Harris Theater for Music and Dance

Chicago, IL

Lindsey Beane
Lighting/Electrical

Primary Project Team

Architect: Hammond Beeby Rupert Ainge
Associate Architect: Kathryn Quinn Architects
Project Manager: The Rise Group
MEP: Environmental Systems Design Inc.
Acoustical Consultant: Jaffe Holden Acoustics
Theatre Consultant: Schuler & Shook

Construction

Size: 130,000 sf
Auditorium seating: 1525 people
Number of Stories above grade: 1 story above grade with 8 partial stories total
Construction Dates: Feb. 2002-Nov. 2003

Lighting

- Colored Fluorescents for color identification
- Energy efficient metal halide in auditorium
- Linear Fluorescent on working half of theater
- Specialtly theater and stage lighting
- Accent lighting in lobby with color filters

HVAC

- (4) AHUs range from 20,000 cfm to 45,000 cfm
- (16) two pipe fan coil units
- Oversized ductwork for strict acoustics

Structural

Foundation: caissons, grade beams, and concret slabs.
Walls: precast concrete
Other structural materials: Steel framing
W shape beams range in size and weight

Electrical

Power distribution: 480/277V and 208/120V
Summary: 35 panel boards
Lighting Loads: 208/120V system
Mechanical Loads: 480/277V system
Emergency system: 425KVA/340KW generato

Specialty

- Acoustical systems in auditorium
- Sound system for performances
- Dimming rack controls for stage and auditoriu

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Table of Contents

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Executive Summary

The following report is an analytical approach to describe the details of a new lighting design for a few spaces of the Harris Theater for Music and Dance. The lighting design was given the most consideration throughout this analysis, and was integrated into a construction management cost study as well as an acoustical study. The electrical design is also affected by the lighting design, so the changes to that system are also included in this report. The four main sections of the report are described below.

The Harris Theater for Music and Dance provides spaces for a number of different functions. The spaces I focused on to analyze the lighting design are the entrance, lobby, theater, and main offices. This variety of spaces provides an opportunity to make design considerations for a number of functions. In the following report there is an in-depth analytical approach to lighting designs for each of those spaces. Each space describes the design criteria, themes, equipment, and layouts used for the design. Following initial design considerations is a detailed report of the performance of each space. The spaces were analyzed for performance requirements that were set at the beginning of the design including: illumination, aesthetics and power density requirements. An analysis of the performance is found at the end of each design summary.

The new design required a revision to the circuiting information and lighting controls which is detailed in the report. The lighting design also includes plans for controls which drove the circuiting plan and can be found in the electrical depth section of this report. Also, after studying the layout of distribution panels it was determined that some panels could be consolidated to reduce installation and material costs which is found in the electrical depth section of the report.

The next two sections are an acoustical and cost analysis study. The acoustical study was driven by an architectural change needed to accommodate the lighting design, and the cost analysis study is also related to the lighting design. The cost analysis compares the existing design of the typical lobby lighting to the design I have studied an analyzed in this report.

Finally, there is an end discussion about the designs plan throughout this report. The discussion describes the difficulties and successes reach through designing process and documentation. Overall these designs were determined to be fitting although the cost of some items was higher than anticipated.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Site and Architecture

The Harris Theater for Music and Dance is a new building located in the heart of Chicago in Millennium Park. Hammond Beeby Rupert Ainge Architects planned the theater to have a simple layout and classy feel. The theater was completed construction in November 2003, and is now hosting mid-sized performance groups of operas, choirs, and ballets. With a budget of $39 million the theater provides 1525 seats and stretches a full 6 stories underground. The building also houses theater staff offices and accommodates visiting organizations with dressing rooms, storage and lounge areas. The building is conveniently accessed by patrons on the street or through the shared underground parking garage at Millennium Park. The theater was designed for great performance and a minimalist approach to finishes allows for affordable tickets.

The majority of the building is underground, so the exterior walls are load bearing precast concrete. There is one portion of the building above ground which is the entrance to the lobby space. The envelope at the lobby entrance is precast concrete for the outside walls, and the front of the entrance is glazing with minimal steel supports. The finishes in most spaces are simple, for instance, painted precast concrete and sealed concrete floors.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lighting Depth

Introduction to Lighting Depth

For the lighting depth design I have chosen four spaces of the theater to complete a design analysis of the architectural lighting. The four spaces I have chosen to design for are the entrance, lobby, auditorium seating, and main offices. The design addresses lighting quality, aesthetics and power density. A schematic design idea was proposed and critiqued by professionals to collaboratively makeup the design found in this report. Design details are illustrated in the report including calculation grids, equipment details, renderings and control information. To really get the essence of the design the entrance, lobby, and offices were rendered to a realistic quality. Due to the complexity and size of the auditorium the house lighting was analyzed through calculations only. The following section begins with the details of the auditorium house lighting. The smaller segments of the lighting depth section are organized as design criteria, lighting schedules, lighting layouts, calculations, renderings and then they are followed with a performance discussion.

For questions about the details of the lighting design please reference Appendix A. This appendix includes enlarged lighting layouts, cut sheets for fixtures, lamps, and ballasts as well as existing conditions.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Entrance

Design criteria

- Remove view of sources from exterior
- Reduce the washed out appearance of the artwork
- Provide a level of dimensionality in this tall open space
- Provide of means of attraction to catch the attention of pedestrians

Design Theme and Mood

The main level of the lobby serves as an entrance and building identifying façade. The entrance is the only portion of the theater visible from the street level and park area. This space is the most important because it gives the first impression of the theater. The artwork hanging just inside the glazing serves as an announcement that the building is a host for the arts. The entrance and lobby space should be very inviting and elegant. Cool color temperatures (4100K) should be used to work well with the daylight entering this space at the start of performances.

Lighting Layout

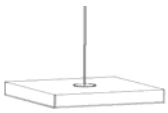
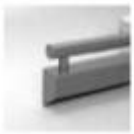
The entrance space ties into the lobby areas on this first floor. The focus of this section is specifically the lighting treatment to the entrance artwork, tall open atrium and stairs. There are essentially two types of fixtures used for lighting the entrance. This in effect creates two layers of light. The first layer of light is fill light which is used to create dimensionality to this tall rectangular space. Track metal halide fixtures create a light gradient from the side walls and then meet in the center at the artwork hanging above the entrance. The center is brighter than the sides and is the highlighted by a spot fixture. The second layer of light is a spot fixture. The spot fixture will be programmed to continuously pan over the artwork to catch your attention from the exterior. All of the track fixtures are placed on the interior of the vertical columns to hide the source from the outside. Additionally, the lighting on the first set of stairs is treated with under railing fixtures. This is the final detail provided to eliminate view of sources from outside of the building.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lighting Schedule

D		**Winona Lighting P1-MC-*T5-*-MCVU-RA-*** Description: Fluorescent cove light with 1-28T5 lamp (in cross-section).	1-28T5 lamp (in cross-section)	Location: Lobby
F		**Custom Fixture 4.5' x 4.5' x 6" Square Pendant** Description: 4.5' x 4.5' x 6" Pendant with acrylic glass on sides and bottom. Top is opaque and reflective on inner side of fixture.	(4) 28T5 bi-pin linear	Location: Lobby
I		**Lighting Services Inc M2907-**** Description: 6" track-mounted metal halide accent light with 1-70W PAR38 lamp. Optics: glare shield.	1-70W PAR38 lamp	Location: Entrance
J		**Vari-lite** Description: Requires DMX controls, to be programmed with designer to pan over artwork in entrance window.	(1) 700 watt short arc lamp	Location: Entrance
M		**Cole Lighting LR 1P-T8** Description: Surface-mounted fluorescent step light with 1-T8 lamp (in cross-section). Optics: acrylic prismatic lens.	1-32T8 lamp (in cross-section)	Location: Auditorium/Entrance

Light Loss Factors

Type	Manf.	Fixture Description	Parameters	LDD	RSDD	LLD	BF	LLF
D	Winona	Linear Cove	VI, Clean 24 mo	0.77	0.85	0.94	1.00	0.62
F	Custom	4.5' x 4.5' Pendant	V, Clean, 24 mo	0.84	0.96	0.94	1.00	0.76
I	LSI	Accent Track	IV, Clean, 24 mo	0.80	0.93	1.00	1.00	0.74
J	Vari-Lite	Automated Spot Light	assumed LLF					0.75
M	Rail Lights	Linear Fluorescent	V, Clean, 24 mo	0.84	0.95	0.95	0.85	0.64

Power Density Calculation

	Type	Quantity	Watts
Track	I	16	1286.4
Automated	J	1	700
Railing	M	20	636
Cove	D	78	2574
Lg Pendant	F	8	1056

Area (s.f.)	6252.4	
Power Density	**1.57**	W/s.f.

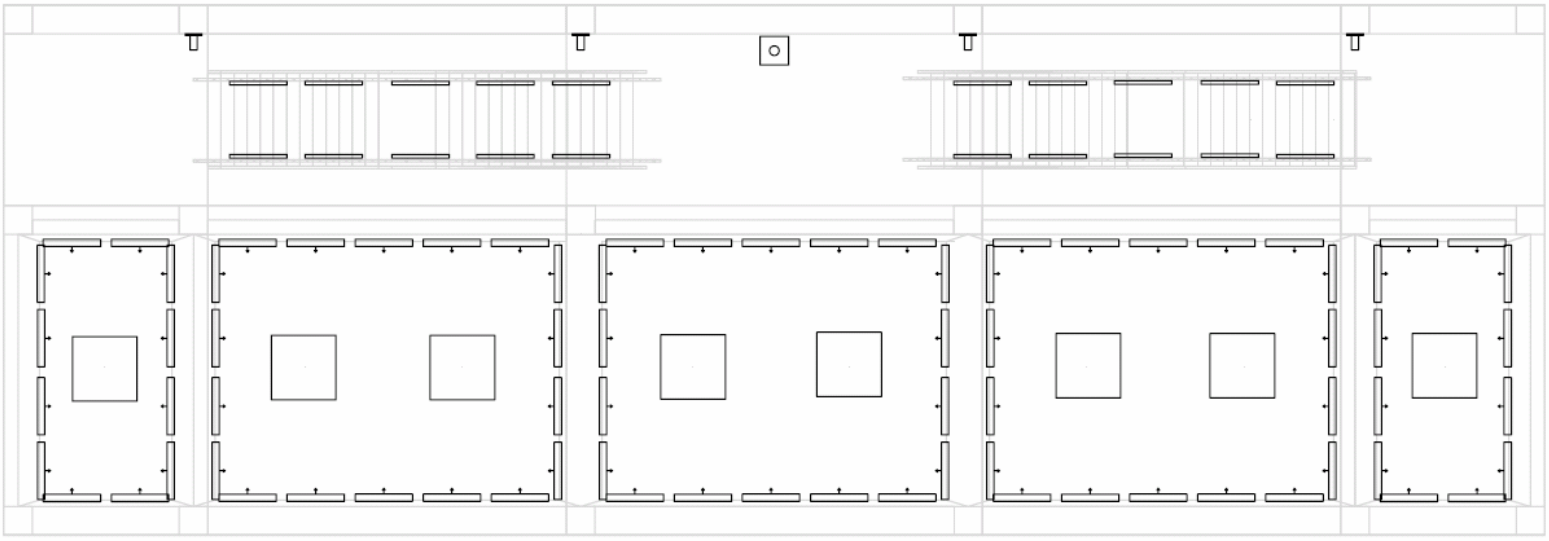
The power density for a performing arts lobby area is 3.3W/s.f. So, this design provides a very efficient lighting system for the type of space. The lighting scheme is more efficient because a very unconventional approach was taken to the lighting source. By using fluorescent dimming in place of the typical halogen in the theater, maintenance and source life issues were improved.

