.2					1	20	2w20		IT RACK T131	C	26
27	L	LTG MTG RM 131		2w20	20	1			1.44	1.2			1	20	2w20		IT RACK T131	C	28
29	R	ELEC LATCH DR GN ROOF		2w20	20	1					1.5	0.18	1	20	2w20		COUNTER REC MTG 131	R	30
31	R	ELEC LATCH DR GN ROOF		2w20	20	1	0.4	1.2					1	20	2w20		FS DAMPERS LEVEL 1	M	32
33	C	SEC PANELS TEL T131		2w20	20	1			0.8	1.2			1	20	2w20		LTG ZONE 1d SEATING 134	L	34
35	R	RECS MTG 131		2w20	20	1					0.18	0.18	1	20	2w20		RECS MTG 131	R	36
37	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	38
39	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	40
41	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	42
43	R	RECS MTG 131		2w20	20	1	0.18	0.18					1	20	2w20		RECS MTG 131	R	44
45	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	46
47	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	48
49	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	50
51	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	52
53	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	54
55	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	56
57	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	58
59	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	60
61	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	62
63	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	64
65	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	66
67	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	68
69	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	70
71	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	72
73	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	74
75	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	76
77	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	78
79	--	SPARE	--	--	20	1	0	0					1	20	--	--	SPARE	--	80
81	--	SPARE	--	--	20	1			0	0			1	20	--	--	SPARE	--	82
83	--	SPARE	--	--	20	1					0	0	1	20	--	--	SPARE	--	84
			PHASE LOAD:				10.71		11		6.85								
			PHASE AMPS:				94.2		96.65		57.08								

LOAD TYPE	CONNECTED	DEMAND/ADJUSTED	LOAD TYPE KEY	BREAKER TYPE KEY	PANEL TOTALS	
M	3.9	2.73	R = RECEPTACLE	BLANK = STANDARD		
R	11.48	10.74	L = LIGHTING	G3 = GROUND FAULT 30 Ma (EQUIP)	CONNECTED LOAD:	28.56
C	3.2	4	M = MECH/EQUIP	G = GROUND FAULT 5 Ma (PERSONNEL)	DEMAND LOAD:	27.45
L	9.98	9.98	K = KITCHEN	A = ARC FAULT	CONNECTED AMPS:	79.29
			C = CONTINUOUS	ST = SHUNT TRIP	DEMAND AMPS:	76.21
			N = NONCONTINUOUS	HT = HANDLE TIE		

Notes:

REVISED SCHEDULES

The panelboard schedules below depict the revised schedules for the new lighting designs. All circuits are 20A loaded to a 15A maximum and all lighting is 120V. A continuous load factor of 1.25 was applied to lighting kVA loads.

Allowable load per circuit: (120V x 15A) / 1000 = 1.8kVA

Circuit Calculations					
Space	Circuit	Type	Quant.	VA/fixture	Total VA
Atrium	PLL1	L1	12	99	1.79
		L2	9	66.5	
	PLL2	L1	5	99	0.86
		L2	5	66.5	
		L3	1	33.9	
	PLL3	L1	6	99	1.76
		L2	17	66.5	
		L3	1	33.9	
	PLL4	L4	5	14	1.28
		L5	4	48	
		L6	4	255	
	PLL5	L7	1572.5 in^2	0.016 W/in^2	0.36
Bookstore	HLB 1	L11	36	48	1.73
	HLB 2	L11	36	48	1.73
	HLB 3	L11	36	48	1.73
	HLB 4	L11	36	48	1.73
	HLB 5	L11	31	48	1.49
	HLB 6	L4	4	14	0.82
		L11	16	48	
	HLB 7	L11	36	48	1.73
	HLB 8	L11	36	48	1.73
	HLB 9	L1	1	99	1.57
		L8	6	132	
		L9	4	110	
		L10	16	15	
	HLB 10	L11	9	48	0.43
	HLB 11	L1	5	99	1.68
		L8	9	132	
Theater	LTGPIPE A	T2	4	90	0.36
	LTGPIPE B	T2	4	90	1.61
		T3	5	250	
	LTGPIPE C	T2	4	90	0.36
	LTGPIPE D	T1	2	148	0.30
	LTGPIPE E	T1	6	148	0.89
	LTGPIPE F	T1	6	148	0.89
	LTG HOUSE	L1	1	99	0.74
		L2	4	66.5	
		L3	11	33.9	
Outdoor	OD1	L7	5352 in^2	0.016 W/in^2	0.80
		L12	12	44	
		L13	4	39	
		L14	5	5	

The above table shows the calculations used to find the kVA contributions of each circuit. These were placed on their respective panelboards as shown below. Loads were placed to try and ensure that all phases were within 10% of each other.

Panel: LP1 | Supply From SDP-LB | BUS AMPS: 225 | MAIN: MLO | DISTR: 208Y/120 | NEUTRAL: 100%

CKT	TYPE	DESCRIPTION	WIRE	TRIP	POLE	A (kVA)		B (kVA)		C (kVA)		POLE	TRIP	WIRE	DESCRIPTION	TYPE	CKT
1	R	REC CORR	2#12	20	1	0.72	0.72					1	20	2#12	FL BOXES MTG RM 131	R	2
3	R	REC MGT RM 131	2#12	20	1			0.72	0.36			1	20	2#12	RECS SUPP 131A	R	4
5	R	RES SUPP 131A	2#12	20	1					0.36	0.36	1	20	2#12	RECS SUPP 131A	R	6
7	R	REC TEL/DATA 131	2#12	20	1	0.72	0.72					1	20	2#12	RECS TEL/DATA 131	R	8
9	R	FLOOR BOX MPR 132	2#12	20	1			0.36	0.54			1	20	2#12	RECS MPR 132	R	10
11	R	RECS MPR 132	2#12	20	1					0.72	0.72	1	20	2#12	RECS MPR 132	R	12
13	L	PLL1	2#12	20	1	1.79	0.86					1	20	2#12	PLL2	L	14
15	L	PLL3	2#12	20	1			1.75	1.29			1	20	2#12	PLL4	L	16
17	M	SSAC-1 T131	4#10	25	2					1.35	0.5	1	20	2#12	AV RACK MTG RM 131	R	18
19						1.35	0.8					1	20	2#12	PROJ. & SCREEN 131	R	20
21	L	LTG MTG/STUDIO SUPP	2#12	20	1			0.66	0.36			1	20	2#12	FLOOR BOX MPR 132	R	22
23	L	LTG MTG RM 131	2#12	20	1					1.44	0	1	20		Spare	--	24
25	R	ELEC LATCH DR GR	2#12	20	1	1.5	1.2					1	20	2#12	IT RACK T131	C	26
27	R	ELEC LATCH DR GR	2#12	20	1			0.4	1.2			1	20	2#12	IT RACK T131	C	28
29	C	SEC PANELS TEL T131	2#12	20	1					0.8	0.18	1	20	2#12	COUNTER REC MTG 131	R	30
31	R	RECS MTG 131	2#12	20	1	0.18	1.2					1	20	2#12	FS DAMPERS LEVEL 1	M	32
33	--	Spare		20	1			0	0.36			1	20	2#12	PLL5	L	34
35	--	Spare		20	1					0	0.18	1	20	2#12	RECS MTG 131	R	36
37	--	Spare		20	1	0	0					1	20		Spare	--	38
39	--	Spare		20	1			0	0			1	20		Spare	--	40
41	--	Spare		20	1					0	0	1	20		Spare	--	42
43	R	RECS MTG 131	2#12	20	1	0.18	0.18					1	20	2#12	RECS MTG 131	R	44
45	--	Spare		20	1			0	0			1	20		Spare	--	46
47	--	Spare		20	1					0	0	1	20		Spare	--	48
49	--	Spare		20	1	0	0					1	20		Spare	--	50
51	--	Spare		20	1			0	0			1	20		Spare	--	52
53	--	Spare		20	1					0	0	1	20		Spare	--	54
55	--	Spare		20	1	0	0					1	20		Spare	--	56
57	--	Spare		20	1			0	0			1	20		Spare	--	58
59	--	Spare		20	1					0	0	1	20		Spare	--	60
61	--	Spare		20	1	0	0					1	20		Spare	--	62
63	--	Spare		20	1			0	0			1	20		Spare	--	64
65	--	Spare		20	1					0	0	1	20		Spare	--	66
67	--	Spare		20	1	0	0					1	20		Spare	--	68
69	--	Spare		20	1			0	0			1	20		Spare	--	70
71	--	Spare		20	1					0	0	1	20		Spare	--	72
73	--	Spare		20	1	0	0					1	20		Spare	--	74
75	--	Spare		20	1			0	0			1	20		Spare	--	76
77	--	Spare		20	1					0	0	1	20		Spare	--	78
79	--	Spare		20	1	0	0					1	20		Spare	--	80
81	--	Spare		20	1			0	0			1	20		Spare	--	82
83	--	Spare		20	1					0	0	1	20		Spare	--	84
			Phase Load			12.12		8.00		6.61							
			Phase Amps			101.00		66.67		55.08							

Type	Connected Load	Demand/Adjusted	Panel Totals	
L	8.15	10.19	Connected Load	26.73
R	11.48	10.74	Demand Load	28.83
M	3.9	3.9	Connected Amps	74.20
C	3.2	4	Demand Amps	120.03

Panel: HLB2T7 | BUS AMPS: 225 | DISTR: 208Y/120
Supply From SDP-HB | MAIN: MLO | NEUTRAL: 100%

CKT	TYPE	DESCRIPTION	WIRE	TRIP	POLE	A (kVA)		B (kVA)		C (kVA)		POLE	TRIP	WIRE	DESCRPTION	TYPE	CKT
1	L	HLB 1	2 #12	20	1	1.73	1.73					1	20	2 #12	HLB 2	L	2
3	L	HLB 3	2 #12	20	1			1.73	1.73			1	20	2 #12	HLB 4	L	4
5	L	HLB 5	2 #12	20	1					1.49	0.83	1	20	2 #12	HLB 6	L	6
7	L	HLB 7	2 #12	20	1	1.73	1.73					1	20	2 #12	HLB 8	L	8
9	L	HLB 9	2 #12	20	1			1.30	0.43			1	20	2 #12	HLB 10	L	10
11	L	HLB 11	2 #12	20	1					1.69	1.39	1	20	2 #12	Relay #8	L	12
13	L	Relay #5	2 #12	20	1	1.82	3.22					1	20	2 #12	Relay #10	L	14
15	L	Relay #9	2 #12	20	1			2.29	0.72			1	20	2 #12	Relay #14	L	16
17	L	LTG BKST OFFICES	2 #12	20	1					2.18	0	1	20		Spare	--	18
19	--	Spare		20	1	0	0					1	20		Spare	--	20
21	--	Spare		20	1			0	0			1	20		Spare	--	22
23	--	Spare		20	1					0	0	1	20		Spare	--	24
25	--	Spare		20	1	0	0					1	20		Spare	--	26
27	--	Spare		20	1			0	0			1	20		Spare	--	28
29	--	Spare		20	1					0	0	1	20		Spare	--	30
31	--	Spare		20	1	0	0					1	20		Spare	--	32
33	--	Spare		20	1			0	0			1	20		Spare	--	34
35	--	Spare		20	1					0	0	1	20		Spare	--	36
37	--	Spare		20	1	0	0					1	20		Spare	--	38
39	--	Spare		20	1			0	0			1	20		Spare	--	40
41	--	Spare		20	1					0	0	1	20		Spare	--	42
			Phase Load			11.95		8.19		7.58							
			Phase Amps			99.60		68.27		63.13							

Type	Connected Load	Demand/Adjusted	Panel Totals	
L	27.72	34.65	Connected Load	27.72
R			Demand Load	34.65
M			Connected Amps	76.94
C			Demand Amps	144.27

Panel: ECHO | BUS AMPS: 100 | DISTR: 208Y/120
Supply From DPL2 | MAIN: MLO | NEUTRAL: 100%

CKT	TYPE	DESCRIPTION	WIRE	TRIP	POLE	A (kVA)		B (kVA)		C (kVA)		POLE	TRIP	WIRE	DESCRPTION	TYPE	CKT
1	L	LTG PIPE A	2 #12	20	1	0.36	0.36					1	20	2 #12	LTG PIPE C	L	2
3	L	LTG PIPE B	2 #12	20	1			1.61	0.16			1	20	2 #12	LTG BALC	L	4
5	L	LTG PIPE F	2 #12	20	1					0.88	0.88	1	20	2 #12	LTG PIPE E	L	6
7	L	LTG PIPE D	2 #12	20	1	0.29	0.73					1	20	2 #12	LTG HOUSE	L	8
9	--	Spare		19	1			0	0			1	20		Spare	--	10
11	--	Spare		20	1					0	0	1	20		Spare	--	12
13	--	Spare		20	1	0	0					1	20		Spare	--	14
15	--	Spare		20	1			0	0			1	20		Spare	--	16
17	--	Spare		20	1					0	0	1	20		Spare	--	18
19	--	Spare		20	1	0	0					1	20		Spare	--	20
21	--	Spare		20	1			0	0			1	20		Spare	--	22
23	--	Spare		20	1					0	0	1	20		Spare	--	24
			Phase Load			1.74		1.77		1.76							
			Phase Amps			14.50		14.75		14.67							

Type	Connected Load	Demand/Adjusted	Panel Totals	
L	5.27	6.5875	Connected Load	5.27
R			Demand Load	6.5875
M			Connected Amps	14.63
C			Demand Amps	27.43

PANELBOARD RESIZING

LOAD CALCULATIONS

Some panelboards were oversized beyond what code required and eight panels in particular were studied for resizing. Appropriate demand factors were applied to the loads to ensure an accurate amperage calculation for each panel. Growth varied from a factor of 1.5 to 3, based on the amount of space left on the panelboard for expansion. Other demand factors used include: 1.25 for continuous loads and lighting and 0.5 applied to receptacles after the first 10 kVA. The panelboards studied are P3, LPG, LPB2T7A, LPB2T7, LPB2T7C, DPHB2, LP2, and DPHB1. In the case of DPHB2 and DPHB1, spare loads were also added to overall load, due to the fact that they were likely to be added in the future since breaker sizes were already designated to some circuits. These were assumed to be at 100% circuit capacity to ensure the panel could handle the load after resizing. The load types included L for lighting, R for receptacles, M for mechanical, C for continuous, and S for spares. Below is a summary of the different loads on each panel, for detailed panel loads, see appendix E.

Panel Loads								
Panel	Size	New Size	Growth	Type	Connected	Demand (kVA)	Demand (A)	Resize?
P3	225	100	2	L	0.89	1.11	93.9	Yes
				R	21.6	15.8		
LPG	225	100	1.5	L	7.77	9.71	131.7	No
				R	24.55	17.28		
				M	4.4	4.4		
				C	0.2	0.25		
LPB2T7A	150	100	2	R	10.47	10.24	56.8	Yes
LPB2T7	150	100	2	L	0.54	0.68	35.9	Yes
				R	5.79	5.79		
LPB2T7C	400	225	3	L	0.54	0.68	117.7	Yes
				R	16.91	13.46		
DPHB2	600	400	1.5	M	95	95	570.2	No
				C	0.2	0.25		
				S	220.8	220.8		
LP2	225	100	2	L	8.31	10.39	162.9	No
				R	20.02	15.01		
				M	3.95	3.95		
DPHB1	400	225	1.5	M	79.93	79.63	213.0	Yes
				S	38.4	38.4		

COST ANALYSIS

Based on these load calculations, five of the eight panelboards studied were able to be resized and a cost analysis using RS Means was performed to determine any savings from the downsizing of the panels and their respective wiring. Wire takeoffs were estimations based on the shortest distance from the source to the panel plus an additional 10' of pull out length.

Panelboard Cost Analysis												
Cost Code	Item	Units	Quant.	Mat'l Unit Cost	Mat'l Cost	Labor Unit Cost	Labor Cost	Total	Wires	Sets	Summing	Totals
120-208V Panel Boards Old												
262416302800	4 wire, 120/208 V, 100 Amp, 32 ckt	Ea	0	$1,025.00	$ -	$ 805.00	$ -	$ -				
--	4 wire, 120/208 V, 150 Amp, 42 ckt	Ea	2	$1,795.00	$ 3,590.00	$1,010.00	$ 2,020.00	$ 5,610.00				
262416301000	4 wire, 120/208 V, 225 Amp, 42 ckt	Ea	3	$1,350.00	$ 4,050.00	$1,250.00	$ 3,750.00	$ 7,800.00				
262416302300	4 wire, 120/208 V, 400 Amp, 42 ckt	Ea	2	$3,225.00	$ 6,450.00	$1,775.00	$ 3,550.00	$ 10,000.00				Old Panel
262416302350	4 wire, 120/208 V, 600 Amp, 42 ckt	Ea	1	$4,775.00	$ 4,775.00	$2,125.00	$ 2,125.00	$ 6,900.00				$30,310.00
120-208V Electrical - 600 Volt Copper type THHN, standed, #6 Old												
260519901500	#2 Wire	CLF	0.0	$ 161.00	$ -	$ 95.00	$ -	$ -	4	1	$ -	
260519901650	2/0 Wire	CLF	3.5	$ 320.00	$ 1,120.00	$ 147.00	$ 514.50	$ 1,634.50	4	1	$ 6,538.00	
260519902200	250 kcmil wire Copper	CLF	0.1	$ 605.00	$ 60.50	$ 213.00	$ 21.30	$ 81.80	4	1	$ 327.20	Old Wire
260519902000	4/0 Wire	CLF	3.4	$ 500.00	$ 1,700.00	$ 194.00	$ 659.60	$ 2,359.60	4	2	$18,876.80	$25,742.00
120-208V Panel Boards New												
262416302800	4 wire, 120/208 V, 100 Amp, 32 ckt	Ea	3	$1,025.00	$ 3,075.00	$ 805.00	$ 2,415.00	$ 5,490.00				
--	4 wire, 120/208 V, 150 Amp, 42 ckt	Ea	0	$1,795.00	$ -	$1,105.00	$ -	$ -				
262416302250	4 wire, 120/208 V, 225 Amp, 42 ckt	Ea	4	$1,350.00	$ 5,400.00	$1,250.00	$ 5,000.00	$ 10,400.00				
262416302300	4 wire, 120/208 V, 400 Amp, 42 ckt	Ea	0	$3,225.00	$ -	$1,775.00	$ -	$ -				New Panel
262416302350	4 wire, 120/208 V, 600 Amp, 42 ckt	Ea	1	$4,775.00	$ 4,775.00	$2,125.00	$ 2,125.00	$ 6,900.00				$22,790.00
120-208V Electrical - 600 Volt Copper type THHN, standed, #6 New												
260519901500	#2 Wire	CLF	3.3	$ 161.00	$ 531.30	$ 95.00	$ 313.50	$ 844.80	4	1	$ 3,379.20	
260519901650	2/0 Wire	CLF	0.0	$ 320.00	$ -	$ 147.00	$ -	$ -	4	1	$ -	
260519902200	250 kcmil wire Copper	CLF	3.7	$ 605.00	$ 2,238.50	$ 213.00	$ 788.10	$ 3,026.60	4	1	$12,106.40	New Wire
260519902000	4/0 Wire	CLF	0.0	$ 500.00	$ -	$ 194.00	$ -	$ -	4	2	$ -	$15,485.60
											Old - New	$17,776.40

CONCLUSION

The cost analysis revealed that if the panelboards P3. LPB2T7A, LPB2T7, LPB2T7C, and DPHB1 were to be resized, the expected savings is around $18,000. The majority of the savings comes from the wire downsizing, which equates to a $10,000 savings. The remainder comes from the panelboards themselves. Although the system would lose some capacity with this downsizing, the growth factors still allow for significant additions to the system without the need for larger or more panelboards. Ultimately, the owner may chose the extra capacity over the cost savings, especially considering that the savings is minimal compared to the overall project cost.