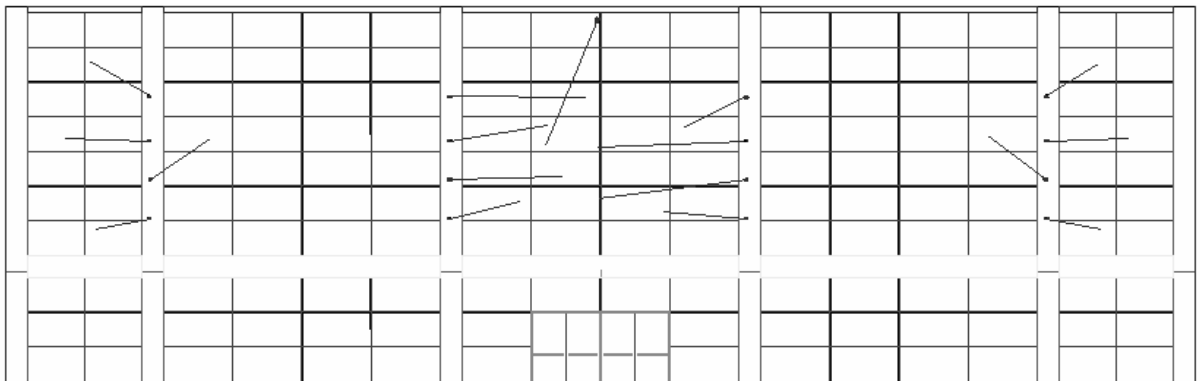
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lighting Layout





Symbol	Type
	D
	F
	G
	I
	J
	M

The top figure shows the plan view of the lighting layout for the entrance and first lobby level. Note the vertical placement of type I fixtures mounted on vertical track. The lower figure is an elevation of the entrance from the interior.

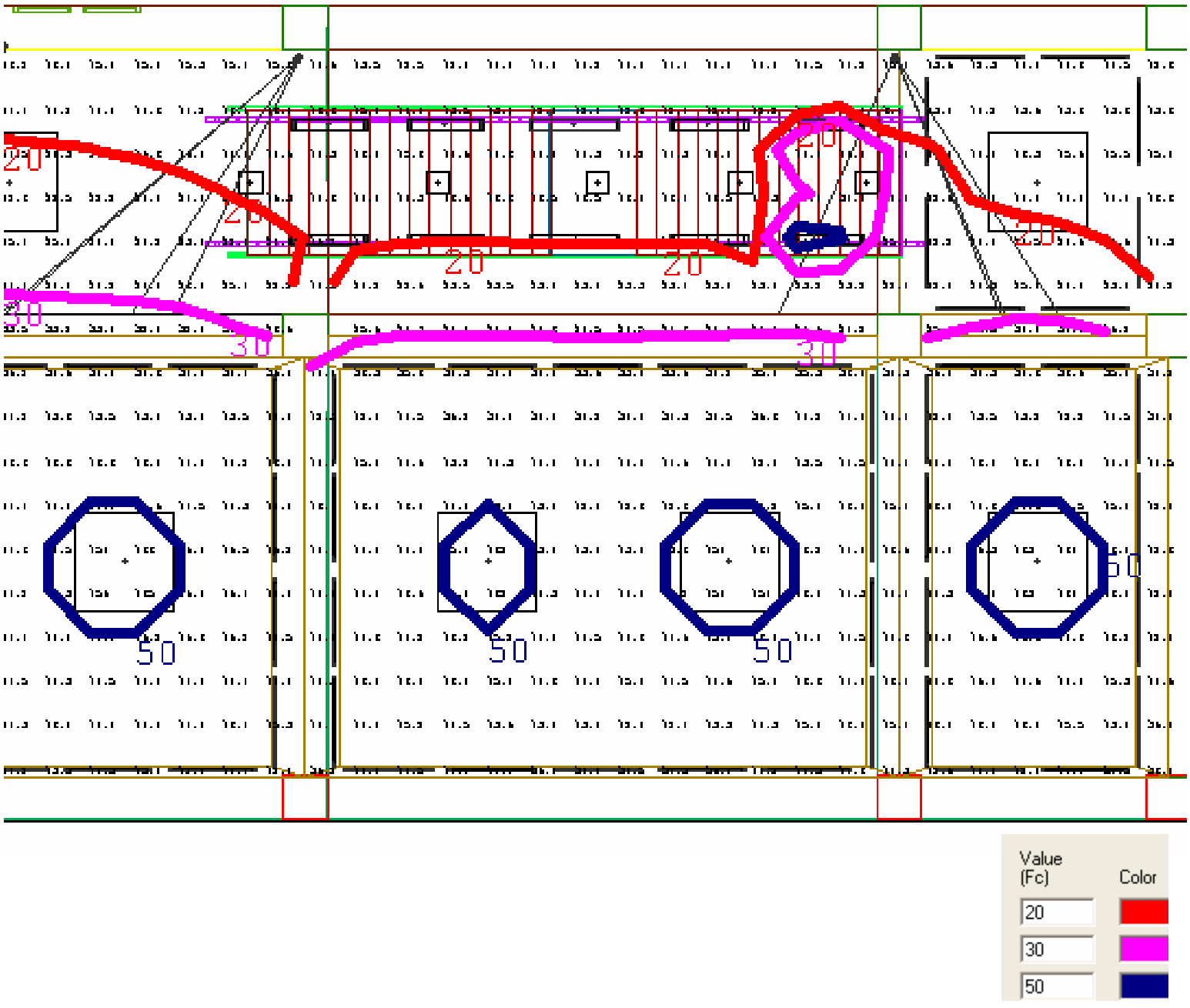
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

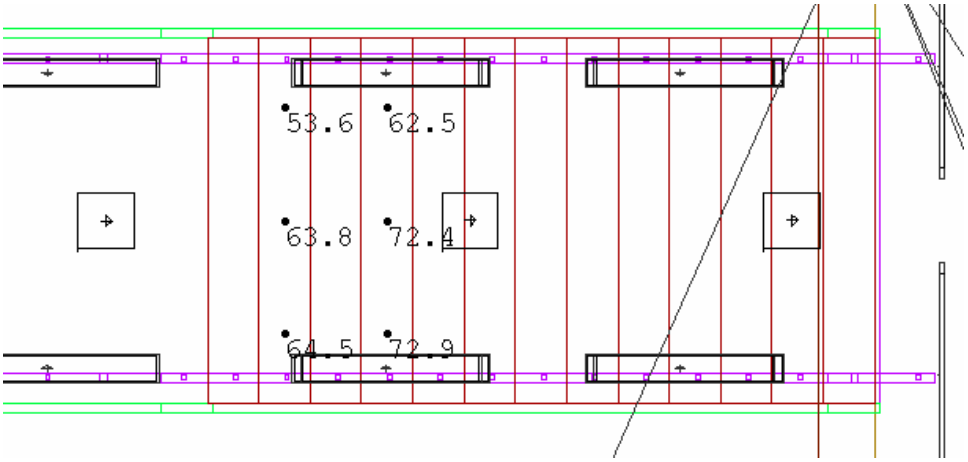
Calculation:

The performance shown below is at floor level on the first and main floor. The illuminance values of 50fc under the large decorative pendants are higher than desired. These fixtures should be dimmed in the field to provide closer to 30fc over the floor plane. The cove fixtures may also be dimmed to reduce overall lighting level on the floor.



Final Report

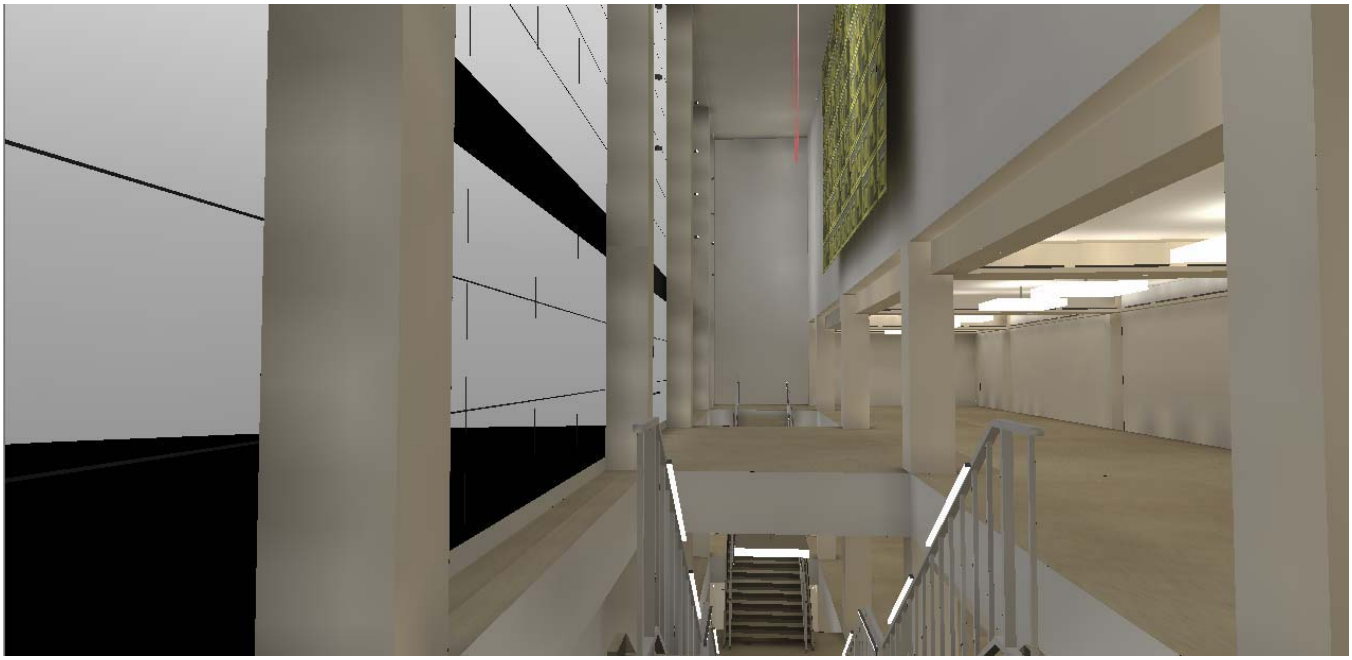
Calculation:



The performance of the under railing lighting provides an illuminance value much higher than needed. This source needs to be dimmed in the field to meet 20-30fc over the stair floor.