Integrated Daylighting, Mechanical, Construction Management Depth & Breadths

DEPTH & BREADTHS INTEGRATION

INTRODUCTION

With sustainability and technology being more integrated into the design and construction process, it becomes not only beneficial, but necessary to look at a system from multiple disciples. The impact of an architectural system can be widespread and without looking at various aspects more problems may be created than solved. The upcoming sections will explain the process used for daylighting and the integrated energy and cost analysis. This informed method of designing will allow meaningful design decisions to be made to choose the best fit for the project and allow the design team to move forward with their eyes open.

PURPOSE & GOALS

1) Use parametric design to study various daylighting system options and combinations to allow informed choices to be made by the design team, balancing daylighting and energy performance, as well as overall cost.
2) Manage excessive daylighting in the atrium to comfortable levels.
3) Know the mechanical impacts that the various daylighting options have on the space and if possible improve on the current mechanical performance.
4) Weigh the various costs options of the systems against their performance.
5) Learn and apply the parametric design process.
6) Demonstrate the impact and potential of parametric analysis and informed design on this and other projects in the construction industry.

PARAMETRIC WORKFLOW

Parametric design is essentially changing different parameters within a design or model and then testing it to see the impact of that combination of variables. This can apply to many things from optimizations to daylighting and energy modelling. Within in the construction industry, parametric design is just now obtaining a foothold with a few companies leading the effort. The ultimate goal is to allow design teams to know what to expect when a design decision is made and shape the design as early as possible. The earlier this style of designing is implemented on a project, the more informed decisions the team can make. With this the team can not only see potential issues with their design, but can address them when they have enough influence over the design to make a difference, rather than sticking a Band-Aid on something that could've been avoided. For the following analysis, Rhino was used due to its accessibility, user friendly interface, and plugin support.

Rhino is a 3D modelling software used by designers of all kinds. Unlike other modelling software, it is fairly constraint free and easy to create forms of various complexity. It accomplishes this by using mathematical representations of the curves that make up the geometry in addition to using point coordinates to define the vertexes of a plane or solid. Rhino also supports a number of plugins that make it an invaluable design tool and allow it to break into the realm of parametric design.

Grasshopper is a visual coding interface plugin for Rhino. It allows the instantaneous creation and manipulation of geometry and other variables within Rhino. This toolset allows for iterative analysis to be done as designated variables change to reflect the different options created by the designer.

Ladybug and Honeybee are plugins for Grasshopper that allow the connection of various platforms to Grasshopper and Rhino. Ladybug can apply .epw weather data and allows for radiation, solar, and comfort analyses to take place. It is also the primary visualizer for all results from both Ladybug and Honeybee. Honeybee connects Radiance, Daysim, Energy Plus, and Open Studio to Grasshopper and Rhino. It can load in models with fully defined material properties into any of these platforms for a variety of analyses. Radiance and Daysim are primarily used for lighting design and daylighting simulations, while Energy Plus and Open Studio are used for mechanical simulations.

With this collection of software any number of tests and simulations can be set and run while the designer works on other aspects of the project. The results can then be visualized in any number of ways and analyzed to find only those solutions that meet all criteria. For this a web based app called Pollination was used along with visual analysis of each scenario.

MAE DEPTH DAYLIGHTING

INTRODUCTION

This section goes into detail on the daylighting design for the Atrium space. This includes the goals and criteria for the design, the variables studied, the methods and processed used, results of the analysis, and an evaluation of the various scenarios. Visualizations from Rhino and renders from Radiance are included to visually understand the results of the various studies.

GOALS

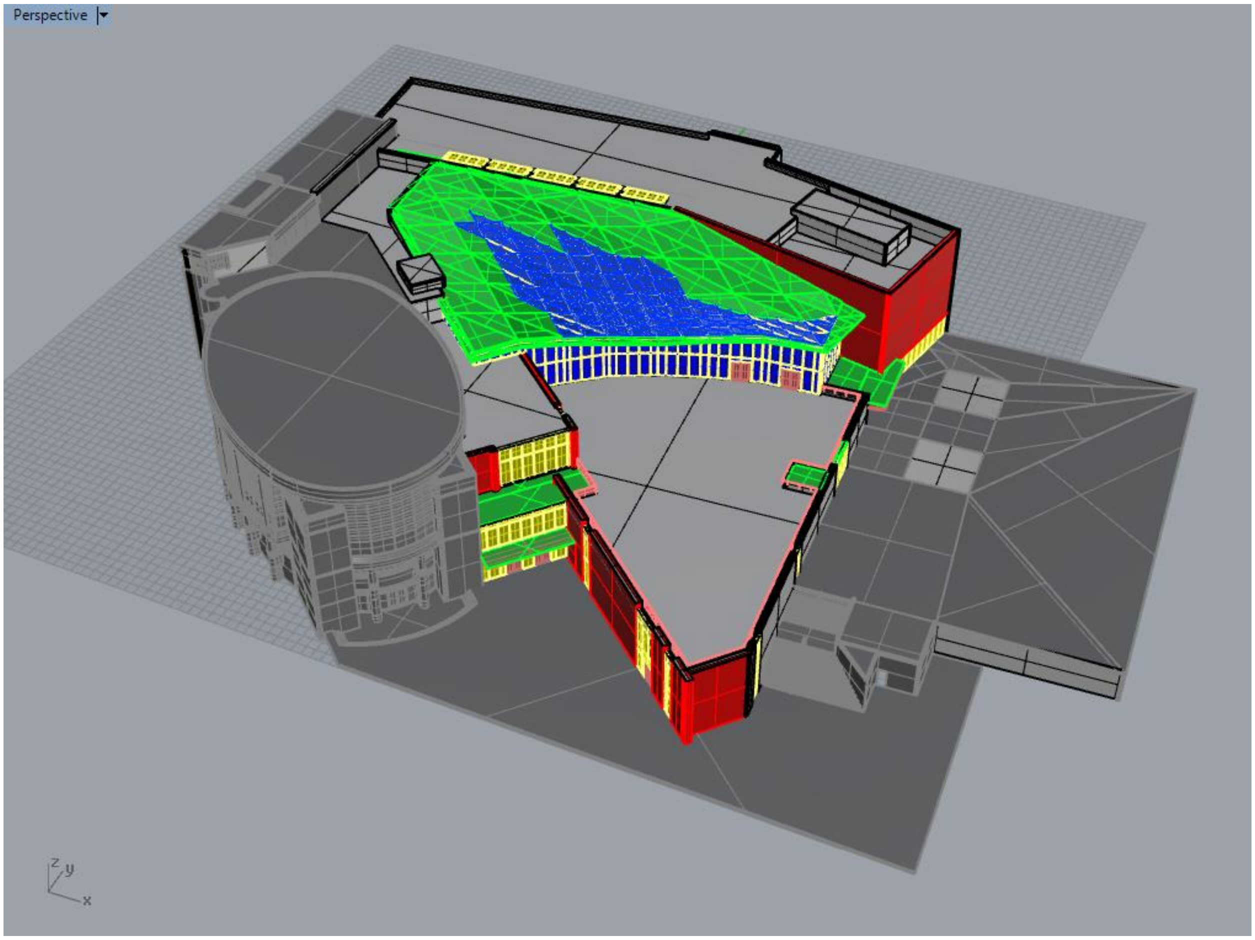
1) Manage excessive daylight within the Atrium space.
2) Create parametric model to simulate multiple scenarios.
3) Use visual result data and metrics to evaluate scenario performance.

METHODOLOGY

By using Ladybug and Honeybee, it is relatively easy to test and evaluate the performance of various models and scenarios. This extend beyond daylighting and into mechanical and architectural performance. The following is the general sequence used to import and test the base model, along with adding parametric variables that made up 16 initial scenarios that was narrowed down to four for more in-depth study.

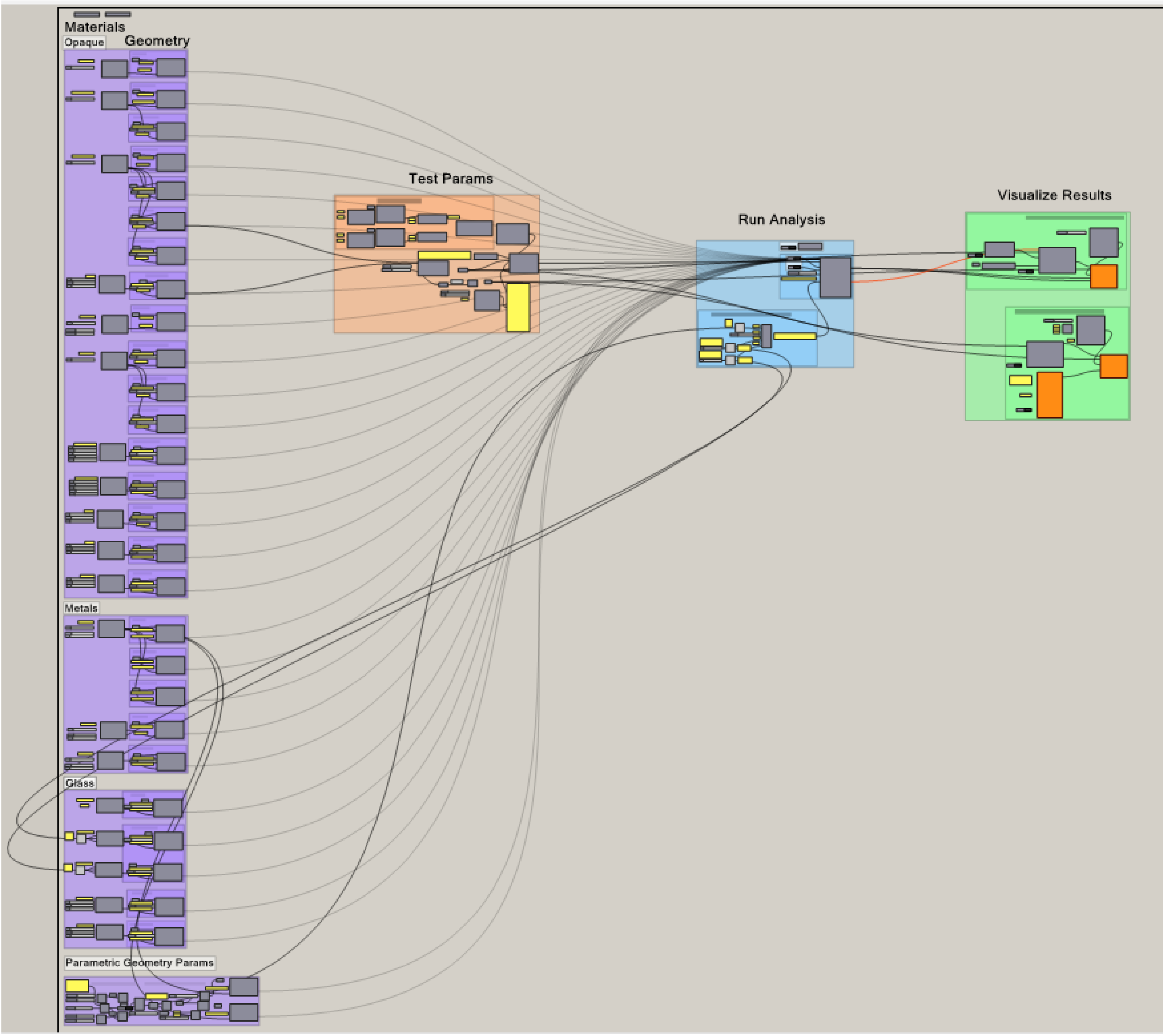
1: Import Geometry

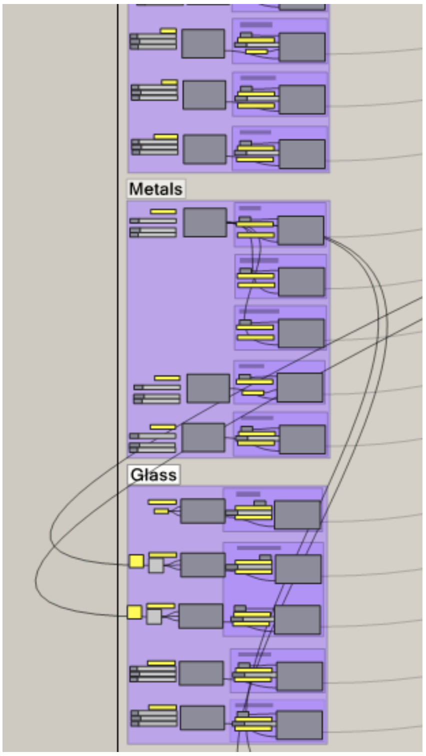
Import Revit geometry into Rhino. The area of study needed to be isolated from the context to avoid excessive simulation times in Radiance and Daysim. The Exterior walls of the immediate context were kept, while the interior of that context was excluded.

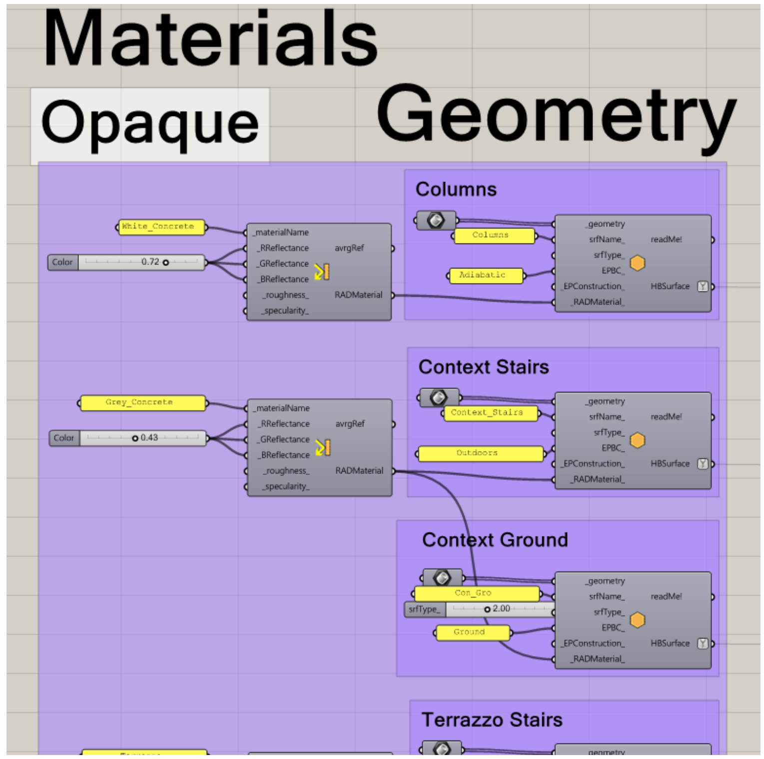


2: Define Workflow, Reference Geometry, and Set Materials

Create Grasshopper workflow and reference model geometry. This step lays the groundwork for the rest of the process, so it is imperative that the geometry be appropriately referenced. With the geometry referenced, materials can be assigned. Radiance materials are assigned to each referenced geometry for daylighting as .rad text files, while Energy Plus constructions were used for the mechanical studies.

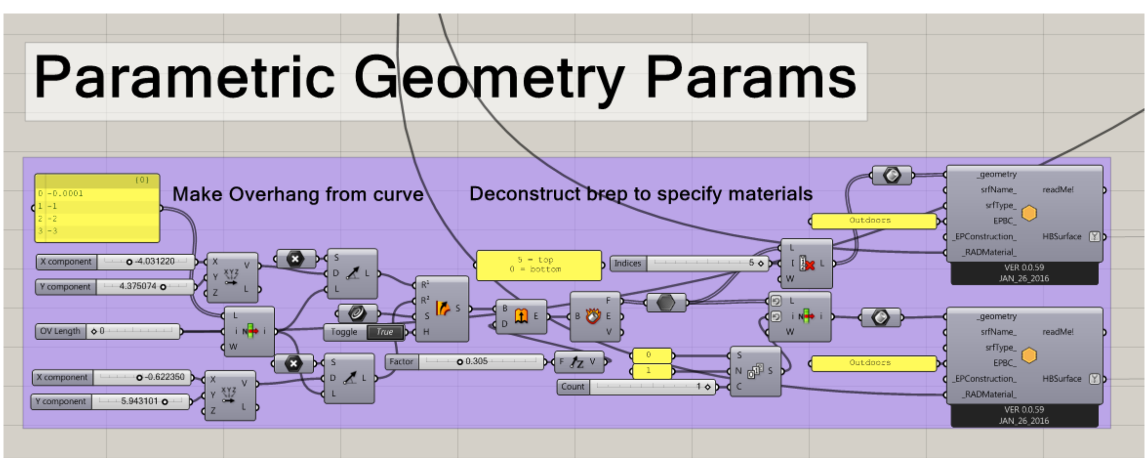

Materials
Opaque
Geometry
Test Params
Run Analysis
Visualize Results
Metals
Glass
Parametric Geometry Params



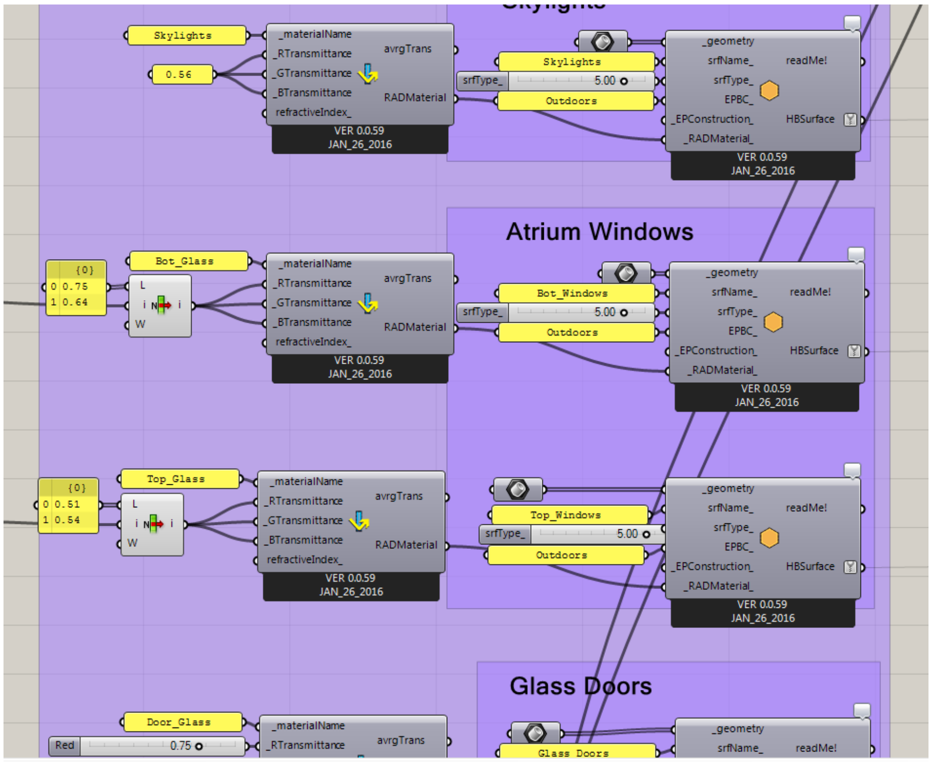


3: Incorporate Parametric Variables

With the geometry properly defined the parametric variables can be introduced. The parametric variables included both geometry and material variations. The first variable was the addition of an overhang with a depth of either one, two, or three meters. The other was one alternative glass material for both the top and bottom curtain wall sections. Additionally to address the large

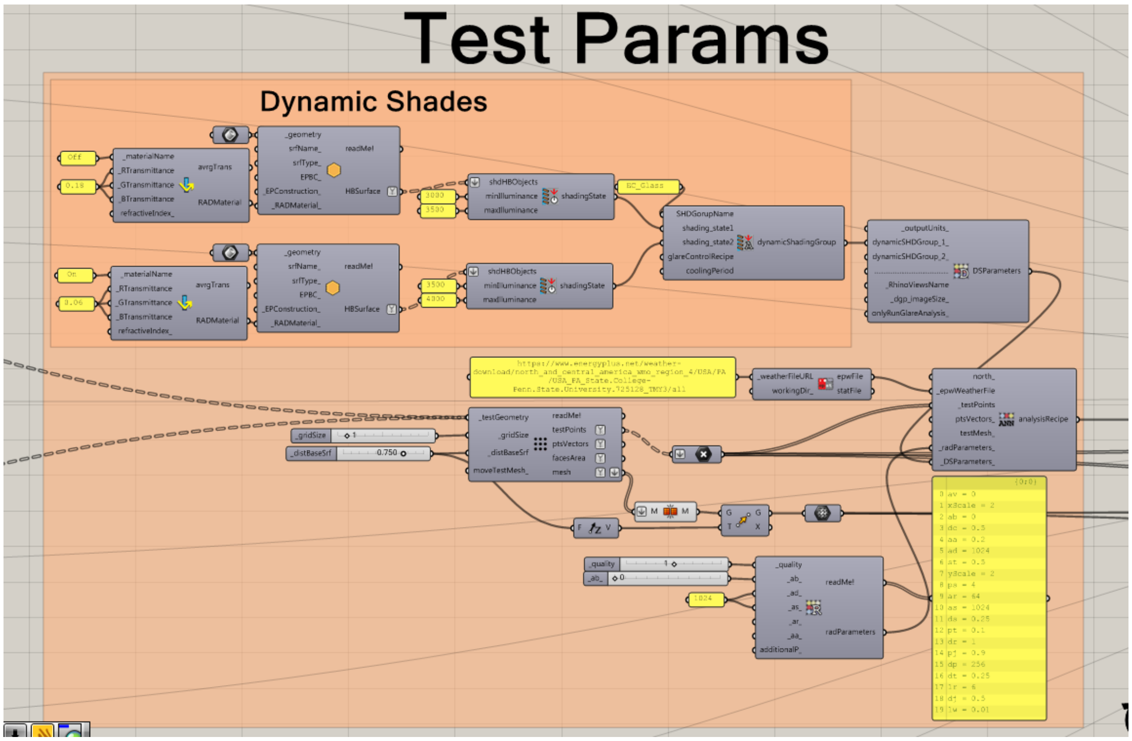


amount of skylights in the space, electrochromic glass was implemented as a shading component. Two cases for both the top and bottom curtain wall materials and four overhang configurations gave 16 separate scenarios to be tested.



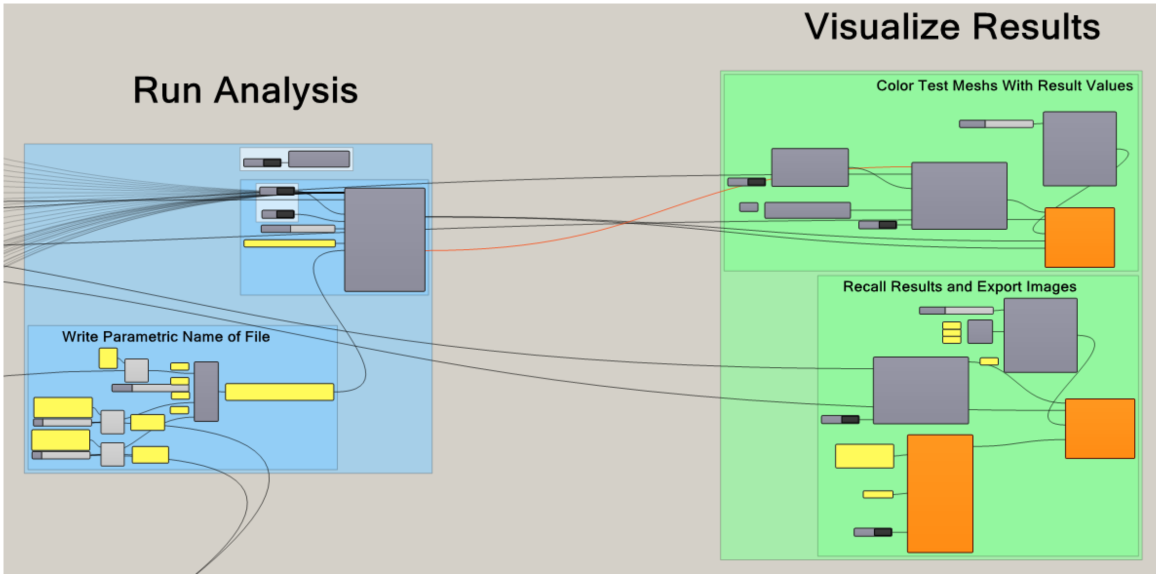
4: Select Analysis Type and Parameters

The next step is to set the analysis type and respective parameters. In the daylighting portion, two analysis types were used. The first being a grid based analysis that computes illuminance values at the specified times of the year. The second is an annual analysis that gives daylighting metrics for the test space. More specific Radiance and Daysim parameters can be set for both analysis types.



5: Run Simulation and Visualize Results

The final steps are to run the analysis and then set up the visualization of the results for final interpretation. These can range from looking at the average space metrics to coloring the test mesh based on a point's value.



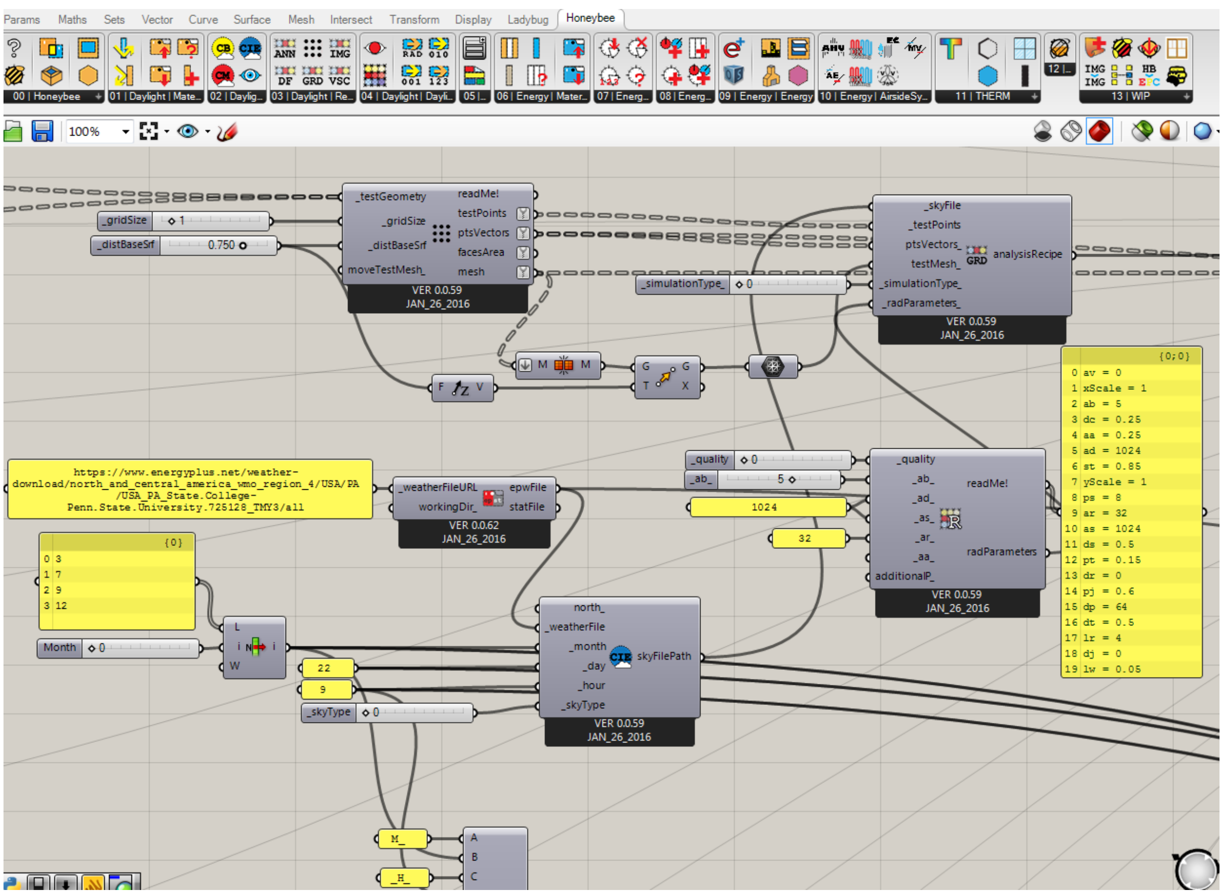
ILLUMINANCE STUDY

INTRODUCTION

To hone in on the most promising solutions before conducting more detailed analysis, an illuminance study was performed on all 17 scenarios. This study allows the use of visual results to determine a rough idea of daylighting performance. For each case, three hours, 9:00, 12:00, and 15:00, from both solstices and equinoxes were studied. These dates and times were chosen because they represent a wide variety of solar conditions. The effect of electric lighting was not considered.

PARAMETERS

To ensure an accurate simulations, the sky conditions and Radiance parameters needed to be set to reasonable settings. A CIE sky was set to sunny with sun and the time itself was variable based on the time that was being studied. The Radiance parameters can be seen in the picture below. To ensure a more accurate calculation, the ambient bounces were increased to 5, ambient divisions and super-samples were set to 1024, and ambient resolution is set to 32.



BASE CASE

The existing design for the Atrium utilizes a great deal of glass in the form of both curtain walls and skylights. Low-e IGUs of two different constructions were used. The first being the a 1" thick 2 lite glazing system with low-e coating on the #2 surface, an argon filled air space, and clear glazing for the interior lite. This type has a transmittance of 70%, U-value of 0.24, SHGC of 0.39, and is used for all glazing except the top of the curtain wall. The second type that is used for the top pane of the curtain wall is a similar construction, adding silk screen dots that cover 40% of the interior lite. This type has a transmittance of 51%, U-value of 0.24, and SHGC of 0.32.

MATERIALS

Below is a table of the Radiance materials and their properties that were used within the model. These were assigned to both room and context geometry to ensure an accurate representation of the space.

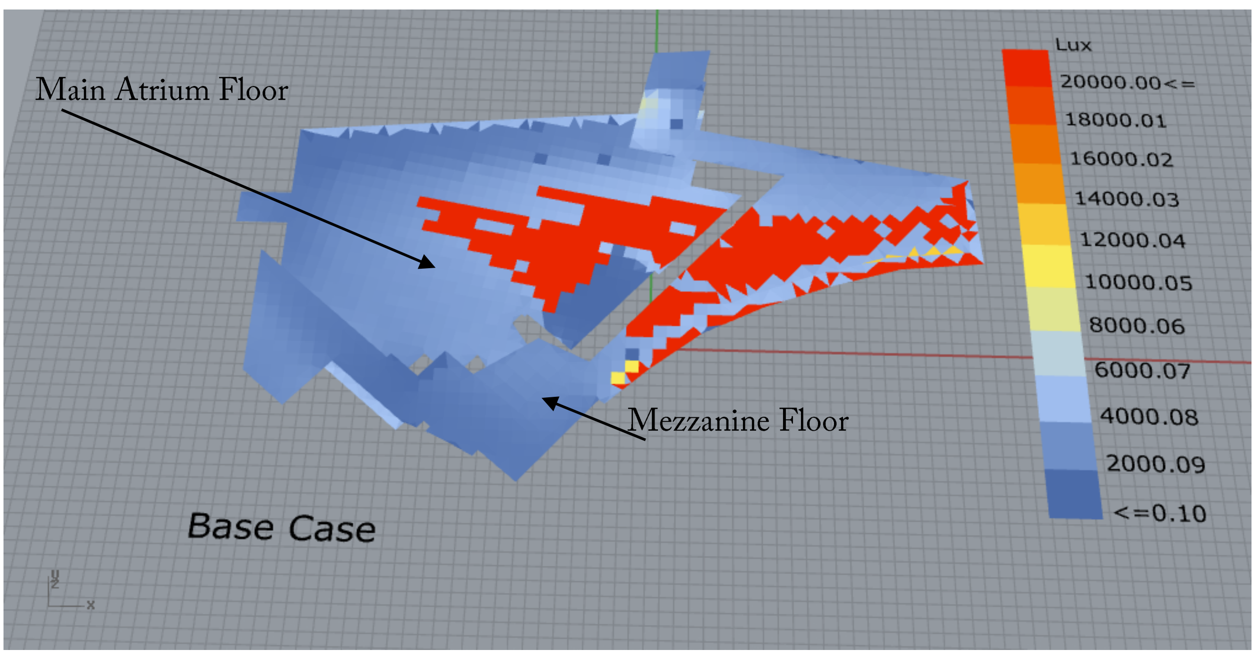
Radiance Materials						
		Reflectance				
Name	Type	Red	Green	Blue	Roughness	Specularity
White Concrete	Opaque	0.72	0.72	0.72	--	--
Grey Concrete	Opaque	0.43	0.43	0.43	--	--
Terrazzo	Opaque	0.85	0.85	0.85	--	--
Carpet	Opaque	0.07	0.28	0.76	--	--
Wood	Opaque	0.2	0.2	0.2	0.02	0.05
White Gypsum	Opaque	0.91	0.91	0.91	--	--
Terracotta	Opaque	0.94	0.39	0.05	0	0
Brick	Opaque	0.4	0.13	0.5	0	0.1
ACT	Opaque	0.8	0.8	0.8	--	--
Gen Roof	Opaque	0.2	0.2	0.2	--	--
Green Roof	Opaque	0.47	0.47	0.47	--	--
Aluminum	Metal	0.7	0.7	0.7	0.2	0.07
Handrail Metal	Metal	0.6	0.6	0.6	0.2	0
Roof Metal	Metal	0.82	0.82	0.82	0.1	0
Skylights	Glass	0.56	0.56	0.56	--	--
Bot Glass	Glass	0.75	0.75	0.75	--	--
Top Glass	Glass	0.51	0.51	0.51	--	--
Door Glass	Glass	0.75	0.75	0.75	--	--
Context Glass	Glass	0.56	0.56	0.56	--	--

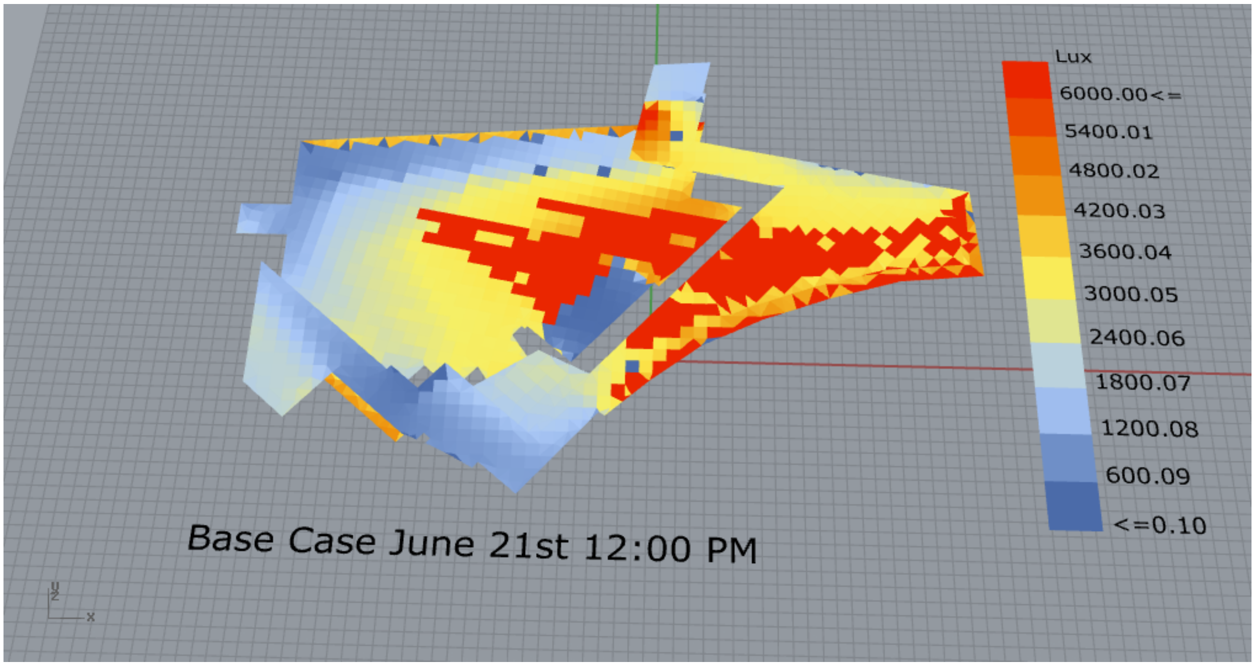
SETUP

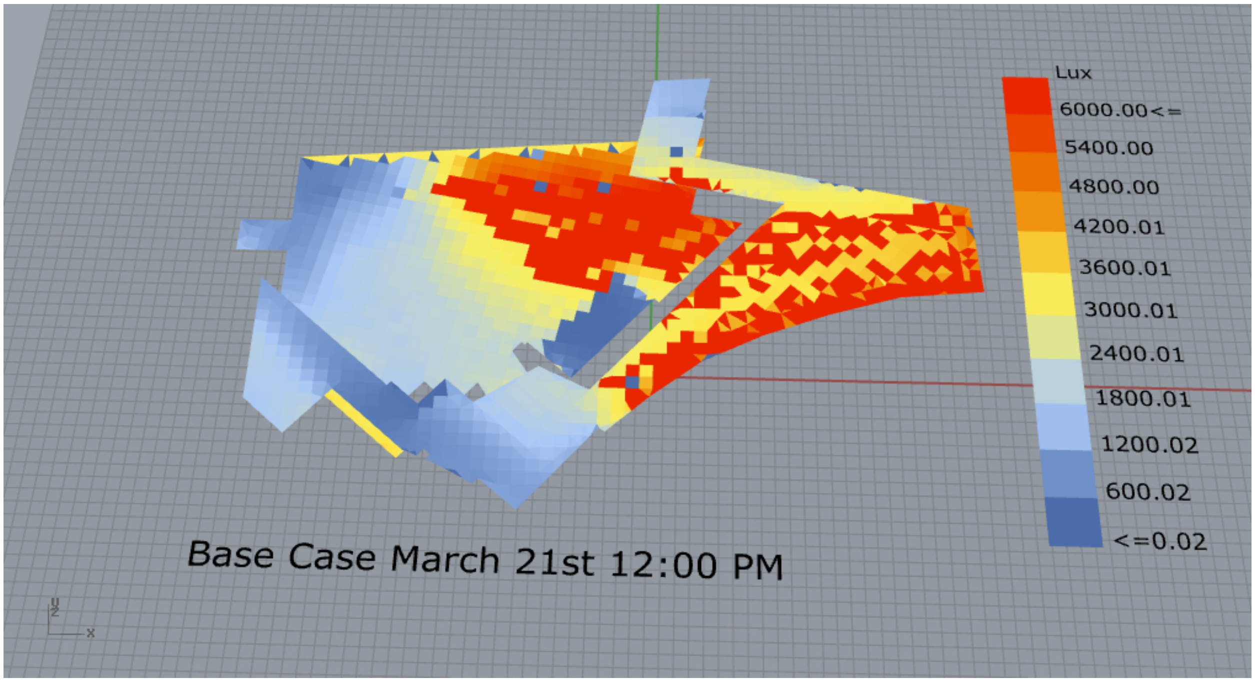
A testing grid with 1' spacing was set up on the testing surfaces, which include the mezzanine floor and main atrium. A standard occupancy profile from 9AM to 5PM was used to define the occupancy of the space.