AGI32 Renderings

Entrance interior view



Entrance exterior view

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Discussion

The entrance provides a softly lighted façade with moving highlights. The fill light on the walls and artwork add dimension to a rectangular space while adding an element of illuminance to the floor as well. The main feature of this space is the automated spot light which will pan over the artwork to accent the work and capture the attention of pedestrians. This space has met the design criteria set forth with the exception of possible color rendering of the artwork. Upon mocking up this design there may be an option to add color filters to the metal halide sources which wash the artwork.

Typical Lobby Level

Design criteria

- Remove bare bulb fixtures to reduce glare
- Provide uniformity over main lobby areas
- Tie the first floor lobby and entrance into the lower lobby levels

Design Theme and Mood

The typical lobby levels should have a similar quality of light as the first level lobby and entrance. These spaces are used as a transition and directing space and should prepare the patron to enter the theater. The lighting should have less contrast than the entrance, but still highlight interesting architectural features. This space should feel very well finished and clean. The idea is to hide functional fixtures and add a decorative element to this minimally finished space. To keep the continuous feel of the lighting this space will be lamped with 4100K color just like the entrance.

Lighting Layout

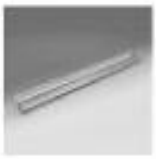
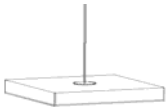
The lobby levels tie into the entrance by continuing a concealed source approach. There is an additional of decorative fixtures to add to the aesthetics of the space. The majority of the lighting contributing to the floor illuminance is indirect and the fixtures are hidden within a cove. To see the details of the cove design please reference Appendix A. The fixtures allowed in view are decorative pendants with very streamlined edges to keep the clean appearance of the simply finished space. These custom fixtures were shaped as squares to compliment the building which in many aspects is rectangular. There is a second type of decorative pendant with different proportions to provide consistency in design while tying different floors of the lobby together. The second decorative pendant is a rectangle stretched vertically and is located at the stairs. This pulls the design together from one floor to the next.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lighting Schedule

D		**Winona Lighting P1-MC-*T5-*-MCVU-RA-*** Description: Fluorescent cove light with 1-28T5 lamp (in cross-section).	1-28T5 lamp (in cross-section)	Location: Lobby
F		**Custom Fixture 4.5' x 4.5' x 6" Square Pendant** Description: 4.5' x 4.5' x 6" Pendant with acrylic glass on sides and bottom. Top is opaque and reflective on inner side of fixture.	(4) 28T5 bi-pin linear	Location: Lobby
G		**Winona Lighting 5450-10-F-*-*-*-*MB-STD** Description: Suspended compact fluorescent decorative pendant with 4-FT40 lamps.	4-FT40 lamps	Location: Lobby

Lighting Loss Factors

Type	Manf.	Fixture Description	Parameters	LDD	RSDD	LLD	BF	LLF
D	Winona	Linear Cove	VI, Clean 24 mo	0.77	0.85	0.94	1.00	0.62
F	Custom	4.5' x 4.5' Pendant	V, Clean, 24 mo	0.84	0.96	0.94	1.00	0.76
G	Winona	Decorative Pendant	V, Clean, 24 mo	0.84	0.96	0.90	0.85	0.62

Power Density Calculation

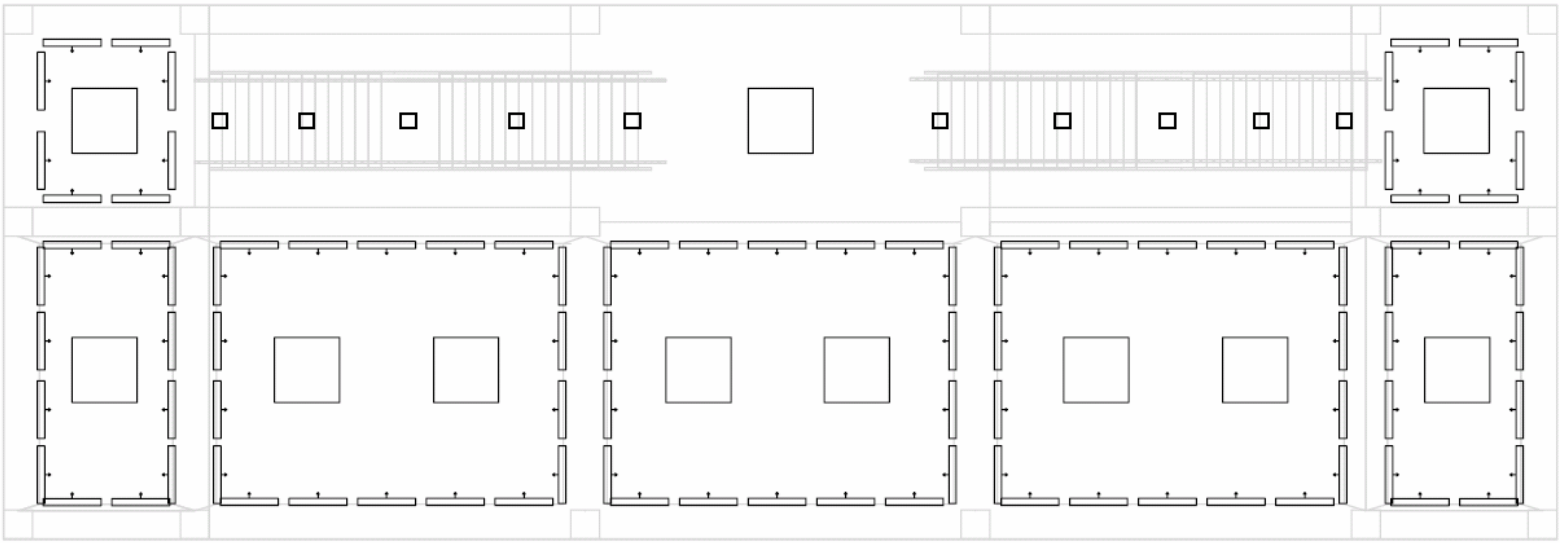
	Type	Quantity	Watts			
Cove	D	94	3102	Total Watts	**5286**	
Lg Pendant	F	11	1452	Area (s.f.)	**3977.5**	
Sml Pendant	G	10	732	Power Density	**1.33**	**W/s.f.**

Lindsey Beane

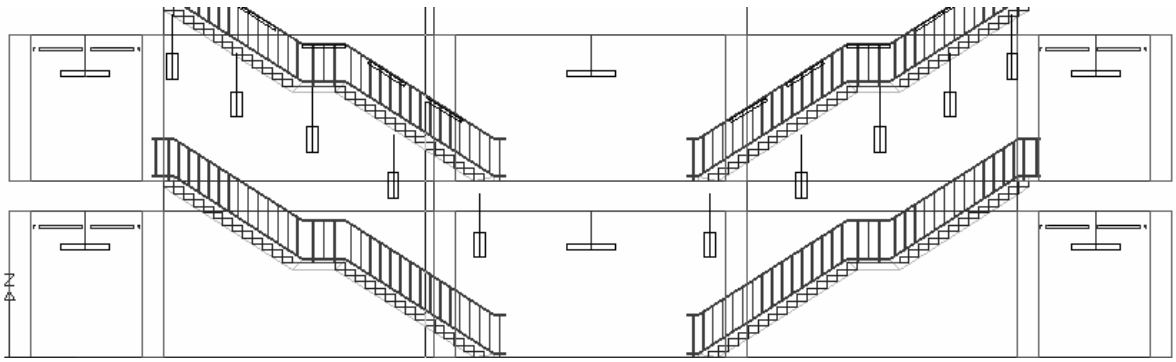
Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lighting Layout

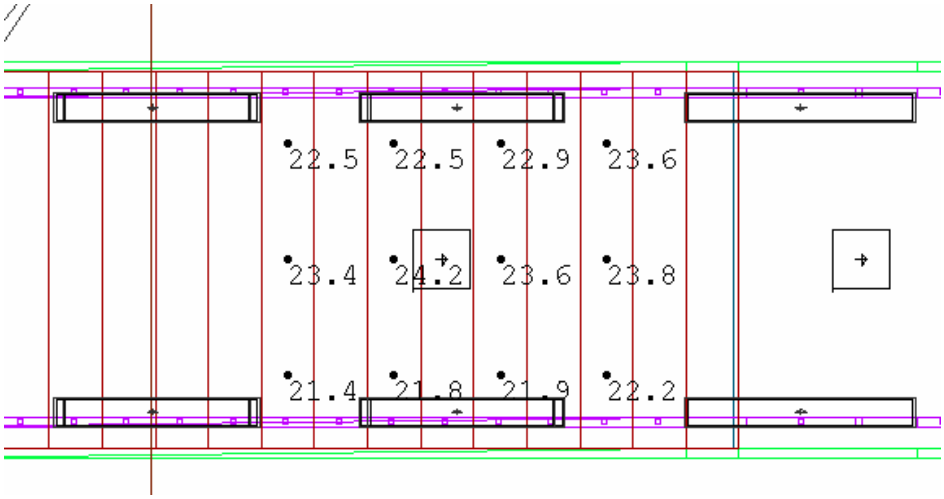


Note the placement of type G decorative pendants to pull together the lobby levels with pendants similar to type G pendants hanging the length of the lobby floors. This lighting scheme is recommended to be implemented on the floor below as well.



Symbol	Type
	D
	F
	G
	I
	J
	M

Calculations:



The decorative pendants mounted 9.5′ above the stairs provides an illuminance (fc) level that was desired. To keep continuity between the lobby floors and stairs these fixtures may be dimmed in the field.

AGI32 Renderings

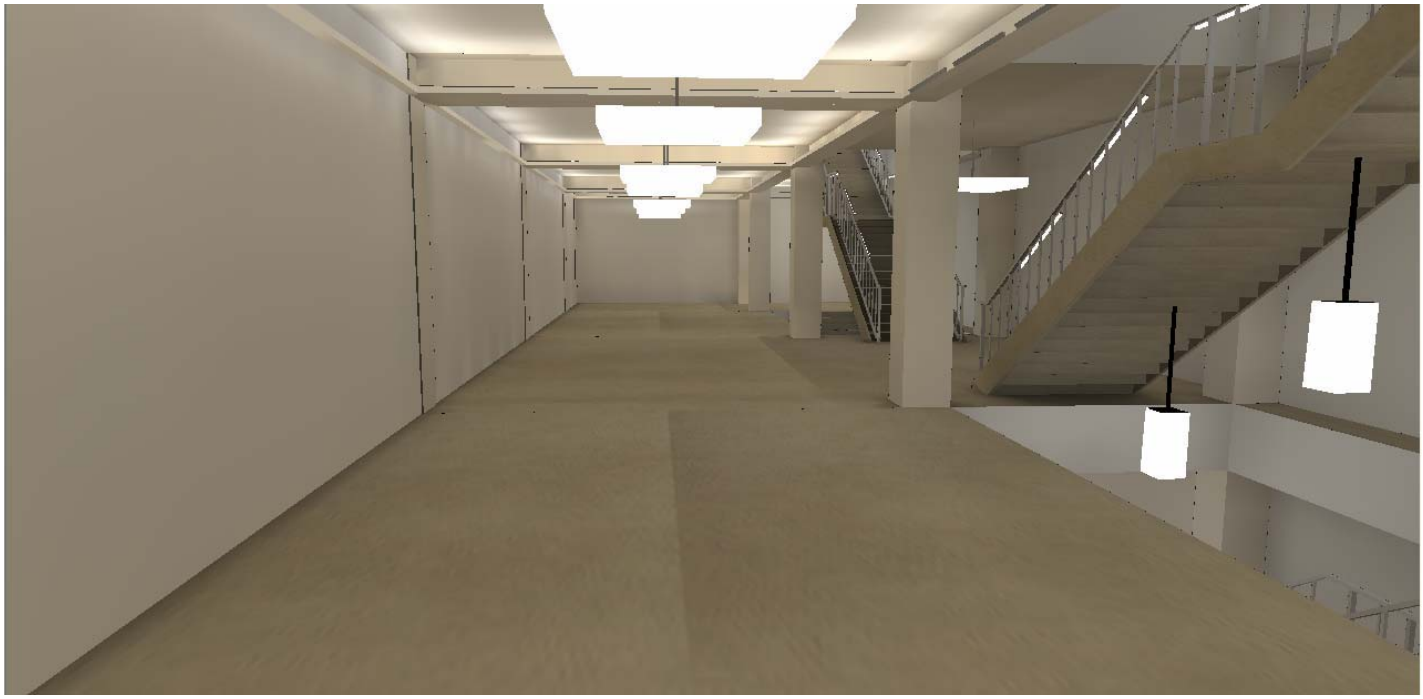
Rendering of the First Level Lobby

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Rendering of a Typical Lobby Floor



Discussion

The lighting system for this space works well to tie in the lighting design from the entrance and also improve the aesthetics of this simply finished space. The illuminance values on the floor are much higher than desired. This is mostly due to the decorative pendants placed in the center of each cove area. So, the large pendant zone will need to be dimmed 30-40% to create more uniformity over the floor area.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Auditorium Seating

Design Criteria

▪ High Contrast for accents–1:5
▪ Uniformly light the seating area to 10-20fc.
▪ Reduce the glare from high intensity sources by using more sources then the existing lighting scheme.
▪ Accent important architectural features including the acoustical reflecting towers
▪ Provide a source with longer life than halogen to reduce the maintenance level of the house lighting fixtures.

Design Theme and Mood

The theme and design chosen for this space should be dynamic in comparison to the lobby space to define the difference in functions. The atmosphere of this space is most like an evening in the park. This connects the theater to the site, Millennium Park, which is located in downtown Chicago. The finishes in the theater are all very dark which allows the lighting design to capture a feeling of outdoors at nighttime. Numerous down lights are used to resemble the way a park would be lighted or the essence of stars above. The tall acoustical panels are up lit in the way that many trees are lighted in a park setting.

Lighting Layout

Due to the complexity of the space the lighting layouts span over many pages to display the design well. There are two reflected ceiling plan layouts and three floor plans to show the lighting layouts more clearly. This space uses direct down lighting over the seating areas with a compact fluorescent source that is dimmable. Then the aisle ways and steps are used with a direct source that is concealed in the armrests and also the handrails. This keeps the reflected light to a minimum for both of these elements of the theater. There was one critical space that was difficult to locate fixtures for direct down lighting. That was right below the balcony and between to major catwalks. Without adding another catwalk it was impossible to add down lights at such a high ceiling height (65'). The fixtures could have been mounted at a height of 50', but this is still too high to reach from below. So, there are halogen theatrical fixtures mounted to an existing theatrical pipe that runs on the outer side of the balcony. There are twice as many fixtures placed then needed to meet the planned illuminance levels, because flexibility is desired in theaters for the direction of visiting companies and shows.

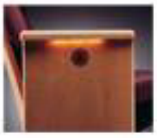
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

The following pages show the layouts of the auditorium house lighting. There are larger scale plans found in Appendix A for reference. Please see the lighting schedule for this space on the following page and use the key to note the fixture type on each page.

Lighting Schedule

K		**Delray Lighting 77143*CF** Description: 13" suspended compact fluorescent downlight with 3-CFTR42W lamps. Optics: anodized aluminum reflector.	3-CFTR42W lamps	Location: Auditorium
L		**Times Square Fresnel for Downlighting** Description: Fresnel adjustable spot, pipe mounted, black finish	100W PAR38FL	Location: Auditorium
M		**Cole Lighting LR 1P-T8** Description: Surface-mounted fluorescent step light with 1-T8 lamp (in cross-section). Optics: acrylic prismatic lens.	1-32T8 lamp (in cross-section)	Location: Auditorium/Entrance
N		**Irwin Seating Company** Description: Concealed aisle fixture. Lamp is located under armrest of seat.	4W	Location: Auditorium/Aisle
P		**Times Square Lighting 702 Borderlight** Description: (8) compartment 8' fixture with tilt and locking rotation. Lens available to color each compartment seperately.	Q250SP	Location: Auditorium

Light Loss Factors

Type	Manf.	Fixture Description	Parameters	LDD	RSDD	LLD	BF	LLF
K	Delray	13" Downlights	IV, Clean, 24 mo	0.80	0.95	0.84	0.95	0.61
L	Times Square	Fresnel	IV, Clean, 24 mo	0.80	0.95	1.00	1.00	0.76
M	Rail Lights	Linear Fluorescent	V, Clean, 24 mo	0.84	0.95	0.95	0.85	0.64
N	Aisle Lights	Low Voltage Concealed	assumed LLF					0.75
P	Times Square	Borderstrip	V, Clean, 24 mo	0.84	0.79	1.00	1.00	0.66

Power Density Calculation

Location	Type	Quantity	Watts
Main Seating			
Railing	M	10	318
Aisle	N	78	312
Borderlight	P	6	12000
Parterre Level			
CFL Downlight	K	18	2224.8
Railing	M	18	572.4
Aisle Light	N	44	176
Balcony Level			
CFL Downlight	K	25	3090
Halogen Downlight	L	10	1000
Railing	M	20	636
Aisle Lights	N	44	176

Total Watt	20505.2	
Area (s.f.)	13000	
Power Density	**1.58**	W/s.f.

The power density allowed in this space is 2.6 W/s.f. Typically the house lighting in a theater is halogen sources, but this design utilizes fluorescent dimmable sources. Some halogen sources were used for accenting and supplement down lighting, but overall this design choice has saved on the power load for this space.

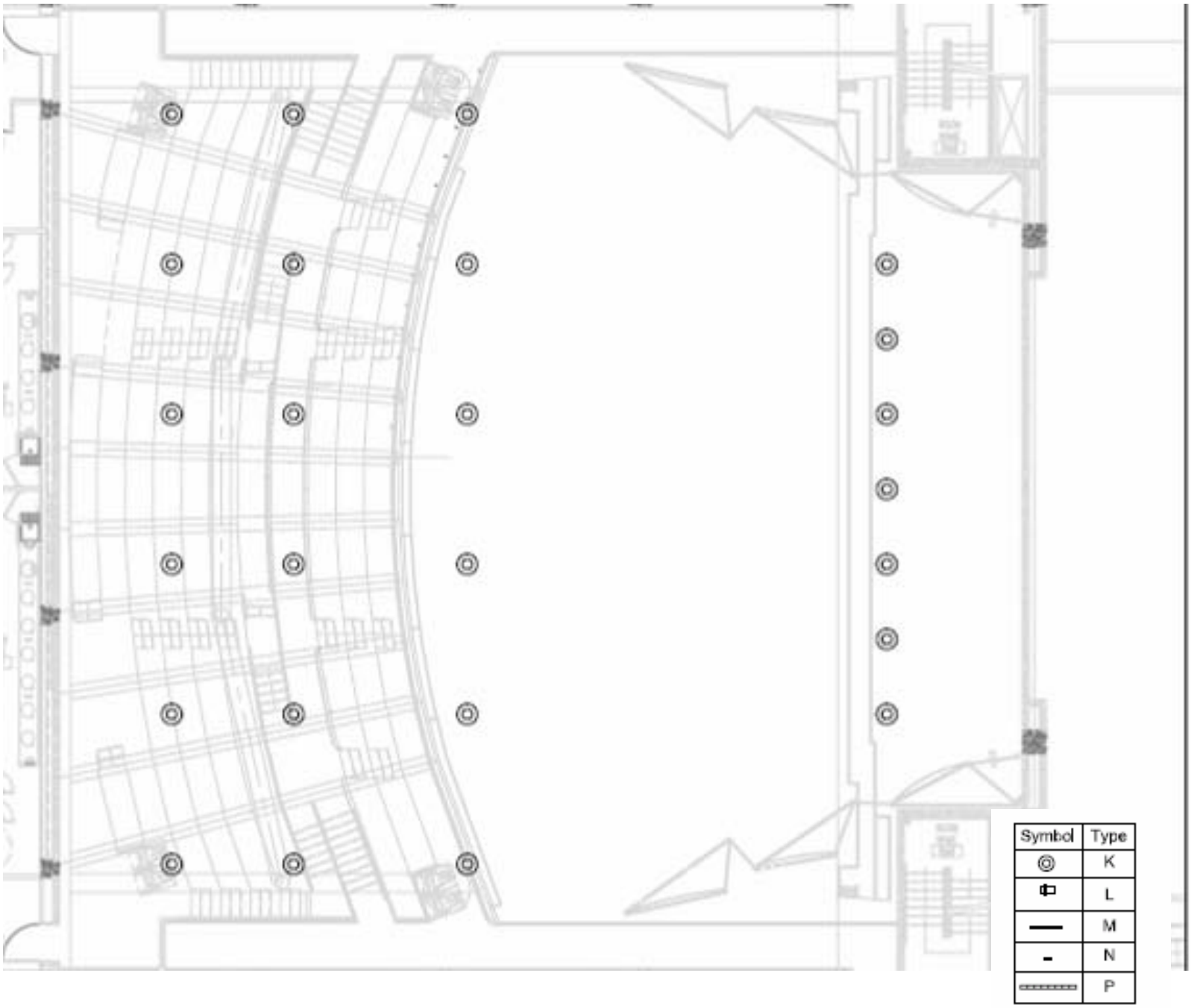
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lighting Layouts