RESULTS

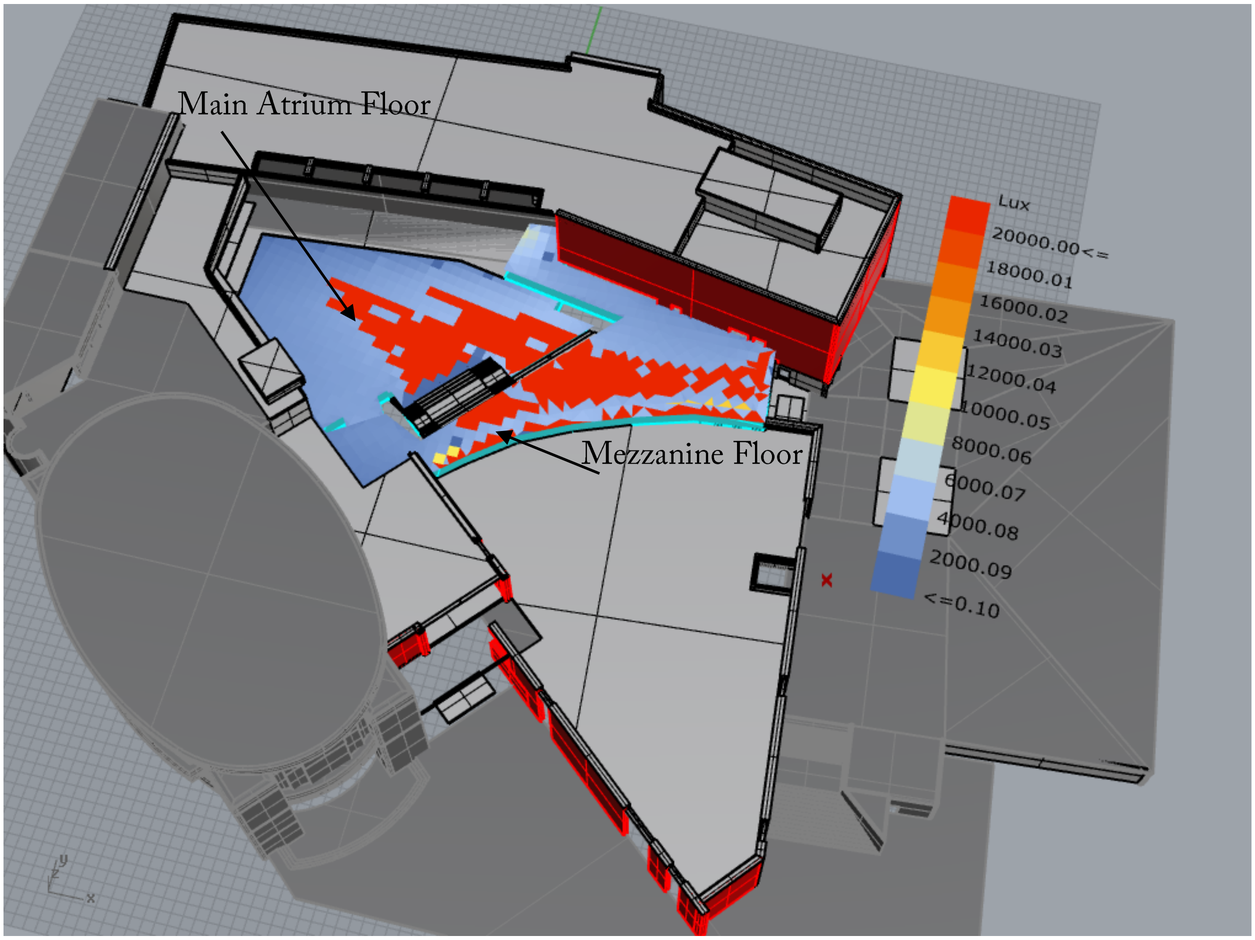
The results of the Base Case revealed that there is excessive daylight levels at various times of the year. The first two pictures below show the Base Case at 12:00 PM on the 21st of June. The first uses a scale with an upper limit of 20,000 lux and the second uses a scale with an upper limit 6000 lux. This was to show the overall upper limit of illuminance in the space, as well as show more detail of the illuminance spread.







Using figures like these to look at times throughout the year, it was determined that the mezzanine level and main seating area were two areas that needed some sort of daylighting solution. The excessive daylighting in these areas needs to be addressed to ensure a comfortable and usable space throughout the year.



The picture above shows the result mesh with surrounding context geometry. Note that there are two meshes, an upper mesh representing the mezzanine floor, and a lower mesh representing the main atrium floor.

PROPOSED DESIGNS

As stated above, there are a total of 16 scenarios that were tested in the illuminance study. From the results, no more than four cases would be chosen for further annual analysis. The variables being changed are the glass types for the both top and bottom panes in the curtain wall and the addition of an overhang ranging from 1m to 3m. All cases have replaced the skylight glazing with electrochromic glass. The electrochromic glass was had two states. The first state decreased the transmittance to 0.18 and triggered at 3000 lux. The second state decreased the transmittance further to 0.06 and triggered at 3500 lux. Both transmittances were taken from SageGlass ™ product information.

Scenarios			
#	Overhang Length (M)	Top Pane	Bottom Pane
1	0	Original	Original
2	0	Alternate	Original
3	0	Original	Alternate
4	0	Alternate	Alternate
5	1	Original	Original
6	1	Alternate	Original
7	1	Original	Alternate
8	1	Alternate	Alternate
9	2	Original	Original
10	2	Alternate	Original
11	2	Original	Alternate
12	2	Alternate	Alternate
13	3	Original	Original
14	3	Alternate	Original
15	3	Original	Alternate
16	3	Alternate	Alternate

MATERIALS

The materials used remained the same from the Base Case. The addition of two addition glass types for the alternative glazing were added and shown below. They were chosen based on their U-values, SHGC's, and LSG (Light to Solar gain Ratio). These factors were all higher compared to the Base Case. The other important factor is the transmittance, which was chosen to be similar to the Base Case.

Glass Types								
Type	Manu.	Composition	Size	Qty	VT	U	SHGC	LSG
1	JEB	1/4" Solarban 60 #2 1/2" Argon 1/4" Clear w/ 40% White Dots #3	6X4	47	51	0.29	0.32	1.59
1A	Trulite	1/4" Solarban 90 Starphire #2 1/2" Argon 1/4" Starphire	6X4	47	54	0.24	0.23	2.35
2	JEB	1/4" Solarban 60 #2 1/2" Argon 1/4" Clear	10X4	30	70	0.29	0.39	1.79
2A	Trulite	1/4" Solarban 70XL Starphire #2 1/2" Argon 1/4" Clear	10X4	30	64	0.26	0.27	2.37

SETUP

Setup is identical to the Base Case with the addition of the shading as noted above.

RESULTS

Using a mesh color component, the test grid was colored based on the corresponding test point's illuminance value. The overall performance of a scenario was based on the visual interpretation of the data. The main goal was to achieve more comfortable illuminance values than those of the Base Case. The main areas of interest are the floor area near the curtain wall and the main atrium floor.

EVALUATION

An overall trend emerged from the illuminance images that suggested that the key factors were an overhang of either 2m or 3m and the bottom curtain wall pane being replaced with the alternative glass material. These performed the best in terms of illuminance across the year. The mezzanine area by the curtain wall generally hovered around 2500 to 3500 lux. This was an improvement over the Base Case which had excesses of up to 20000 lux in that same area.

Based on their performance, the four cases chosen were 11, 12, 15, and 16. These four cases all have either 2m or 3m overhangs, as well as alternative bottom pane glazing material. That leaves the top pane glazing as an open variable.

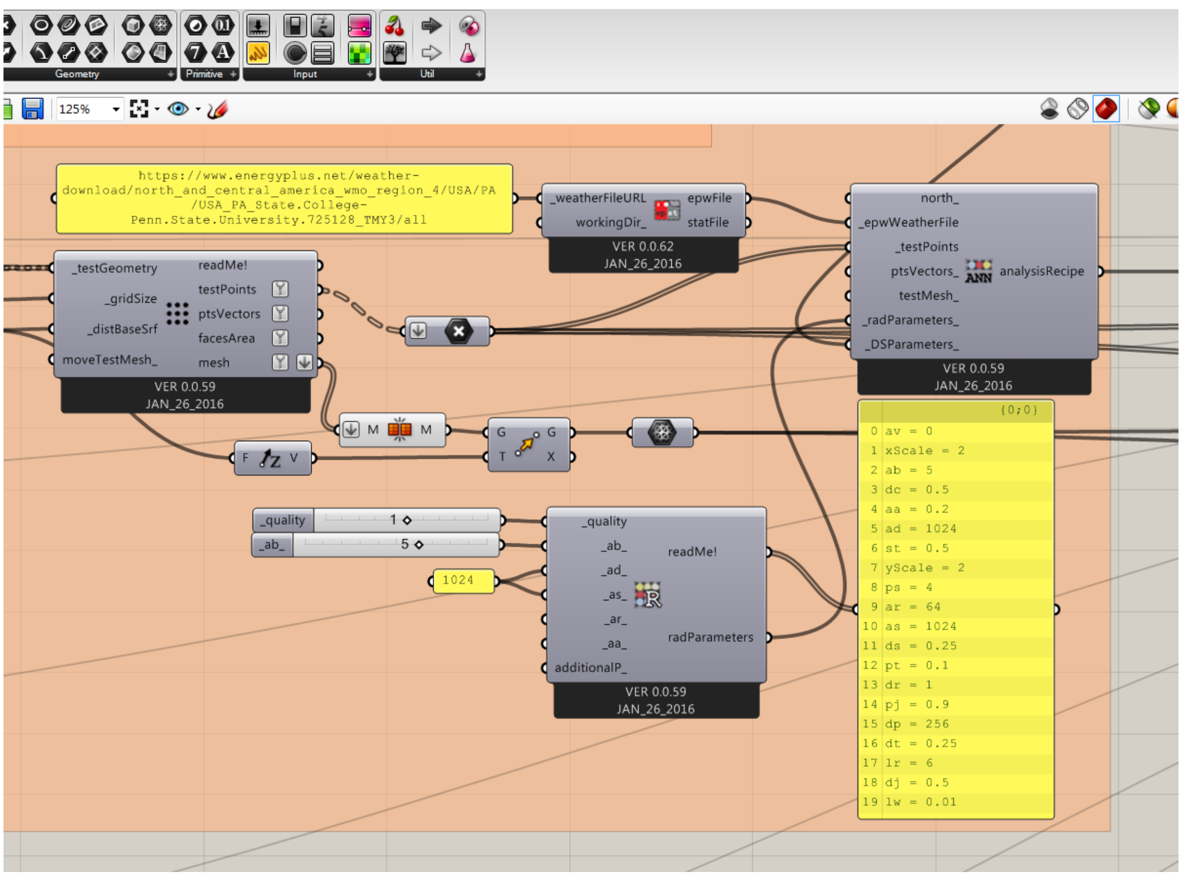
ANNUAL ANALYSIS

INTRODUCTION

With the four most promising scenarios selected through illuminance studies, an annual study is conducted to gather more thorough daylighting performance metrics for each case. These include cDA (Continuous Daylight Autonomy), DLA (Daylight Autonomy), and UDLI (Useful Daylight Illuminance). With these metrics a more concrete conclusion on the performance of each scenario can be reached. Materials and set up remained the same as the illuminance study unless otherwise noted.

PARAMETERS

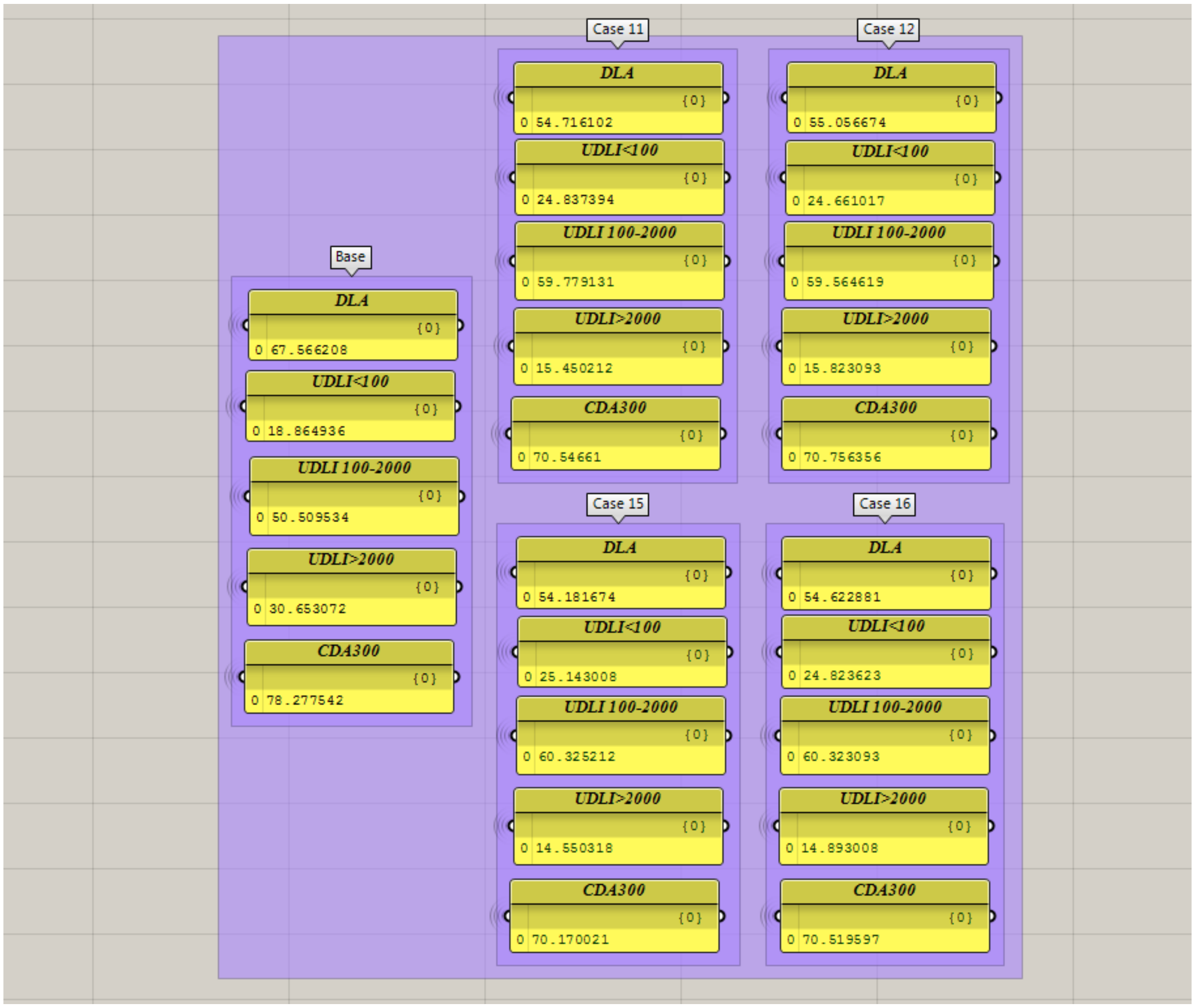
For this study the Radiance parameters were increased to ensure accurate results. They can be seen in the picture below. The State College .epw file was loaded into the analysis for the accurate weather data. The electrochromic glass parameters are the same as the illuminance study. The test surfaces and point grid also remained the same.



BASE CASE

The Base Case was studied to establish results to compare the four proposed scenarios. The daylighting metrics listed above were used to assess the performance for the space. The metric value for the entire space, as well as a colored mesh overlays were used.

RESULTS OF ALL CASES



The first thing that should be addressed is that all of the proposed cases performed similarly for all metrics tested. The most difference between them is a percentage point. Thus, it can be assumed that all solutions perform similarly. This is confirmed when the point data is overlaid on a colored mesh, similar to the illuminance study. The four cases look nearly identical to each other, while the Base Case does differ slightly.