Balcony and Main Ceiling

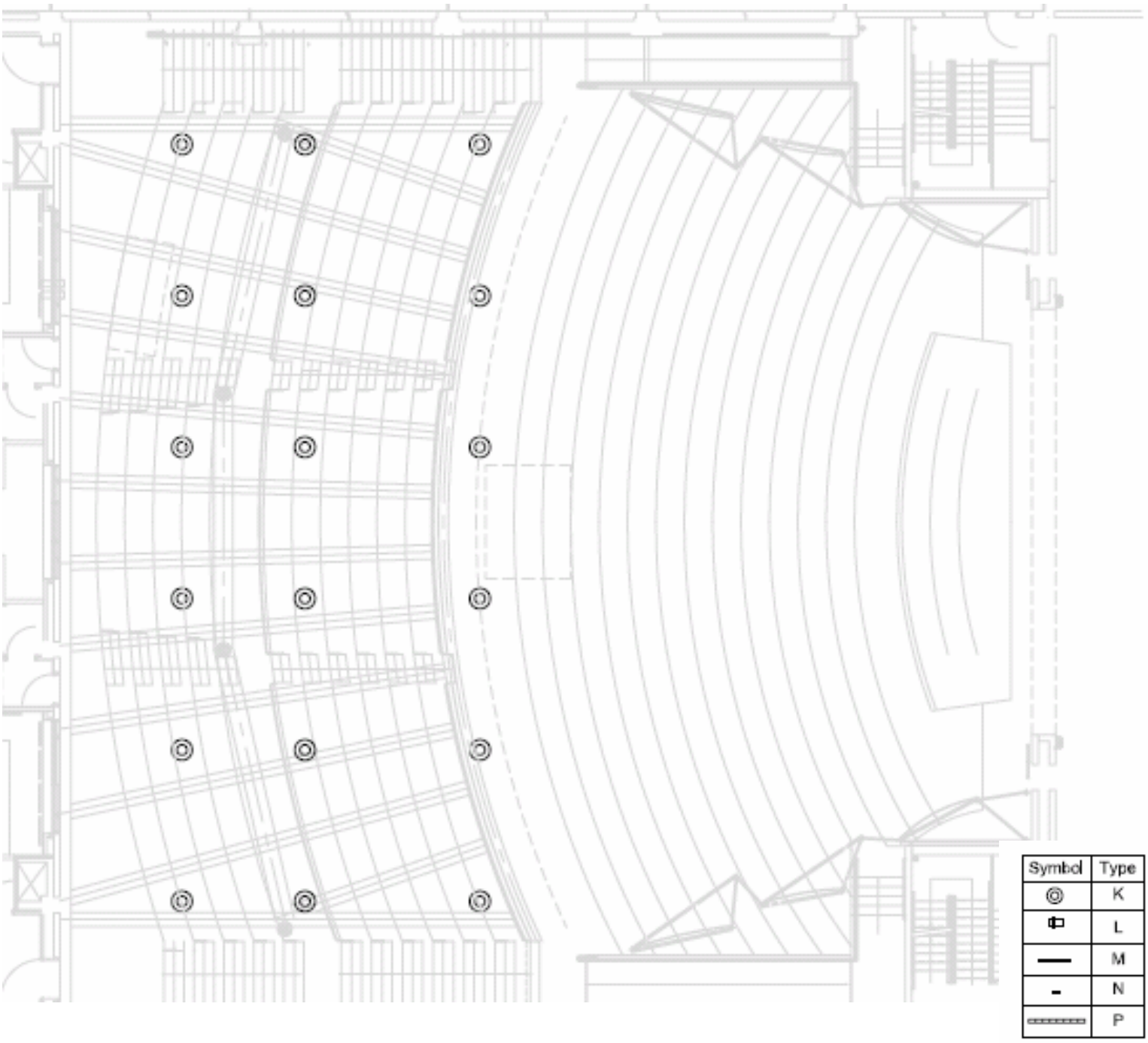


Lindsey Beane

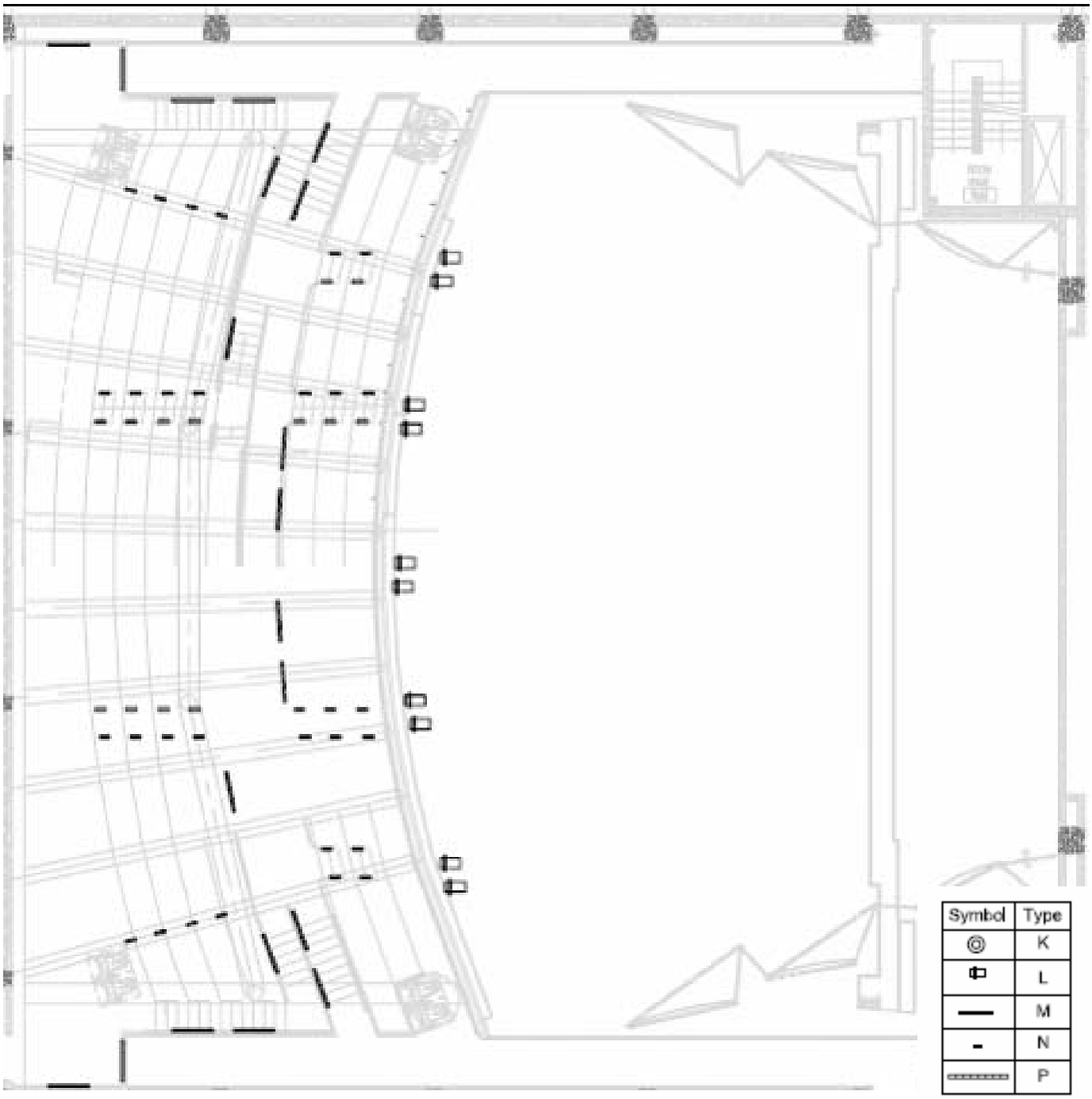
Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Parterre Ceiling