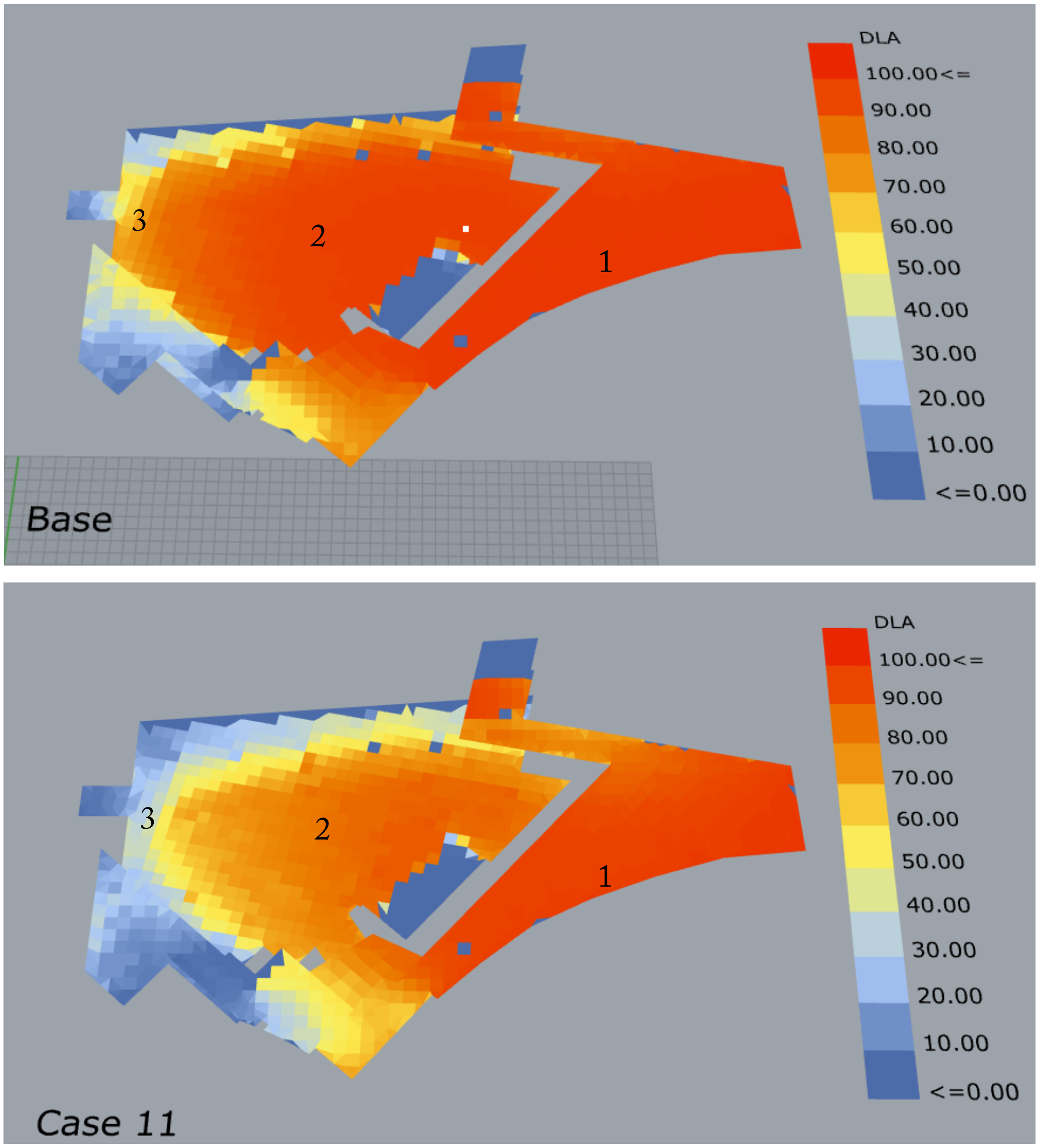
Daylighting Metrics						
Case	DLA300	CDA300	UDLI			DLA4000
			<100	100-2000	>2000	
Base	67.6	78.3	18.9	50.5	30.7	17.3
11	54.7	70.5	24.8	59.8	15.5	7.3
12	55.1	70.8	24.7	59.6	15.8	7.6
15	54.2	70.2	25.1	60.3	14.6	6.4
16	54.6	70.5	24.8	60.3	14.9	6.7

DLA_{300}

DLA shows the fraction of time that a given point meets or exceeds the target illuminance (300 lux). In this case, the DLA is averaged to give one value for the entire space. This is the case for all metrics tested.

Starting with the Base Case, the DLA is 67.6, which means that on average, 67.6% of the time, the space meets or exceeds 300 lux. The proposed designs have a slightly lower DLA of around 54.5%. This drop was expected, since the main goal of each of these designs was to manage excess daylight within the space. The two figures below show the colored mesh overlay for both the Base Case and case 11. Case 11 was chosen, as it was in closest to the average for all daylighting metrics. The scale is from 0% to 100%.

For the area nearest the curtain wall on the mezzanine level (labelled 1), there is a drop of 10% across all points from the Base Case to Case 11. The differences occur on the main atrium floor, (labelled 2). There is a noticeable drop in DLA from upper 90's for the Base Case to 70-80's range for the proposed solutions. The edges of the main floor facing toward the old HUB, (labelled 3), also see a drop-off in DLA from approximately 75% to 30%. These two results suggest that direct daylight that was previously hitting the main floor is now being blocked, most likely from the electrochromic glass that replaced the skylights.

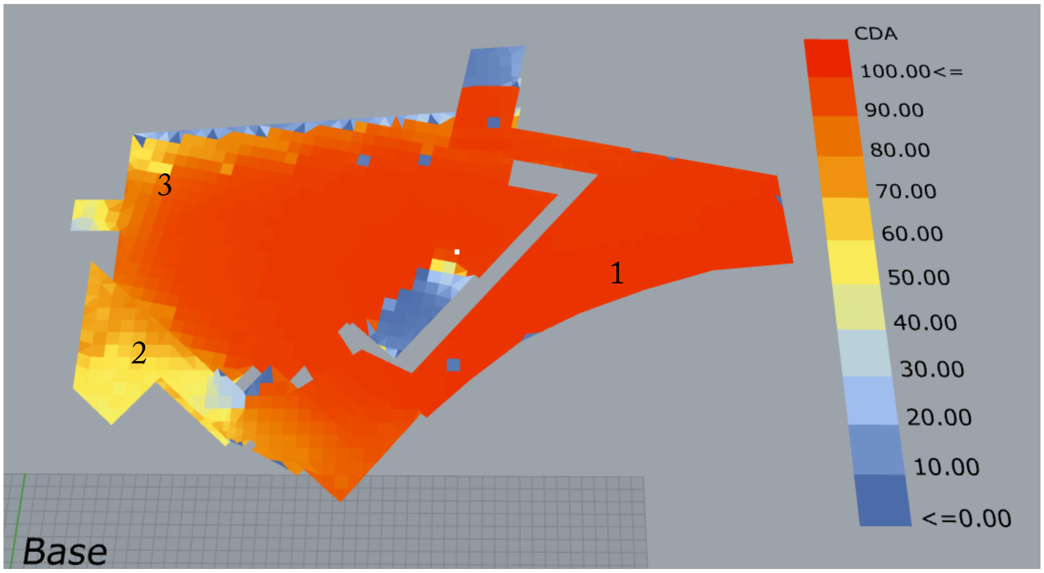


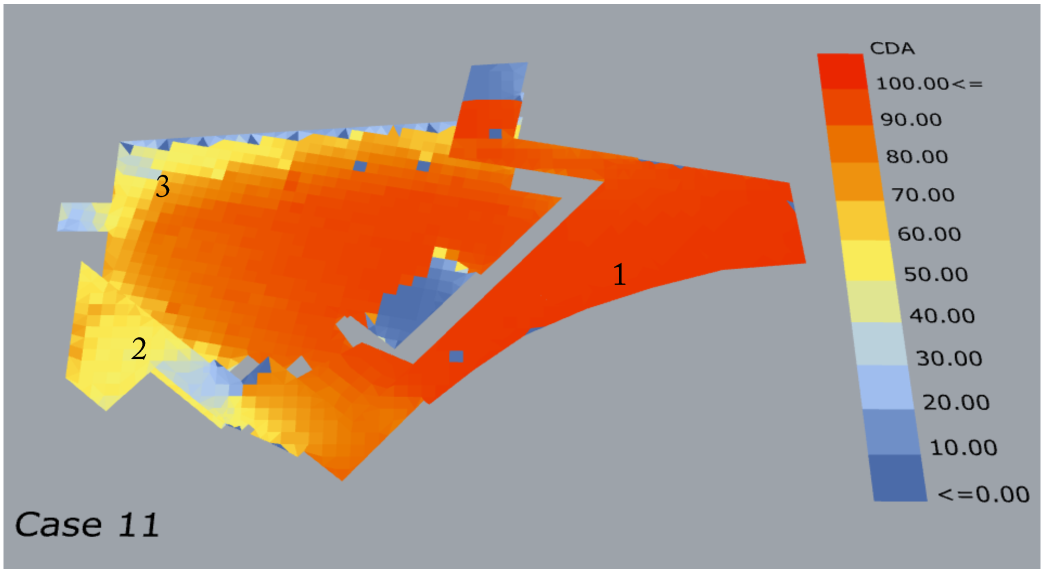
CDA_{300}

CDA is similar to DLA, with the difference being that CDA allows for partial credit to be given to points that don't meet the illuminance criteria, e.g. if the illuminance threshold is 300 lux and a point receives 150 lux, it would have a CDA of 50%.

The CDA between the base case and proposed cases saw an 8% drop, from 78% to 70%. Once again, a drop was expected due to the proposed designs blocking daylight coming into the space. There is some ambiguity with CDA, as there's no way to know if a point that has a CDA_{300} of 10% gets 30 lux 10% of the time or 3 lux 100% of the time.

The two figures below show the colored mesh overlay for CDA_{300}. The mezzanine floor near the curtain wall, labelled 1, is nearly identical for both cases, with CDA hovering around 100%. The two cases differ in CDA on the left side of the mezzanine, 2, and the edges of the atrium floor, 3.





UDLI

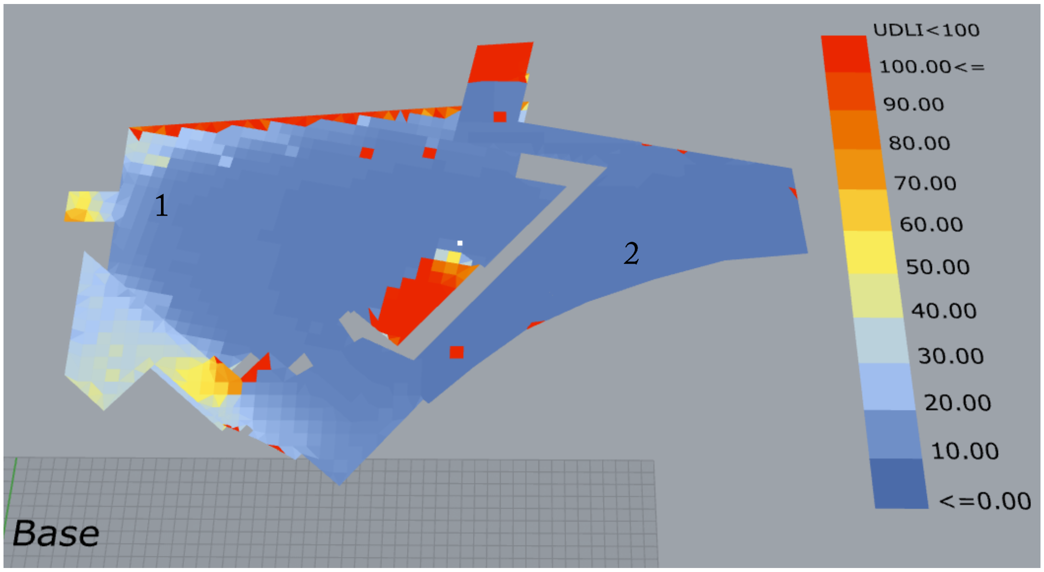
UDLI is broken into three parts, points below the minimum threshold, points within the thresholds, and points above the maximum threshold. Using these three values, a more complete picture of daylighting performance can be formed.

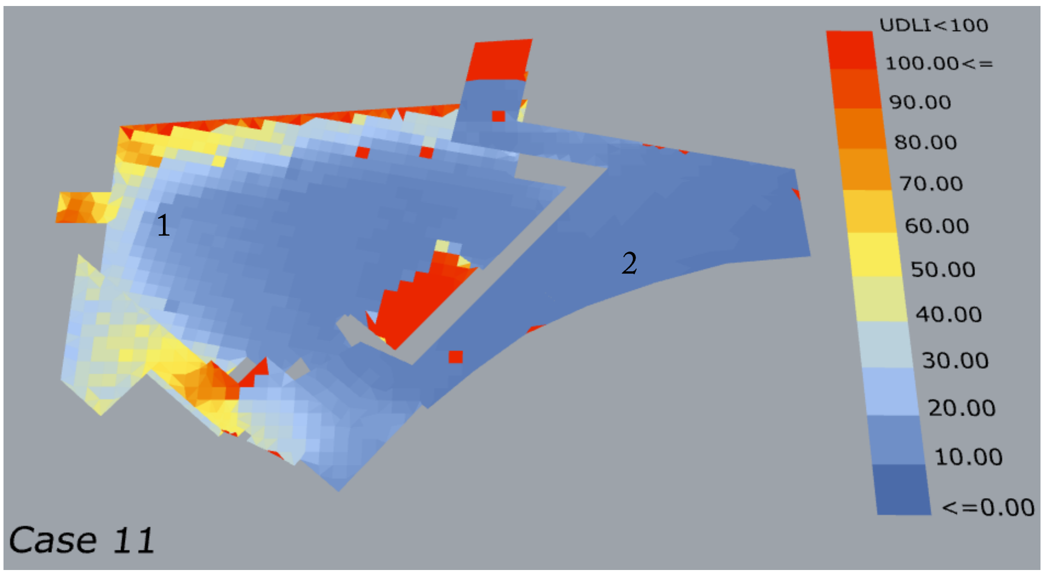
UDLI<100

UDLI<100 is the percentage of time that points within the space fall below the illuminance threshold, 100 lux.

From the Base Case to Case 11, there was a 6% increase for UDLA<100. This means that on average, each point within the space was below the threshold of 100 lux 6% than the Base Case. This isn't unexpected, since less daylight will be reaching deep into the space with the overhang and changed glass types.

Using the two colored mesh figures below, it can be seen that as predicted, UDLI<100 is higher deep in the space, (labelled 1), and remains practically unchanged near the curtain wall, (labelled 2).



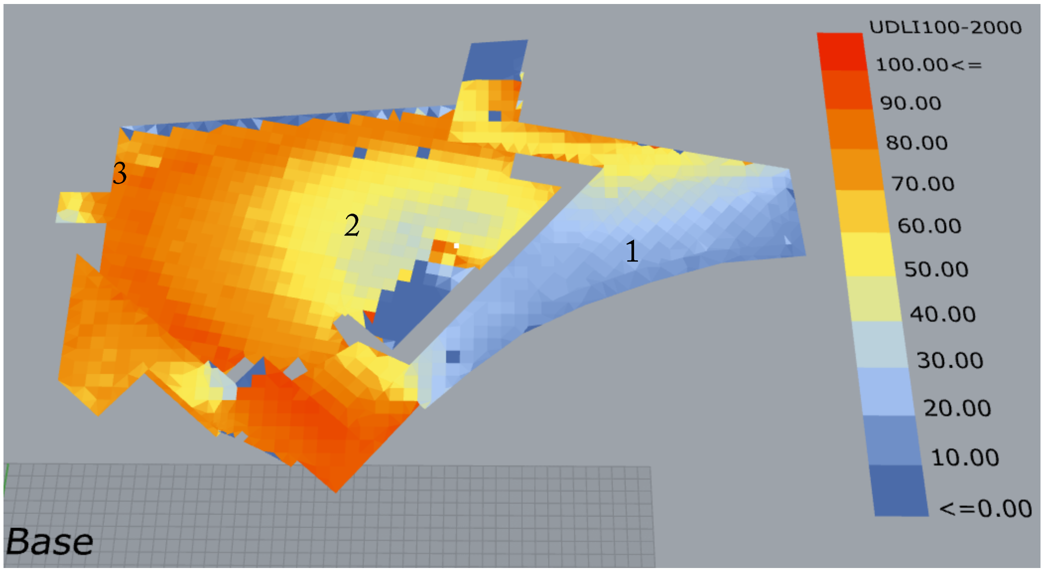


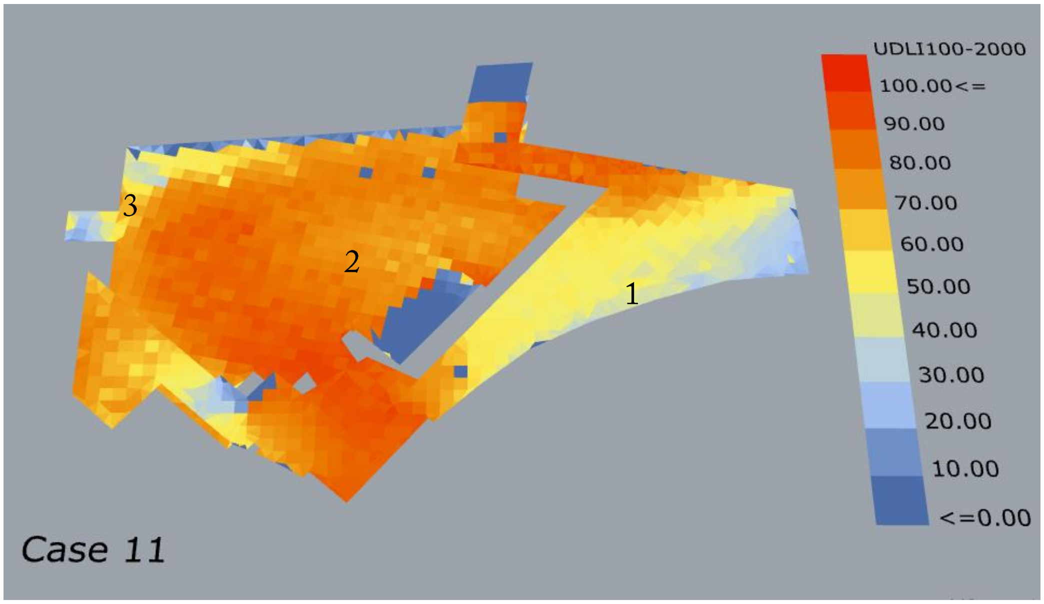
UDLI 100-2000

UDLI 100-2000 is the sweet spot, representing the amount of time a point receives between 100lux to 2000 lux.

From Base Case to Case 11, there was a 9% increase in UDLI 100-2000. This means that on average, the points within the space received between 100 lux and 2000 lux 9% more than the Base Case. This also means that the proposed solutions did perform better for this metric.

From the two figures below, it can be seen that the increase occurs near the curtain wall on the mezzanine, (labelled 1). The points in that area go from the 20-30 range to 40-50 range, around a 20% increase overall. The atrium floor, (Labelled 2), also sees an increase from around 50% to 70%. Some decreases in UDLI 100-2000 did occur near the edges of the atrium floor, (3). Since that area is deeper in the space, it isn't an unexpected result.



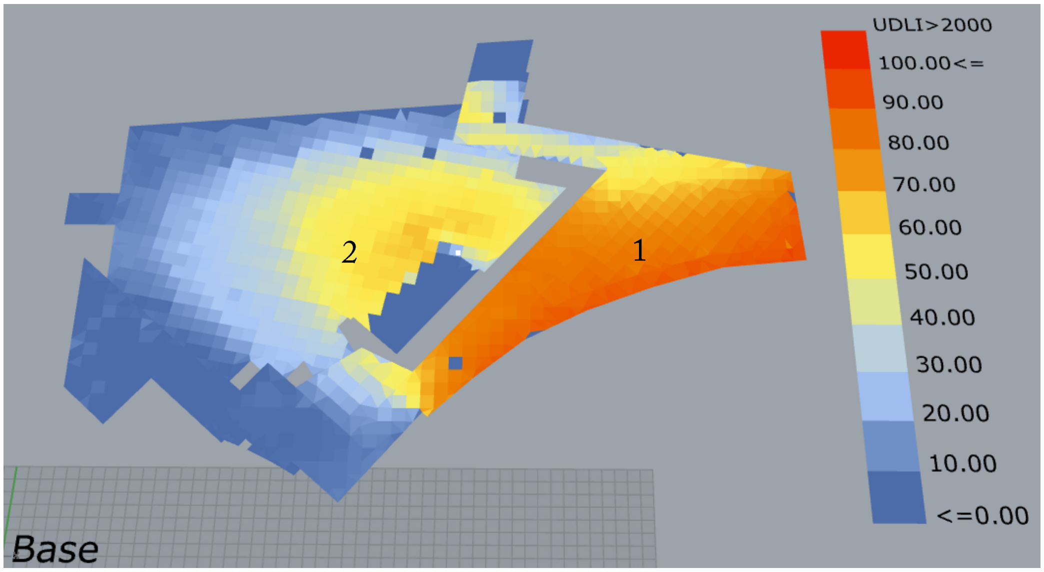


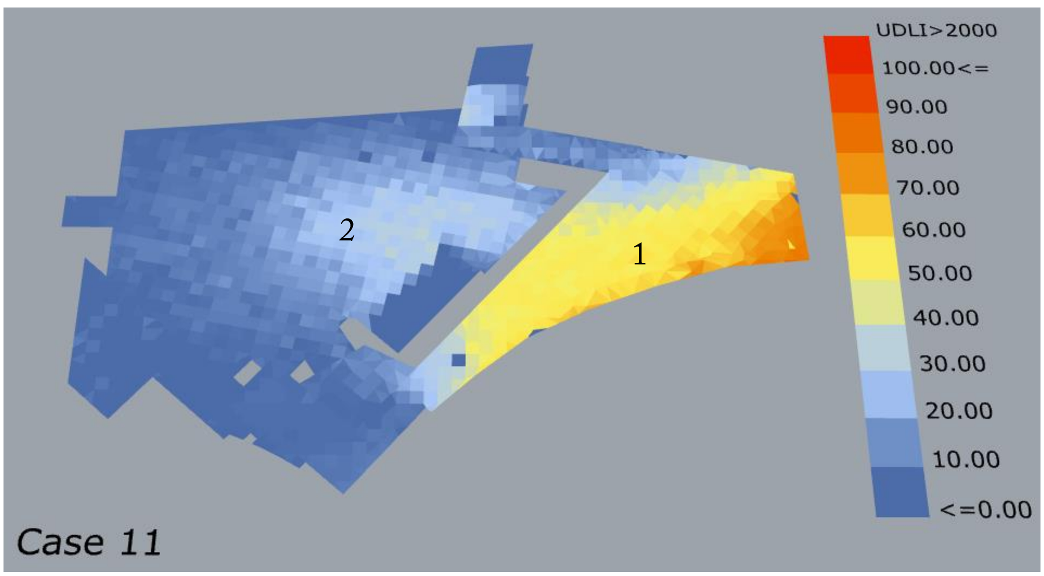
UDLI>2000

UDLI>2000 shows the percentage of time that a point is above the maximum threshold of 2000 lux, which is when glare may occur.

The Base Case had a UDLI>2000 of 31%, whereas Case 11 was only 15%. That means that the space for Case 11 was above 2000 lux 16% less of the time. This is 16% less of the time that glare would be an issue overall as well.

Mirroring UDLI 100-2000, the two figures below show that the main decreases occurred in the mezzanine level by the curtain wall, (1), and in the middle of the atrium floor, (2). Both of these decreases were around 20%.These were two areas that were likely to receive direct daylight and were probably prone to glare issues. With the decreases, those areas will be less likely to be glary and be more comfortable overall.





UDLI CONCLUSION

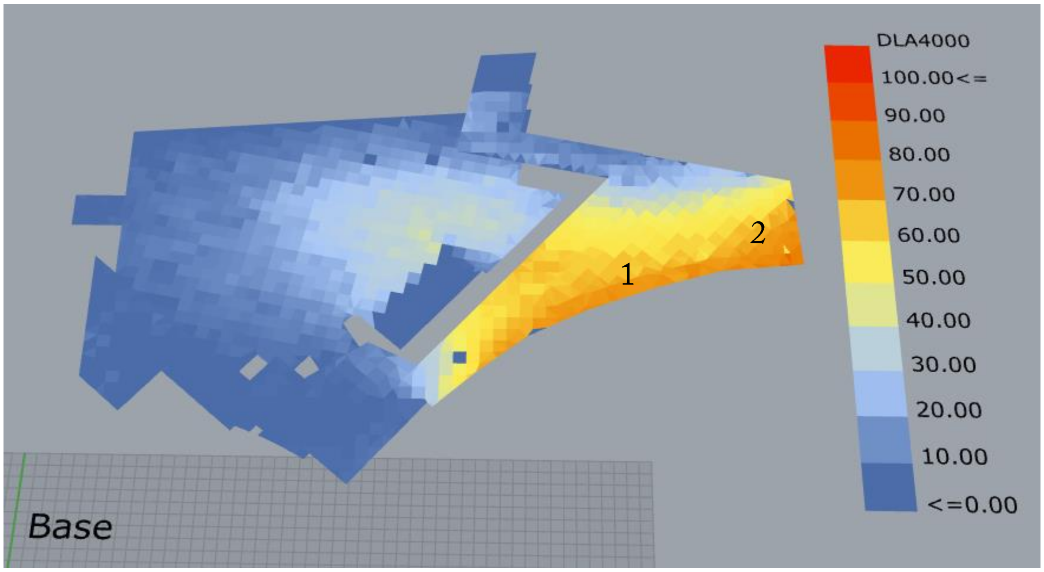
The proposed solutions perform better overall in terms of UDLI. Points deep within the space do get less daylight, as was shown with UDLI<100, however, both UDLI 100-2000 and UDLI>2000 were better. UDLI 100-2000 was higher throughout the space, especially near the curtain wall. UDLI>2000 was lower along the curtain wall and the main atrium floor – two locations where glare would likely occur. It can be concluded that the proposed designs may help alleviate glare and bring trouble areas down to an optimal illuminance range. Even though some areas deep in the space receive less daylight, the areas receiving illumination from daylighting portals are in a more comfortable range.

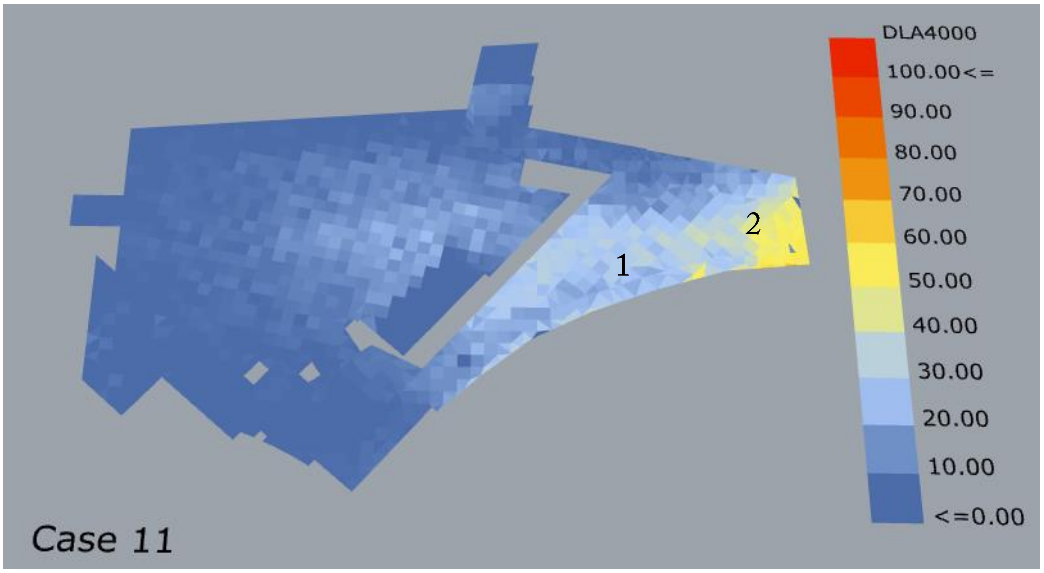
DLA_{4000}

DLA_{4000} is used further evaluate the potential for glare, suggested by UDLI>2000, within the atrium.

The Base case has a DLA_{4000} of 17.3%, meaning that 17.3% of the time, the space would have issues with glare. Compared to Case 11, the DLA_{4000} decreases to 7.3%. On average the space for Case 11 would experience glare 10% less of the time.

Referring to the two pictures below, the trouble area is near the curtain wall, (1). DLA_{4000} hovers between 50% and 70%, getting higher the closer a point is to the curtain wall. That same area drops down to 20% to 30%, with a few points getting up to 50% in the south eastern corner, (2).


DLA4000
100.00<=
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
<=0.00
1
2
Base


DLA4000
100.00<=
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
<=0.00
1
2
Case 11

CONCLUSION

SUMMARY

The initial illuminance studies were used to narrow down the 16 proposed cases to 4 of the most promising. The main criteria for considering a case as viable was the illuminance near the curtain wall on the mezzanine floor. The four cases that were chosen had reduced the illuminance in that area near the curtain wall from 20000 lux down to 2500 to 3500 lux. The other options didn't have as much of an impact, so they were not considered for the annual study.

The annual study tested five cases, the Base Case, and Cases 11, 12, 15, and 16. The daylighting performance was analyzed using both average metrics for the entire space and colored mesh overlays of the point values for each point. The metrics used were DLA_{300}, CDA_{300}, UDLI 100-2000, and DLA_{4000}. The proposed designs showed a decrease in DLA_{300} and CDA_{300}. This was to be expected since the solutions were meant to block incoming daylight. The main areas effected were deep in the space, whereas the area near the windows didn't see as sever a decrease.

UDLI revealed that the proposed designs may reduce glare potential, shown by the decrease in UDLI>2000 by the areas near the curtain wall and the middle of the atrium floor. These areas were reduced to a more comfortable range, as shown by UDLI 100-2000. Similarly to DLA and CDA, points deep in the space did see less daylight, hence the increase in UDLI<100. This isn't a major concern, seeing as such large areas that had a high potential for glare were brought into a more reasonable illuminance range. DLA_{4000} confirmed that the proposed designs reduced glare near the curtain wall significantly.

MECHANICAL BREADTH

INTRODUCTION

This section is devoted to explaining the mechanical portion of the integrated daylighting study. Much like the previous section, goals and criteria will be laid out to judge each case selected for the annual daylighting study.

GOALS

1) Analysis thermal performance of the atrium.
2) Evaluate thermal performance of the proposed designs against Base Case using parametric modelling techniques.
3) Improve thermal characteristics of the space if possible.

METHODOLOGY

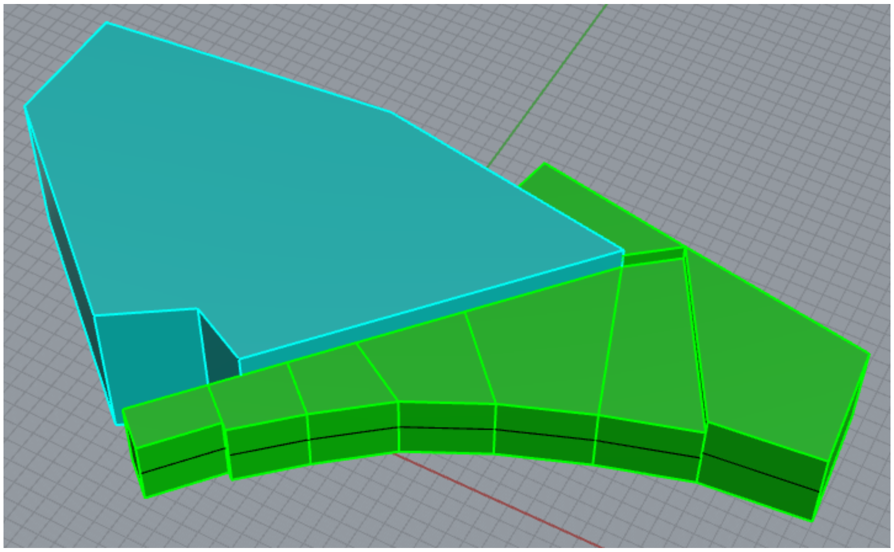
Overall the methodology of the grasshopper model is very similar to the daylighting model. The sequence of steps stays the same, however, there are a few differences in referencing geometry, material types, analysis types, and the addition of building programs and zone loads.

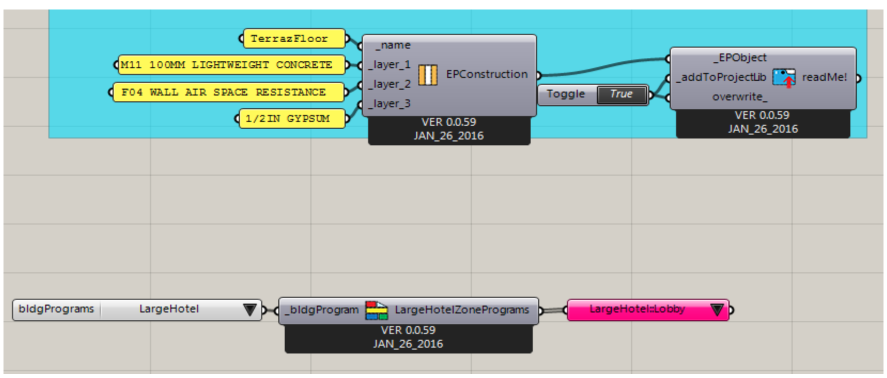
DIFFERENCES

Geometry & Materials

Unlike in the daylighting model, Energy Plus needs geometry to be consolidated into zones. These are essentially boxes that are able to have different materials assigned to each surface, e.g. walls, ceiling, floor. For this study, nine zones were used to define the main atrium area. Eight of the nine zones break up the mezzanine floor. These zones act as buffer zones, green, to the main atrium floor zone, teal. The buffer zones ensure accurate convection and mixing of air between the different zones.

In place of Radiance materials, Energy Plus uses EP constructions to assign materials to zones. EP constructions define U-values and R-values based on thermal properties of the EP materials that make up an EP construction. Once defined, EP constructions are then assigned to the surfaces of the zone based on type or surface by surface. Adjacent zones that are not separated by solid walls can have air walls separating them to ensure air mixing between those zones.





Analysis Types, Building Programs, & Zone Loads

For mechanical studies the type of loads that are output from the simulation are set before-hand. This is done in lieu of choosing an analysis type, as is done for daylighting studies.

Building programs are used to define the general schedules of the building. These include things like occupancy schedules of the space, which controls when 100% of the occupancy load is applied to the model.

Occupancy loads need to be defined to ensure that internal loads are accounted for within the energy model. These include equipment, infiltration, lighting density, number of people per area, ventilation, and recirculated air.

ANNUAL STUDY

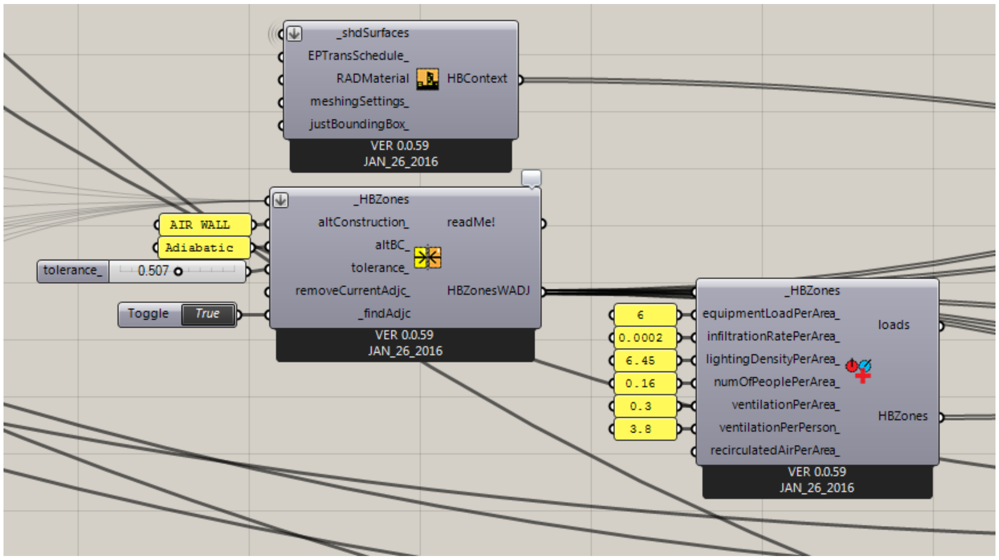
INTRODUCTION

An annual analysis was chosen to get the most complete picture of the thermal conditions in the space throughout the year. This was the best way to get total heating, cooling, and solar loads of the space. Total heating and cooling will be used to evaluate each space, whereas total solar gain will be used to determine the performance of the daylighting system implemented.