Balcony Floor Level

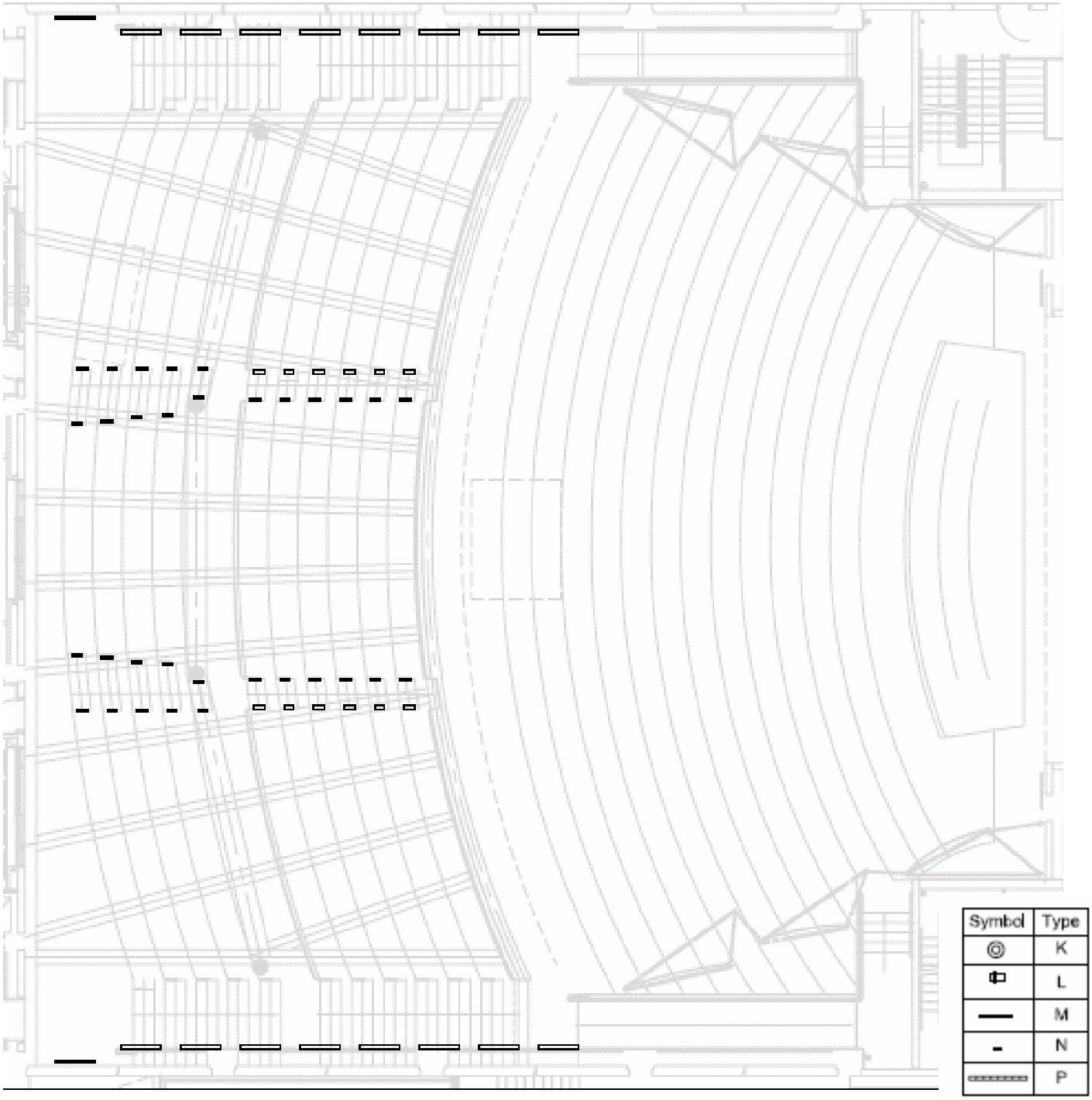


Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Parterre Floor Level



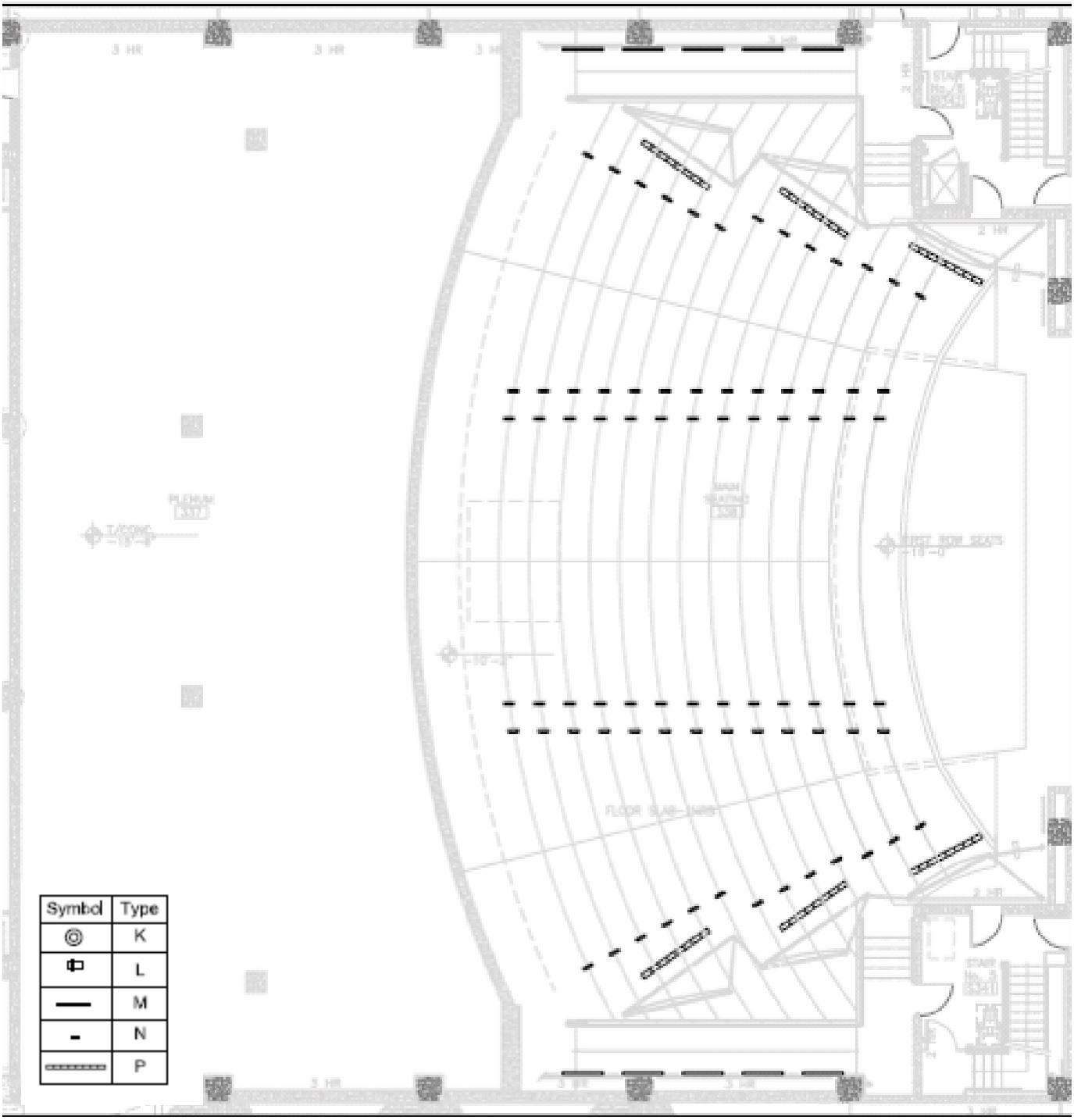
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Main Seating Area

Floor Level Lighting Plan



Lindsey Beane

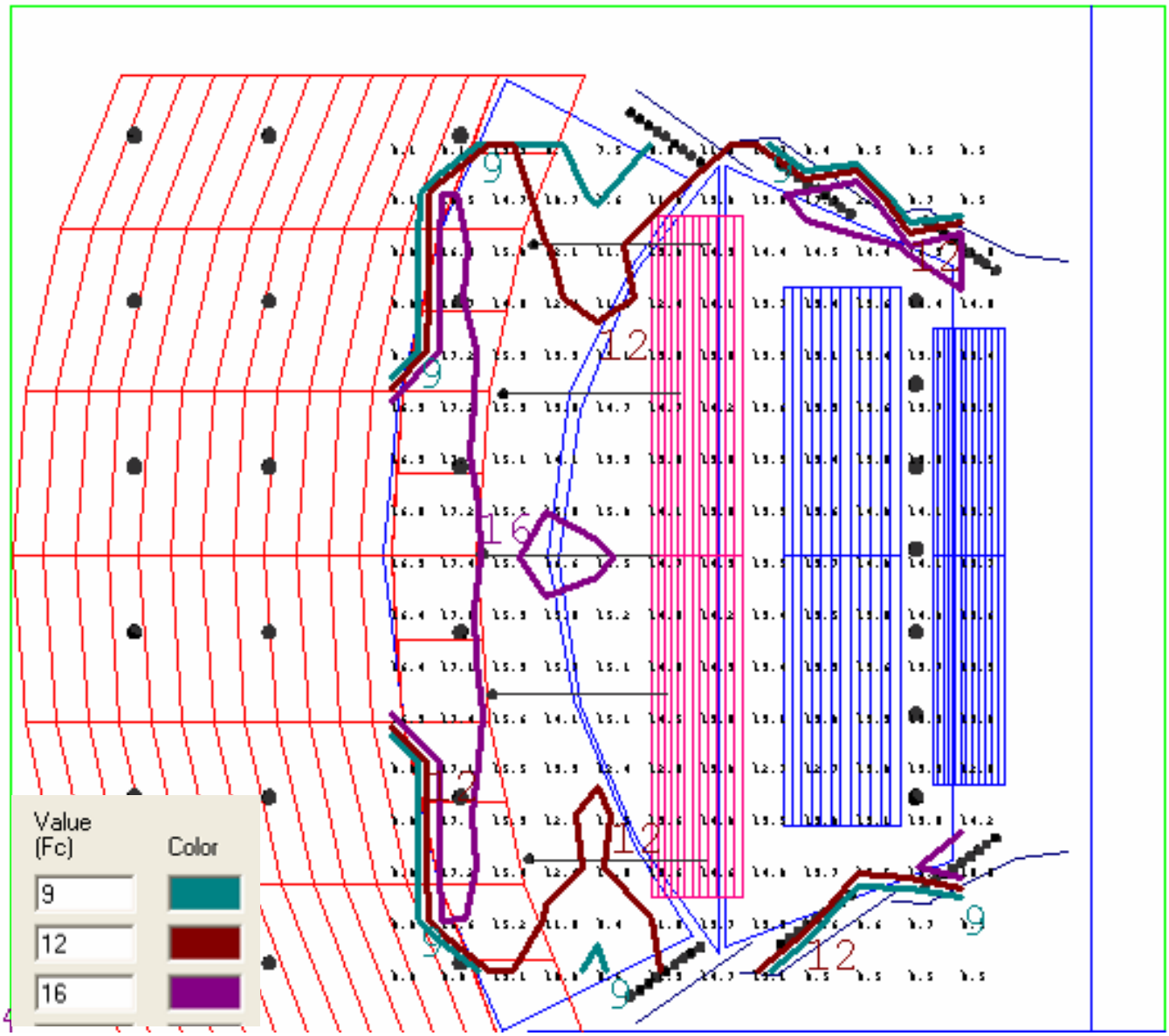
Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Calculation:

Main Seating Area

The main house lighting and tower accent lighting were calculated in this run. This performance is to show the light reaching seating area. There is supplemental aisle lighting for safety before and during performances.



Lindsey Beane

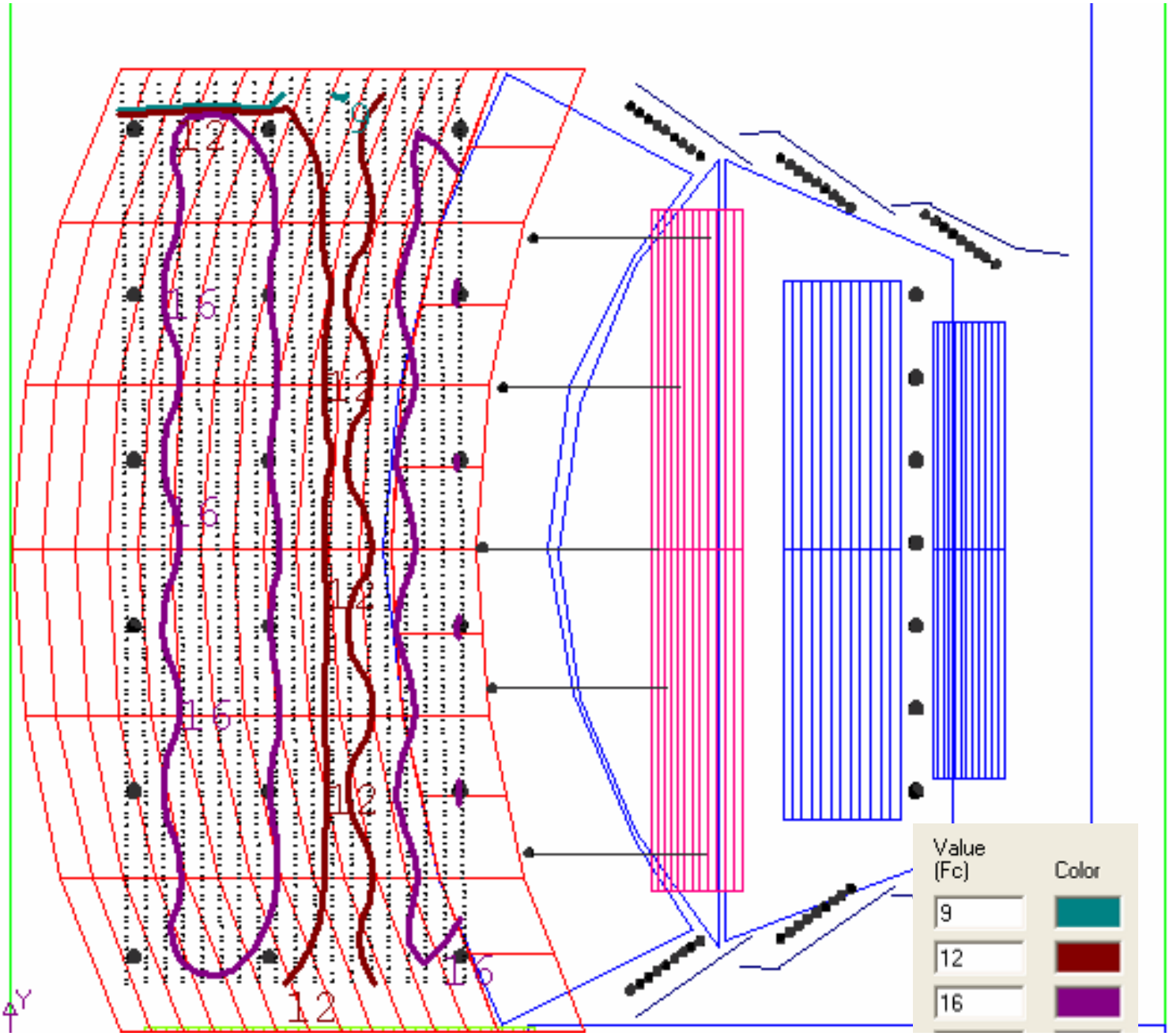
Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Calculation:

Balcony Seating Area

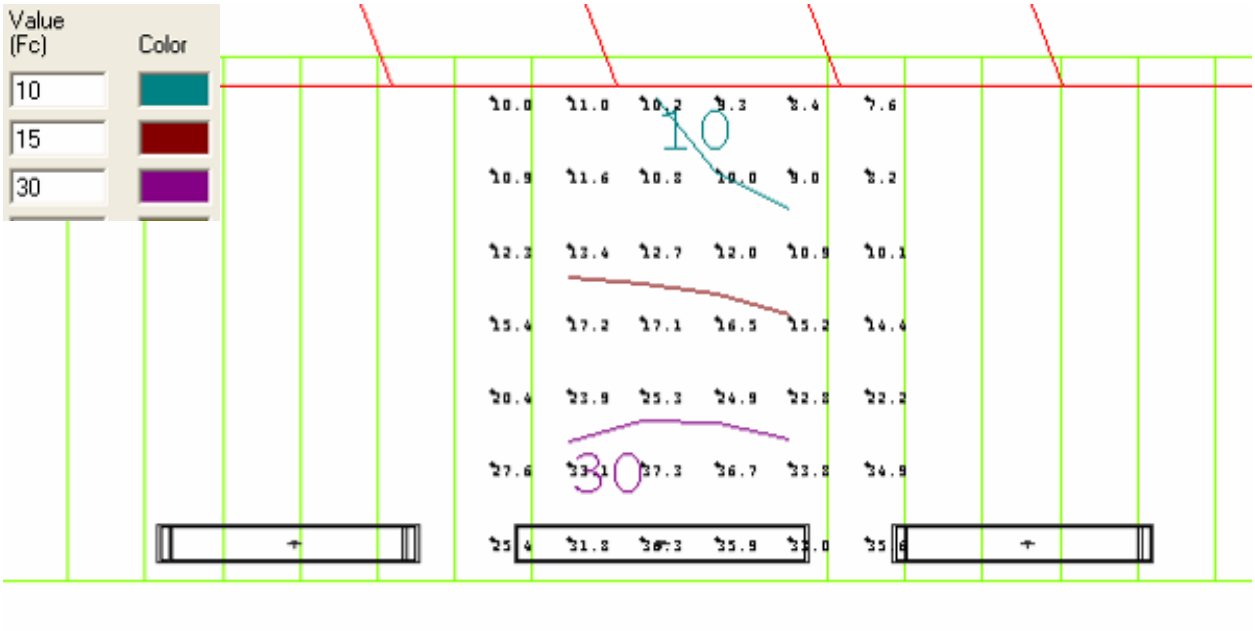
This calculation run shows the downlighting performance for the balcony. This is the same lighting layout and mounting heights as the parterre level below. The performance of the lower level will look just like this lighting situation.



Stair Study

Auditorium Main Stairways and Walkways

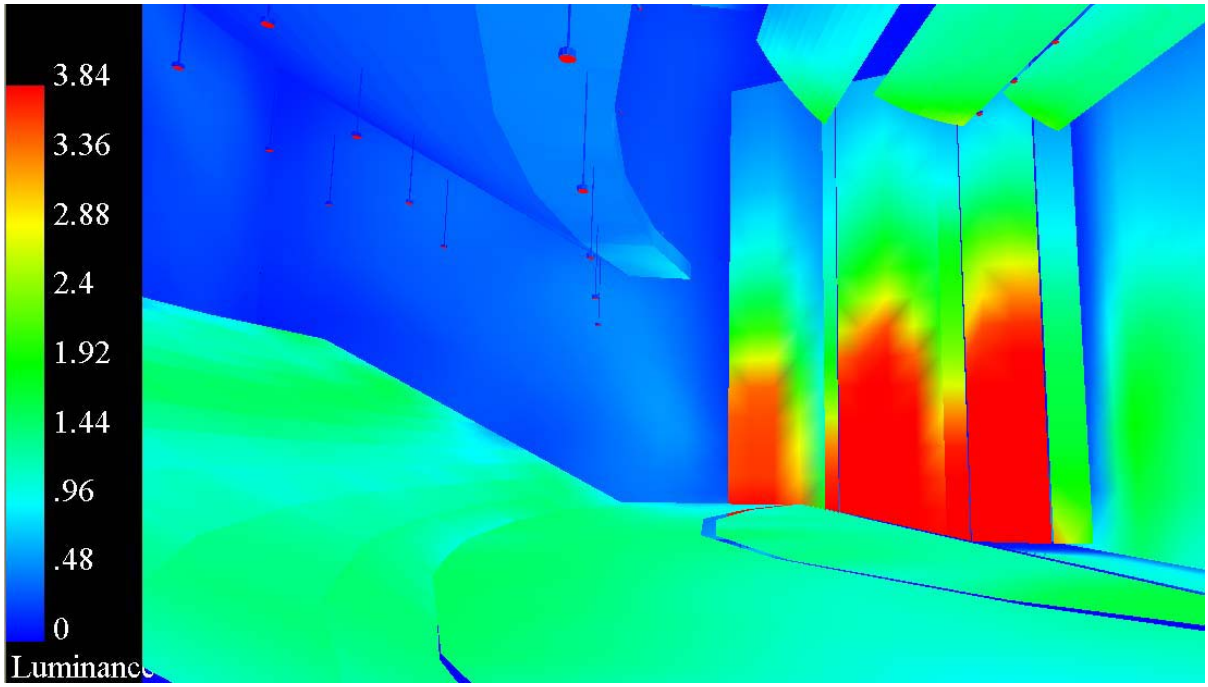
This study was to define a layout spacing distance for the railing light along the stairs. This spacing is 6′ c-c and is used along the main walkways throughout the theater seating areas. These values are somewhat high compared to the main seating area values. So, these fixtures shall be dimmed to reach 5-15fc over the width of the stairs.

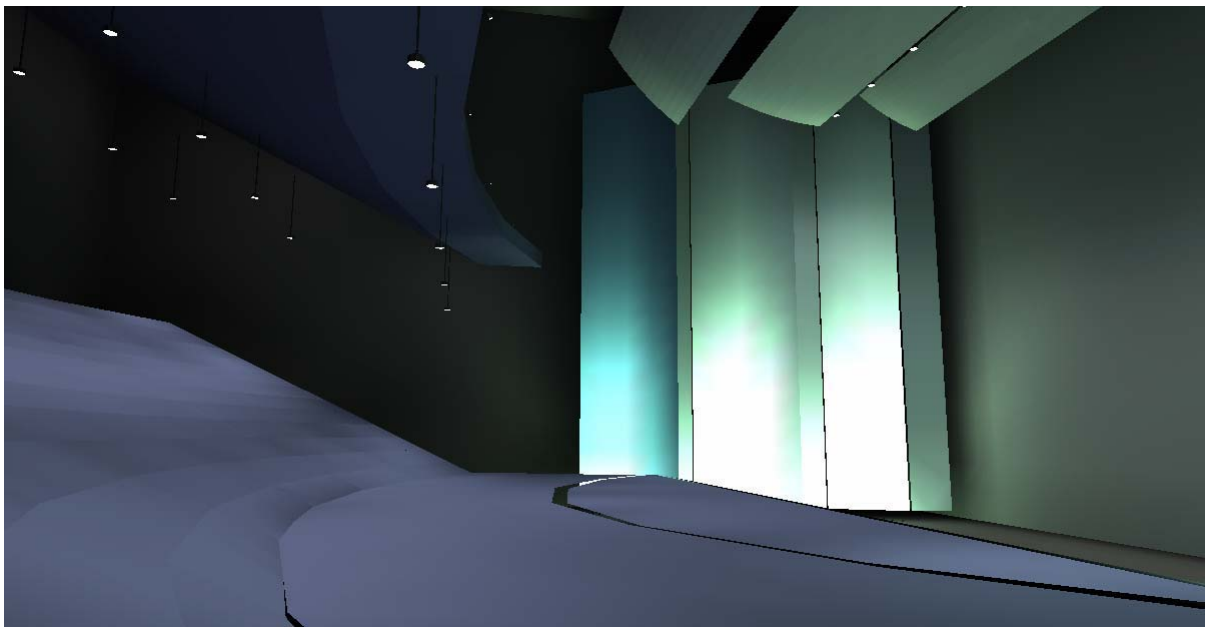


AGI32 Renderings

Auditorium Acoustical Towers

This pseudo color map shows that the accent lighting meets the luminance ratio minimum of 1:3 desired for accenting.





Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Discussion

The auditorium lighting layout was successful mainly due to the source choice. Using fluorescent sources reduces the re-lamping maintenance while maintaining the flexibility for dimming which is desired in a theater. The source also added to the uniformity achieved over the seating areas. By pure design choice, more fixtures were used for the down lighting to add an element of sparkle with the intent to look like stars in the dark sky. This design choice also reduced glare from previously high intensity sources. The illuminance levels desired were also met over the entire space.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Private Offices

Design criteria

- Remove glare sources
- Provide uniformity on desks
- Increase the visual interest and highlight walls to open up the space
- 30-40fc on walls, 40-50fc on desk planes

Design Theme and Mood

The existing offices are treated like all back of house spaces in the theater – very minimal finishes. The lighting is just evenly spaced (2) lamp T12 strips that provide a large glare source. This new design is a transformation to a contemporary office feeling that acts less like an enclosed basement. There are windows in only one office of the main four spaces that the main office is located. These spaces are used by the theater director and other administrative support for the daily coordination of the theater operations. To open the space up there is lighting on the walls to add visual interested and highlight artwork. This also serves as a means to make the space feel more open due to a lack of windows.