PARAMETERS

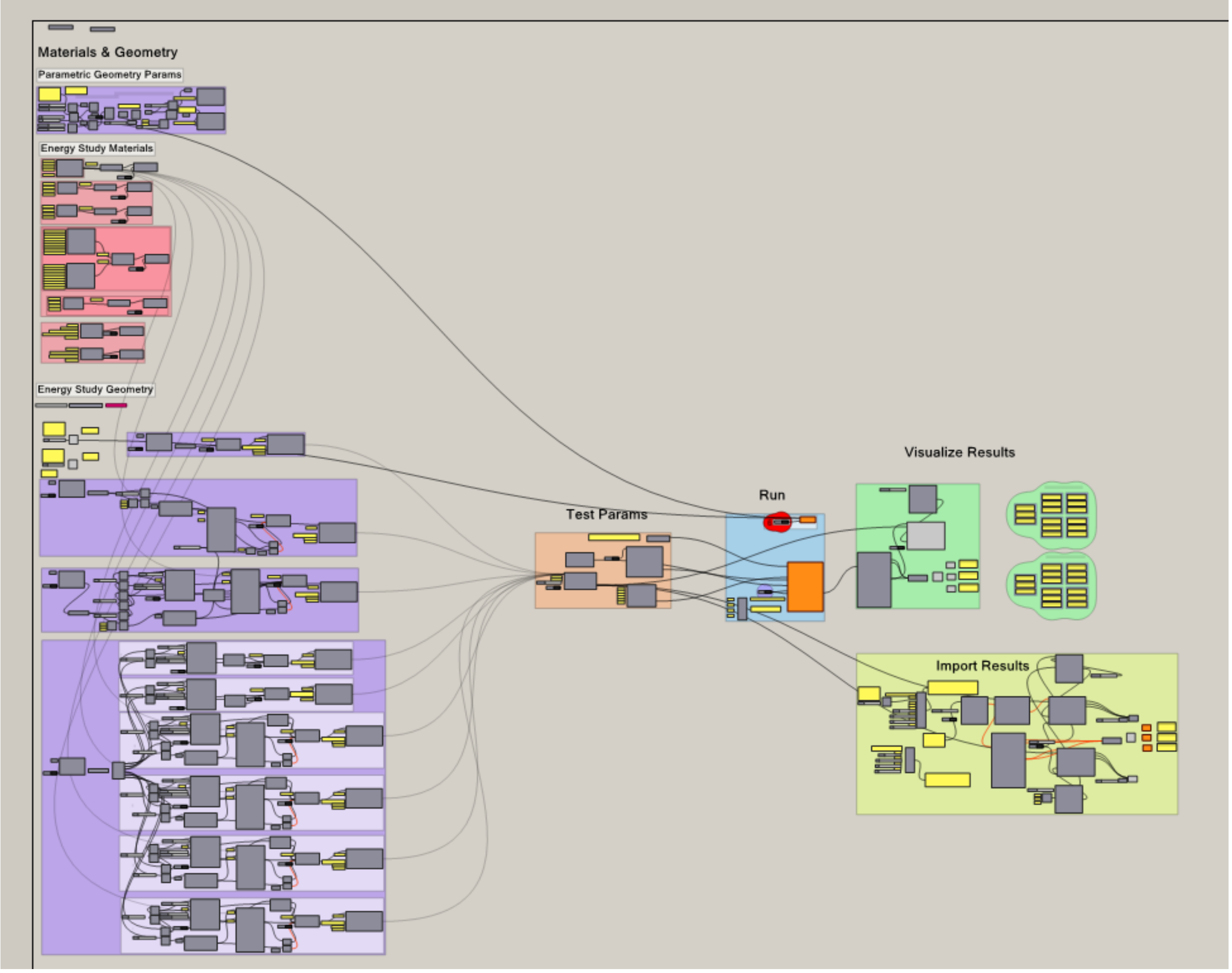
There are a number of parameters that can be changed based on the type of space and desired results of the study. The first is the building program, which in this study was set to a large hotel lobby. This was determined to be the closest program to what an atrium in a multi-purpose building would be.

Next all adjacencies need to be solved and appropriate materials be assigned to those surfaces. Because all adjacent surfaces were on the interior and there were no partitions between them, air wall materials were assigned to these surfaces.



The zone loads for the space also need to be set to ensure accurate load calculations. The equipment load is set to 6 W/m^2 due to the amount of laptops that students use within the space. The infiltration is 0.0002 m^3/s-m^2, which is typical of modern buildings. Lighting density is set to 6.45 W/m^2 to reflect the new lighting design. Number of people per area is set at 0.16 people/m^2, meaning that around 150 people would occupy the space during normal occupancy hours. Lastly, the ventilation per area and ventilation per person were set to 0.3 L/s m^2 and 3.8 L/s m^2 respectively. These values were found in the ASHRAE standards minimum ventilation rates in breathing zones and the space is classified as a multi-use assembly.

The load outputs for the study were the total heating and cooling loads, total thermal energy, and total solar gain. For evaluation, the total heating, cooling, and solar gain will be used.



CASE SETUP

The Base Case was set up similarly to the Base Case of the daylighting simulation. The original glass materials were used and no overhang or electrochromic glass.

MATERIALS

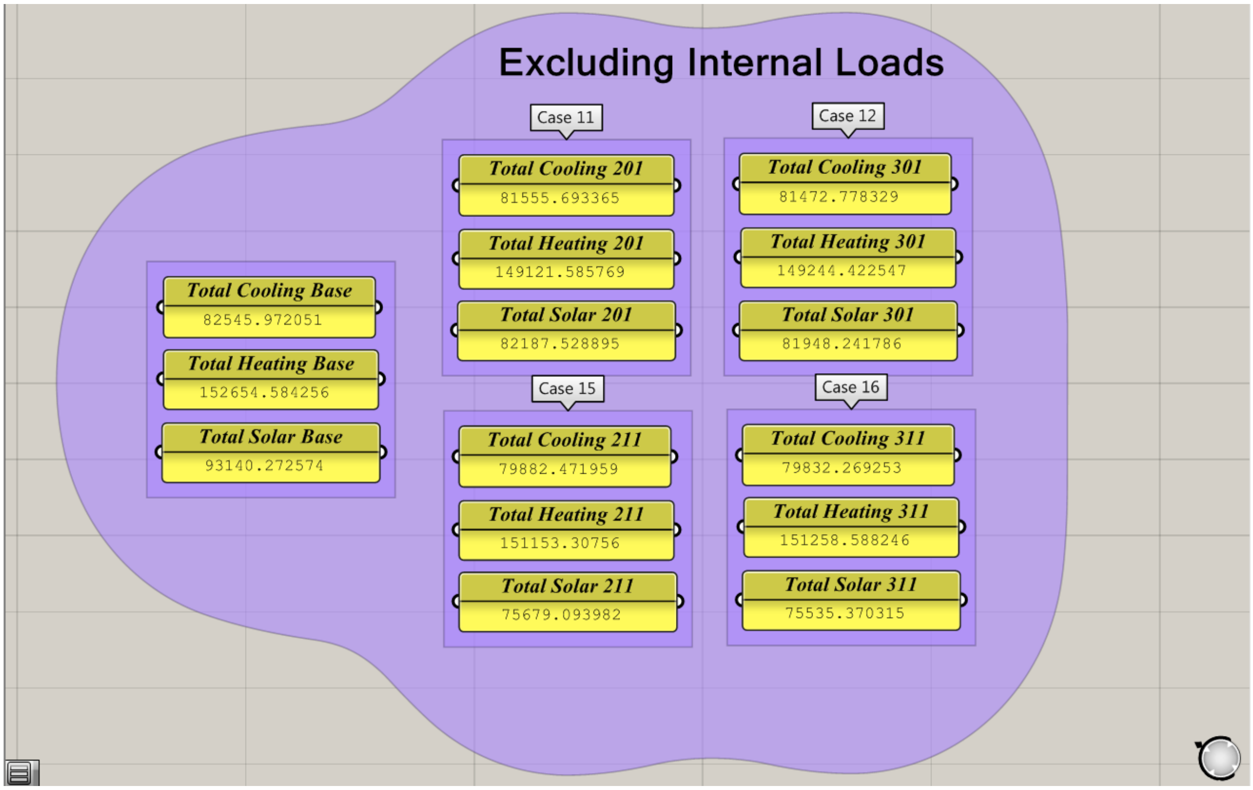
With the model being simplified to only include the nine zones making up the atrium, many of the materials included in the daylighting study were not needed in the mechanical study. For the solid materials, preexisting EP materials were used to create the custom EP constructions. The table below shows the materials used in the model.

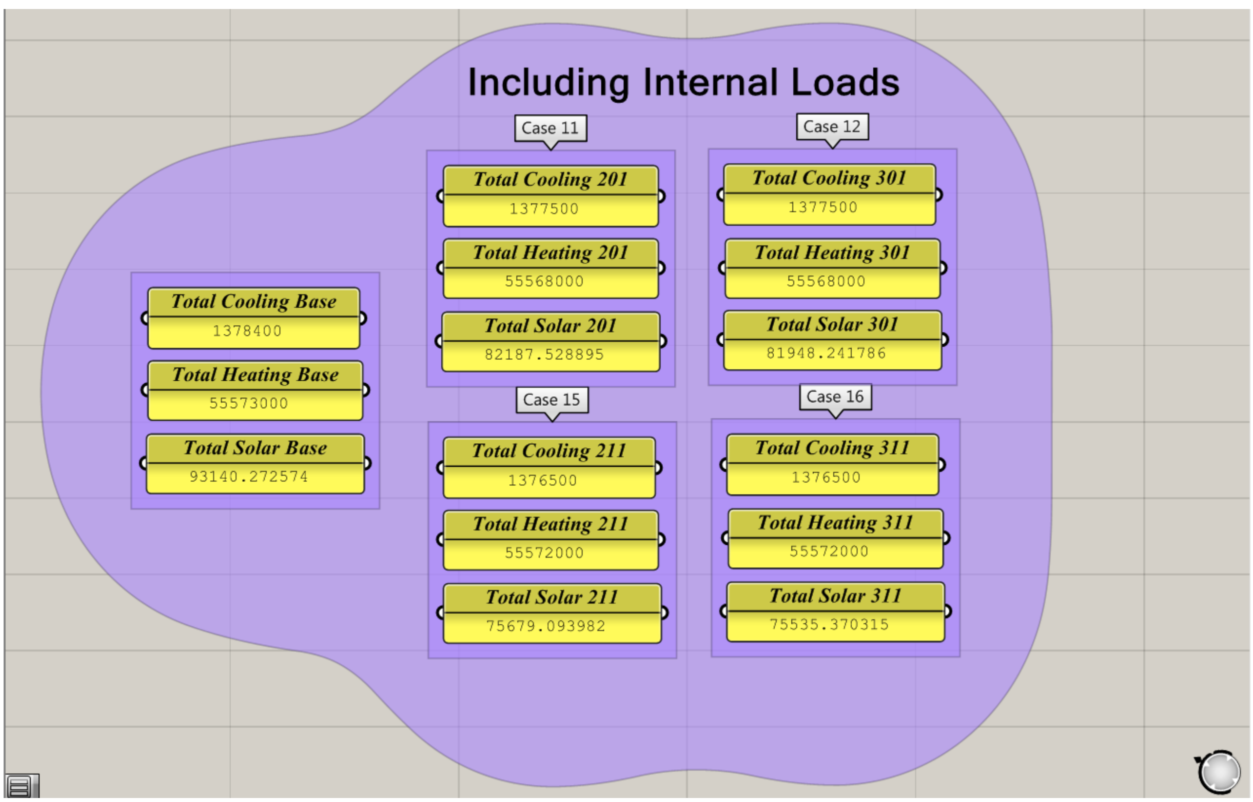
EP Construction					
Name	Type	U-value	R-value	Transmittance	SHGC
Terra Wall	Solid	0.47	2.12766	--	--
Terrazo Floor	Solid	2.37	0.421941	--	--
Air Wall	Fluid	60	0.016667	--	--
Top Glazing	Glass	0.29	3.448276	0.51	0.32
Bottom Glazing	Glass	0.29	3.448276	0.7	0.39
Alt Bot Glazing	Glass	0.26	3.846154	0.64	0.27
Alt Top Glazing	Glass	0.24	4.166667	0.54	0.23
Sage Glass	Shade	0.28	3.571429	0.06	0.1

SETUP

No additional setup was required for the Base Case beyond referencing the geometry and assigning material types. A total of 10 simulations were run, one set including internal loads another excluding them. This was to see the effects of just solar gain on the space, as well as the effect with typical loads.

RESULTS


Excluding Internal Loads
Case 11
Case 12
Total Cooling 201
81555.693365
Total Heating 201
149121.585769
Total Solar 201
82187.528895
Total Cooling 301
81472.778329
Total Heating 301
149244.422547
Total Solar 301
81948.241786
Total Cooling Base
82545.972051
Total Heating Base
152654.584256
Total Solar Base
93140.272574
Case 15
Case 16
Total Cooling 211
79882.471959
Total Heating 211
151153.30756
Total Solar 211
75679.093982
Total Cooling 311
79832.269253
Total Heating 311
151258.588246
Total Solar 311
75535.370315


Including Internal Loads
Case 11
Case 12
Total Cooling 201
1377500
Total Heating 201
55568000
Total Solar 201
82187.528895
Total Cooling 301
1377500
Total Heating 301
55568000
Total Solar 301
81948.241786
Total Cooling Base
1378400
Total Heating Base
55573000
Total Solar Base
93140.272574
Case 15
Case 16
Total Cooling 211
1376500
Total Heating 211
55572000
Total Solar 211
75679.093982
Total Cooling 311
1376500
Total Heating 311
55572000
Total Solar 311
75535.370315

The results shown above are in kWh. Starting off excluding internal loads, it can be seen that each of the scenarios saw a decrease in overall energy usage over the Base Case. Case 11 and 12 had similar results, with total heating, cooling, and solar gain being within 100 kWhs of each other. This is also the case with scenario 15 and 16. This leads to the conclusion that the 2m overhang performs just as well thermally as the 3m overhang. Case desriptions can be found in the daylighting section.

The major differences seemed to come from changing the top pane of glass to the alternative glazing. Comparing case 11 with case 15 and case 12 with case 16, around a 2000 kWh drop in cooling load occurs, however the heating load increases by an equal magnitude. The major difference comes from total solar gain when the top glazing is changed. The solar gain decreases 7000 kWh when the top glazing is changed.

These changes in overall loads can be explained by the change in U-value of the curtain wall when the alternative top glazing was used. The U-value and SHGC were better than the base glazing material. This should and did lead to a decrease in solar gain. This also explains the decrease in total cooling and increase in total heating. During summer months, the window would reject heat gain from the sun, leading to lower cooling loads. This rejection of heat would also happen in the winter when heat from the sun is generally benefitial, leading to higher heating loads.

Similar trends occurred with the inclusion of internal loads. From case 11 to 15 and case 12 to 16, a decrease in cooling and increase in heating is observed. As expected the overall cooling and heating loads are larger, in this case an entire magnitude for cooling and two magnitudes for heating. This reflects the heating dominated climate that the project is located in. Overall, solar loads on the spaces are only 8% for cooling and 2% for heating.

These loads were converted from kWh to ton hours for cooling and klbs for heating. The converstion factors used were 0.284 ton hours/kW and 0.003 klbs/hr kW. These converted values were then multiplied by the utility rates provided by the owner of $0.22/ ton hour and $24.20/klb. The table below shows the operating cost excluding internal loads.

Energy cost				
Case	Type	Load	Convertion to Proper Units	Energy Cost
Base	Cooling	82546	23471.56	$16,246.50
	Heating	152655	457.97	
11	Cooling	81556	23190.05	$15,928.07
	Heating	149122	447.37	
12	Cooling	81473	23166.45	$15,931.73
	Heating	149244	447.73	
15	Cooling	79882	22714.06	$15,970.80
	Heating	151153	453.46	
16	Cooling	79832	22699.84	$15,975.37
	Heating	151259	453.78	

CONCLUSION

On average $300 per year in energy is saved over the Base Case. There is not much variation between the four proposed solutions, with a $40 difference existing between the best, case 11, and worst, case 16, case. This leads to the conclusion that although several thousand kWhs separate each case, the monetary impact is not that significant.

CONSTRUCTION BREADTH

INTRODUCTION

This section describes the third and final disciple that is part of the integrated daylighting study. A cost analysis of the Base Case and four proposed solutions serves as the final parameter for measuring each potential solutions success.

GOALS

1) Conduct a cost analysis for each of the annually tested cases.
2) Use RS means and manufacturer cost data to create an accurate cost summary.

METHODOLOGY

Quantity takeoffs were gathered from the construction documents provided by the owner. RS means and cost data provided by the manufacturers of the glazing materials were used to get an accurate cost estimate. Both the material and labor costs were included into the analysis. The schedule was also consulted to ensure that no changes to the critical path would take place with the additional construction and material changes. A detailed schedule can be found in appendix F.

COST ANALYSIS

As stated above, RS means 2016 supplemented by manufacturer cost data is used to determine an approximate cost for each of the four purposed options. These estimated costs were used to weigh each of the options against the Base Case and each other. Below is a table that includes the cost data gathered for each of the scenarios.

Panelboard Cost Analysis								
Cost Code	Item	Units	Quant.	Mat'l Unit Cost	Mat'l Cost	Labor Unit Cost	Labor Cost	Total
Base Case								
086113100130	High Perf TMP glazing, metallic frame 72" x 28"	SF	2150	$ 90.00	$193,500.00	$ 41.00	$ 88,150.00	$281,650.00
088130102500	Reduced Heat Transfer Glass Heat reflective, film inside, 1" thick, clear	SF	2300	$ 27.50	$ 63,250.00	$ 6.55	$ 15,065.00	$ 78,315.00
Scenario 11								
B10203100100	Canopies, wall hung, prefinished alumium	SF	689	$ 27.00	$ 18,603.00	$ 18.85	$ 12,987.65	$ 31,590.65
--	Sage Glass	SF	2,150	$ 115.00	$247,250.00	$ 45.00	$ 96,750.00	$344,000.00
088130102500	Reduced Heat Transfer Glass Heat reflective, film inside, 1" thick, clear	SF	1,100	$ 27.50	$ 30,250.00	$ 6.55	$ 7,205.00	$ 37,455.00
088130102000	Both lites, light and heat reflective	SF	1,200	$ 31.50	$ 37,800.00	$ 6.55	$ 7,860.00	$ 45,660.00
Scenario 12								
B10203100100	Canopies, wall hung, prefinished alumium	SF	689	$ 27.00	$ 18,603.00	$ 18.85	$ 12,987.65	$ 31,590.65
--	Sage Glass	SF	2,150	$ 115.00	$247,250.00	$ 45.00	$ 96,750.00	$344,000.00
088130102000	Both lites, light and heat reflective	SF	2,300	$ 31.50	$ 72,450.00	$ 6.55	$ 15,065.00	$ 87,515.00
Scenario 15								
B10203100100	Canopies, wall hung, prefinished alumium	SF	1,034	$ 27.00	$ 27,918.00	$ 18.85	$ 19,490.90	$ 47,408.90
--	Sage Glass	SF	2,150	$ 115.00	$247,250.00	$ 45.00	$ 96,750.00	$344,000.00
088130102500	Reduced Heat Transfer Glass Heat reflective, film inside, 1" thick, clear	SF	1,100	$ 27.50	$ 30,250.00	$ 6.55	$ 7,205.00	$ 37,455.00
088130102000	Both lites, light and heat reflective	SF	1,200	$ 31.50	$ 37,800.00	$ 6.55	$ 7,860.00	$ 45,660.00
Scenario 16								
B10203100100	Canopies, wall hung, prefinished alumium	SF	1,034	$ 27.00	$ 27,918.00	$ 18.85	$ 19,490.90	$ 47,408.90
--	Sage Glass	SF	2,150	$ 115.00	$247,250.00	$ 45.00	$ 96,750.00	$344,000.00
088130102000	Both lites, light and heat reflective	SF	2,300	$ 31.50	$ 72,450.00	$ 6.55	$ 15,065.00	$ 87,515.00

The glazing types were chosen based on the closest representation available in RS means. Sage Glass is the brand of electrochromic glass used in the proposed solutions. The material cost for Sage Glass represents the entire glazing system that the glazing units need to operate.

Cost Comparisons					
Case	Base	11	12	15	16
Cost	$ 359,965.00	$ 458,705.65	$ 463,105.65	$ 474,523.90	$ 478,923.90
Case - Base	$0.00	$ 98,740.65	$ 103,140.65	$ 114,558.90	$ 118,958.90

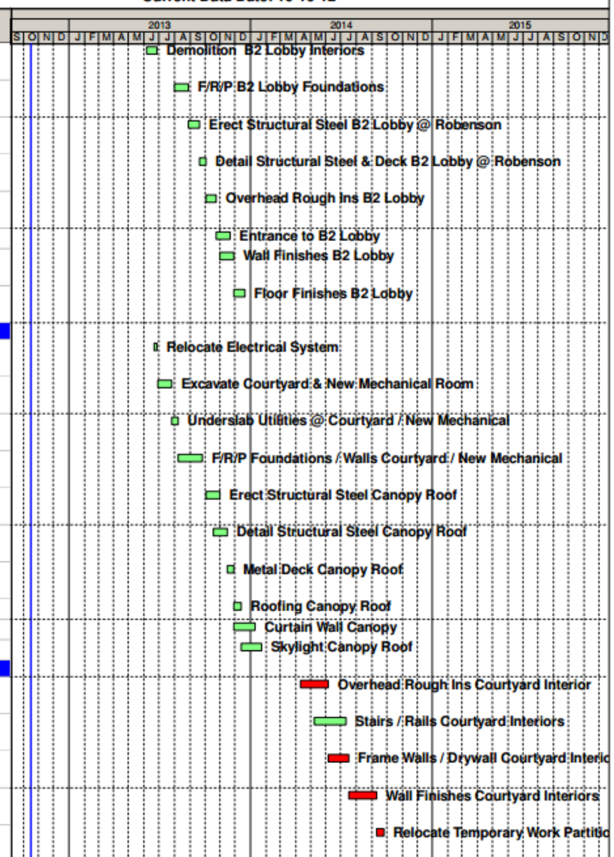
The skylight systems were by far the most expensive portion of each option, accounting for at least 70% of the total cost of each system. The glazing types were fairly similar in price as well, with the replacement windows being slightly more costly. The addition of the overhang is expected to cost around $31,000 for the 2m option up to $50,000 for the 3m option.

SCHEDULE

As stated above the schedule was consulted to ensure that no changes to the critical path would take place. Below is the atrium construction portion of the schedule.

PSU - HUB Expansion Project 10-16-12U - Project ID: HUB Expansion — Current Data Date: 10-16-12

Activity ID	Activity Name	Rem Dur	Total Float	Start	Finish	Predecessors	Successors
4280	Demolition B2 Lobby Interiors	15	231	06-06-13	06-26-13	4240, 4220	4300
4300	F/R/P B2 Lobby Foundations	20	205	08-01-13	08-29-13	4280, 3220	4320
4320	Erect Structural Steel B2 Lobby @ Robenson	15	205	08-29-13	09-19-13	4300, 4034	4322, 5200
4322	Detail Structural Steel & Deck B2 Lobby @ Robenson	10	230	09-19-13	10-03-13	4320	4400, 4400
4400	Overhead Rough Ins B2 Lobby	15	230	10-03-13	10-24-13	4322, 4322	4420
4420	Entrance to B2 Lobby	20	230	10-24-13	11-21-13	4400	4440
4440	Wall Finishes B2 Lobby	20	230	10-31-13	11-28-13	4420	4460
4460	Floor Finishes B2 Lobby	15	230	11-28-13	12-19-13	4440	3240
Atrium / Courtyard							
5700	Relocate Electrical System	5	210	06-21-13	06-27-13	2800	5720
5720	Excavate Courtyard & New Mechanical Room	20	210	06-28-13	07-25-13	5700	5740
5740	Underslab Utilities @ Courtyard / New Mechanical	10	210	07-26-13	08-08-13	5720	5760
5760	F/R/P Foundations / Walls Courtyard / New Mechanical	35	210	08-09-13	09-26-13	5740, 5604	5780
5780	Erect Structural Steel Canopy Roof	20	205	10-03-13	10-31-13	5760, 5200	5800
5800	Detail Structural Steel Canopy Roof	20	205	10-17-13	11-14-13	5780	5820
5820	Metal Deck Canopy Roof	10	205	11-14-13	11-28-13	5800	5840, 5860
5840	Roofing Canopy Roof	10	205	11-28-13	12-12-13	5820	5870
5860	Curtain Wall Canopy	30	210	11-28-13	01-09-14	5820	5870
5870	Skylight Canopy Roof	30	205	12-12-13	01-23-14	5840, 5860	3240
Courtyard Interiors							
8600	Overhead Rough Ins Courtyard Interior	40	0	04-10-14	06-05-14	8250	8620, 8700
8700	Stairs / Rails Courtyard Interiors	45	5	05-08-14	07-10-14	8600	8640
8620	Frame Walls / Drywall Courtyard Interiors	30	0	06-05-14	07-17-14	8600	8640
8640	Wall Finishes Courtyard Interiors	40	0	07-17-14	09-11-14	8620, 8700	8660, 9200
9200	Relocate Temporary Work Partitions	10	0	09-11-14	09-25-14	8640	9220



Start Date: 07-18-12
Finish Date: 06-18-15
Data Date: 10-16-12
Run Date: 10-16-12 14:20
Page 7 of 10

PSU - HUB Expansion Project 10-16-12U
WBS Full Schedule - Basic Current

Gilbane

Date	Revision	Checked	Approved
10-16-12	For Review and Comments Includes 09/26/12 ...	Teddy	

With all of the items under the atrium/courtyard section having at least 200 days of float, there should be plenty of room for the addition of the overhang and increases install time for the electrochromic skylight glazing. The other item that was checked was the tower crane, since it is needed to install the both the overhang and skylights. The removal of the tower crane is set for the 10th of April 2014, whereas the items in the atrium needing the tower crane will be completed by the 23rd of January 2014. The float on the tower cranes removal is set at 150 days, which should leave plenty of time for completion of the additional items without any shift in critical path.

CONCLUSION

After pricing out the four potential scenarios and Base Case, it was determined that all of the purposed designs will cost more than the Base Case. This extra cost to the project ranges from $100,000 to $120,000. Although it is costly to add the elements in the purposed solutions, overall it still only accounts for a 0.27% increase in cost for the $44.6million project. Now that the four options have been evaluated across three disciplines, a comprehensive analysis can take place to get a complete picture on the overall performance for each option.

INTEGRATED DESIGN ANALYSIS

INTRODUCTION

This section explains the integrated performance analysis of each of the studies in the sections above. With this data a complete evaluation of each option can take place. The main goal of this study is not to choose the option with the best performance, but to choose the one that best fits the project and the limitations that are inherent with any design. With this final step, the design team will be able to make an informed decision based on the data gathered from each of the studies. Moving forward, the team should have a good idea of what they're getting with whatever option is chosen.

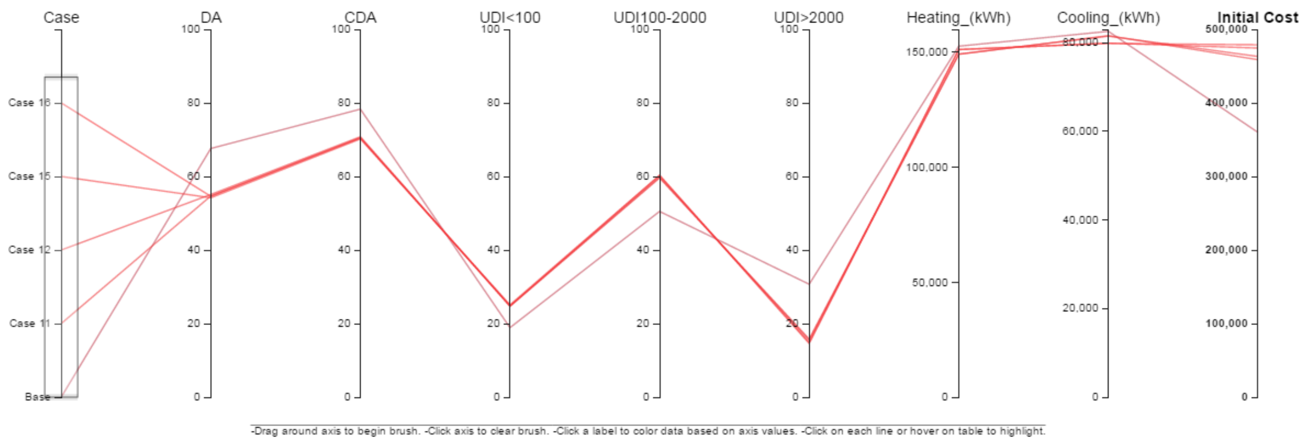
GOALS

1) Perform a comprehensive analysis of each option
2) With the data from this study, as well as the previous studies, make an informed decision as to which is the best option for the project

METHODOLOGY

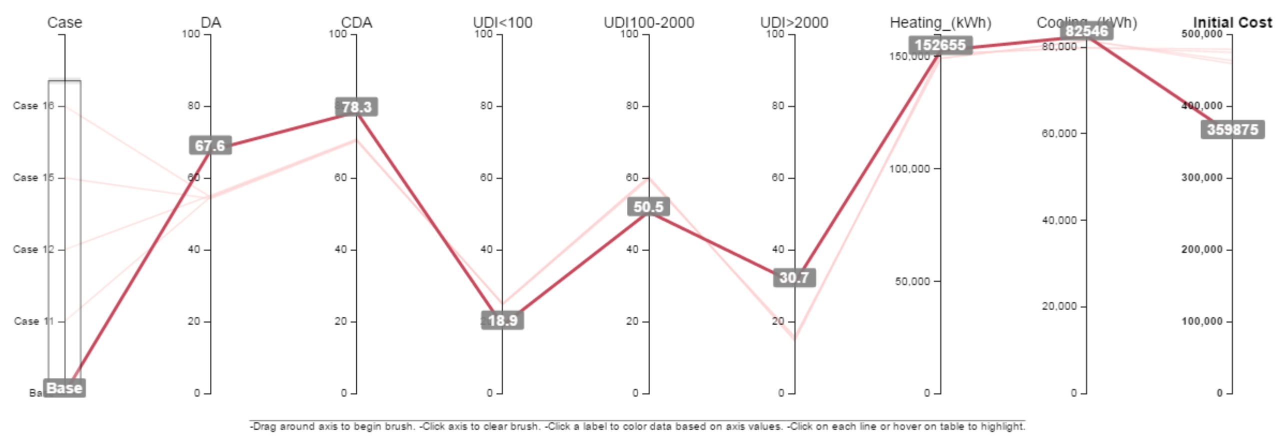
To assist with the visualization of the data, Pollination will be used to analysis the cases side by side. By using Pollination, each performance metric can be compared and the options that don't meet the criteria set can be easily excluded.

POLLINATION ANALYSIS



Case	DA	CDA	UDI<100	UDI100-2000	UDI>2000	Heating_(kWh)	Cooling_(kWh)	Initial Cost
Base	67.6	78.3	18.9	50.5	30.7	152655	82546	359875
Case 11	54.7	70.5	24.8	59.8	15.5	149122	81556	458705
Case 12	55.1	70.8	24.7	59.6	15.8	149244	81473	463105
Case 15	54.2	70.2	25.1	60.3	14.6	151153	79882	474523
Case 16	54.6	70.5	24.8	60.3	14.9	151259	79832	478923

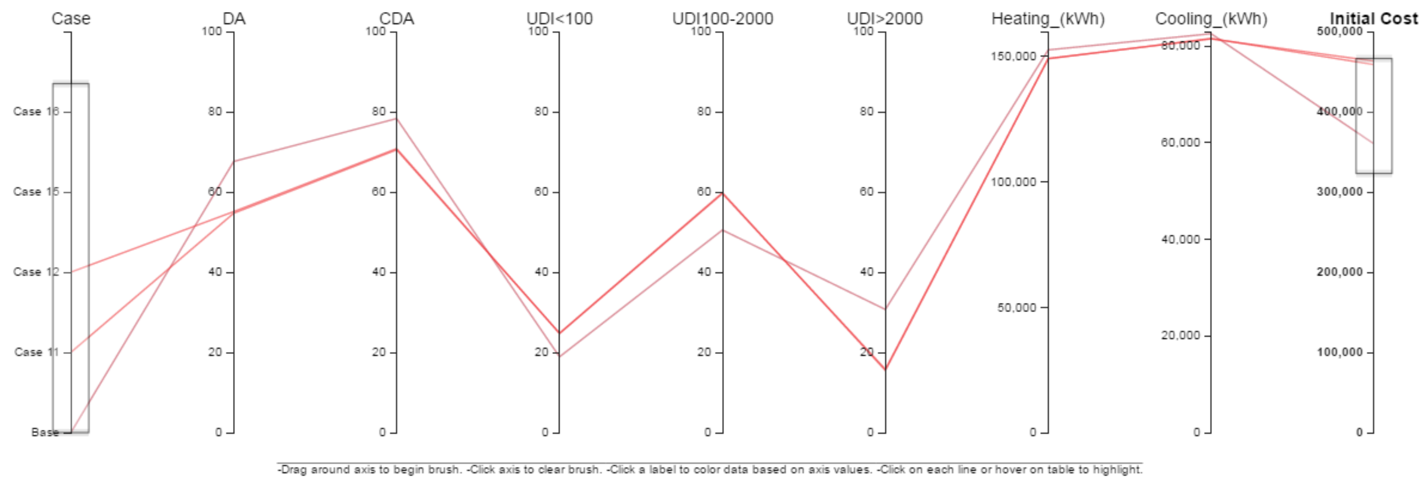
Above is the Pollination interface. Each case is listed on the left, which each line intersecting each axis at that cases respective value.



Case	DA	CDA	UDI<100	UDI100-2000	UDI>2000	Heating_(kWh)	Cooling_(kWh)	Initial Cost
Base	67.6	78.3	18.9	50.5	30.7	152655	82546	359875
Case 11	54.7	70.5	24.8	59.8	15.5	149122	81556	458705
Case 12	55.1	70.8	24.7	59.6	15.8	149244	81473	463105
Case 15	54.2	70.2	25.1	60.3	14.6	151153	79882	474523
Case 16	54.6	70.5	24.8	60.3	14.9	151259	79832	478923

Here the Base Case is highlighted, showing its' line, intersecting each axis based on the value inherent to that case. For instance, DA is 67.6, CDA is 78.3, etc.

Along each axis ranges of values can be selected to be shown as seen below.



Case	DA	CDA	UDI<100	UDI100-2000	UDI>2000	Heating_(kWh)	Cooling_(kWh)	Initial Cost
Base	67.6	78.3	18.9	50.5	30.7	152655	82546	359875
Case 11	54.7	70.5	24.8	59.8	15.5	149122	81556	458705
Case 12	55.1	70.8	24.7	59.6	15.8	149244	81473	463105

In this case the two more costly cases were excluded by selecting the range of costs that were of interest. Looking at the three cases remaining, Base Case, Case 11 and Case 12, the other performance metrics can be evaluated. The main factor that sets Case 11 and Case 12 apart are the cost, since all other metrics are nearly identical. This leads to the conclusion that Case 11 would be the optimal case to implement. It performs better than the base case in terms of daylighting and mechanical loads, as well as being the cheapest of the four proposed solutions.

To actually implement Case 11 would require an extra $100,000 added to the project with no practical payback, since the energy savings only amounts to $300 per year. In the grand scheme, $100,000 only equates to 0.22% of the total cost of $4.6 million. This cost could be offset by the fact that the space will have less potential for glare and be more comfortable overall.

CONCLUSION

The HUB addition was meant to better connect the building to campus. Building on this idea of connection, the lighting concept and later an entire integration study were based around this idea of connections.

Starting with the outdoor walkways, the lighting helps distinguish campus from the building, as well as guide people to the entryways, hence connecting people to the building. The change in general illumination marks the transition from campus to the building, while the highlighted entryways and Light Tape™ façade lighting create a beacon that adds a level of interest, as well as beckons passerby's to investigate.

The atrium lighting highlights areas which were most likely to foster conversation and interaction between people and events within the space, connecting people to people. A hierarchy is created by highlighting these landmarks within the space, helping to differentiate transition and conversation areas.

The bookstore lighting promotes a journey through the space, ultimately leading to the book section, and abstractly represents the learning process, thus connecting people to knowledge. Five stages of the learning process are represented by the lighting design, starting with the initial grasping of concepts and ending with synthesizing ideas into more complex and new information.

Finally, the flex theater connects people to emotions by providing a theatrical fixture layout with various levels of control for any experience level that the user might be. The three layers of control allow for different amounts of the lighting system to be controlled based on the needs of the user. This ranges from control of just the house lights to full control of the theatrical layout within the space.

To reflect the new lighting design, branch circuits were redone or eliminated. Additionally, several panelboards were resized based on more realistic demand factors than were originally used. This lead to a potential $18,000 initial cost savings over the current system.

Finally, an integrated daylighting, mechanical, and construction management study was conducted. Using parametric modelling tools and analysis, 16 potential daylighting solutions were narrowed down to 4. Through further analysis a final solution was reached base on the performance in each disciple's metrics. In all honesty, this analysis was something that took a great deal to learn how to do. The learning curve was steep, however it was beyond worth it. Looking past thesis and graduation, these tools and techniques allow for the integration of various disciples into one model. Parametric constraints and variables make this a very powerful design tool. Knowing how to do these types of analysis will allow engineers to design with architects, influencing designs from the beginning, rather than being called in to fix problems that could've been avoided. This truly is the epitome of what we as architectural engineers strive for, to make a real difference in design and work with designers and architects from the moment the first idea is jotted down to the moment the ribbon is cut.

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Dr. Richard Mistrick
Professor Kevin Parfitt
Dr. Moses Ling

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SOFTWARE

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- Elumtools
- Rhino 5
- Grasshopper
- Ladybug
- Honeybee
- Adobe Photoshop CS6
- LBL Window

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