Lighting Layout

There are three types of fixtures used in this space. All of the sources are fluorescent and have the ability to be dimmed by zones. The sources used to provide uniformity of the desk work planes is a modern looking T5 direct/indirect pendant. Then the conference room uses a completely direct pendant light only the two main tables in the space. All spaces have wall washers which are used o light the walls for artwork and also to light the bookshelves throughout the offices.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Schedule

A		**Zumtobel Staff AQ-2285-4-T-SE** Description: Suspended fluorescent up/downlight with 2-F28T5 (48in) lamps. Optics: acrylic prismatic lens , anodized aluminum reflector 81% up/19% down.	2-F28T5 (48in) lamps	Location: Office
B		**Winona Lighting P1-*-FT139-*-LS9-*** Description: 20" surface-mounted compact fluorescent wallwasher with 1-FT40 lamp. Optics: anodized aluminum reflector , single.	1-FT40 lamp	Location: Office
C		**Zumtobel Staff 1580-*-*-U-*** Description: 7" suspended compact fluorescent downlight with 2-CFQ13W lamp. Optics: painted or anodized aluminum reflector.	2-CFQ13W lamp	Location: Office

Light Loss Factors

Type	Manf.	Fixture Description	Parameters	LDD	RSDD	LLD	BF	LLF
A	Zumtobel Staff	9"x4' Pendant	V, Clean, 24 mo	0.84	0.89	0.94	1.00	0.70
B	Winona	Surface Wall washer	IV, Clean, 24 mo	0.90	0.94	0.94	0.85	0.68
C	Zumtobel Staff	10" Circle Pendant	IV, Clean, 24 mo	0.80	0.96	0.84	1.00	0.65

Power Density Calculation

	Type	Quantity	Watts			
Linear Pendant	A	14	924	Total Watts	**2293.2**	
Wall Washer	B	34	1244.4	Area (s.f.)	**1470**	
CFL Pendant	C	4	124.8	Power Density	**1.56**	W/s.f.

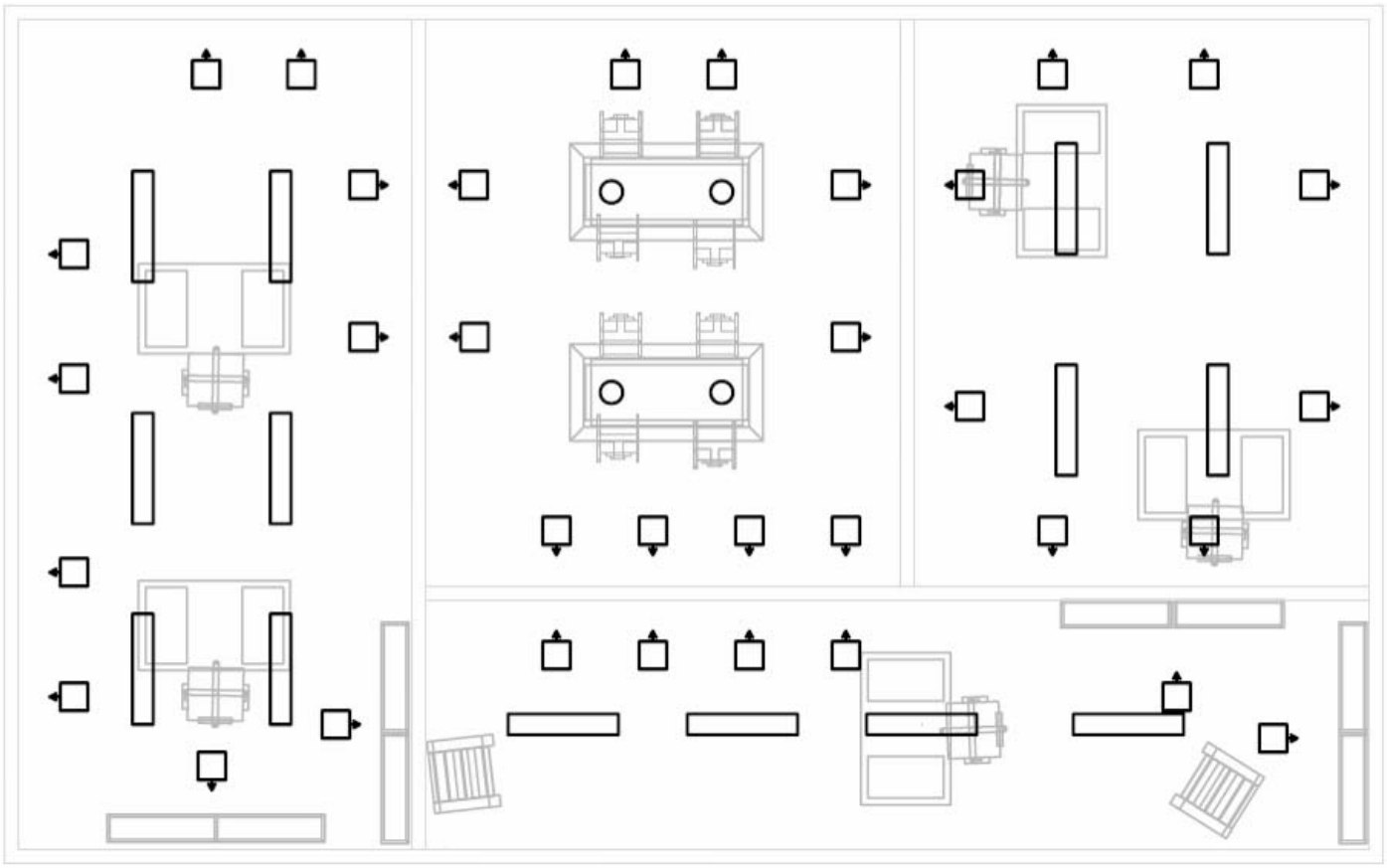
Where the typical lighting only is only: 0.71 W/s.f.
Where the wall lighting is 0.85 W/s.f.and is allowed to be 1.0 w/s.f.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Lighting Layout



Symbol	Type
▭	A
⏛	B
○	C

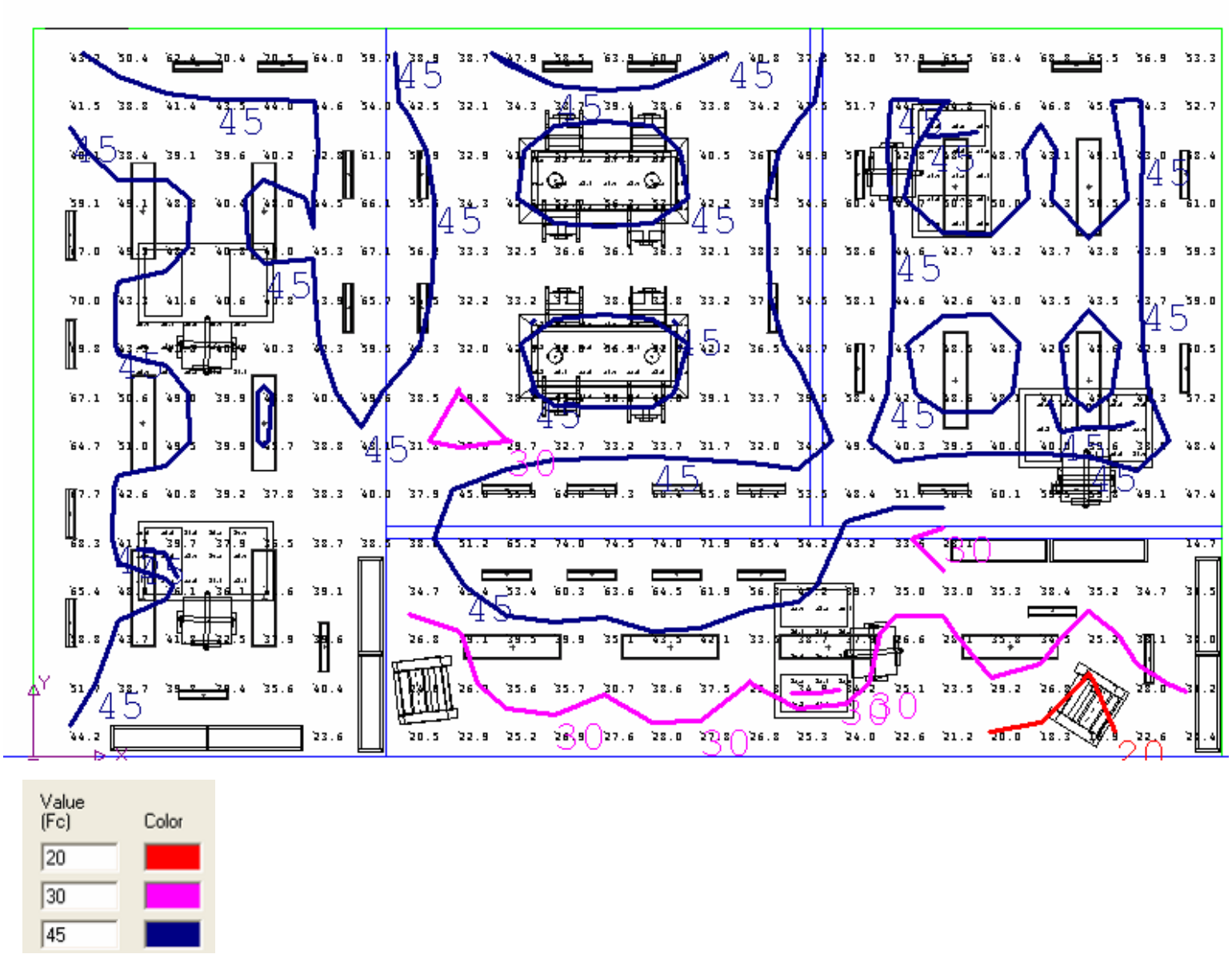
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Calculation:

Calculation grid placed at 2.5'
The uniformity over the work plane creates an environment conducive to working at a desk and makes the plan flexible to rearrange the spaces.



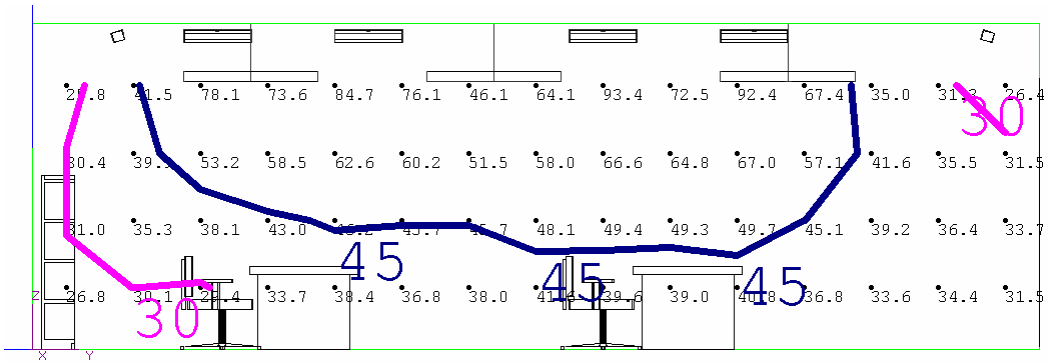
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

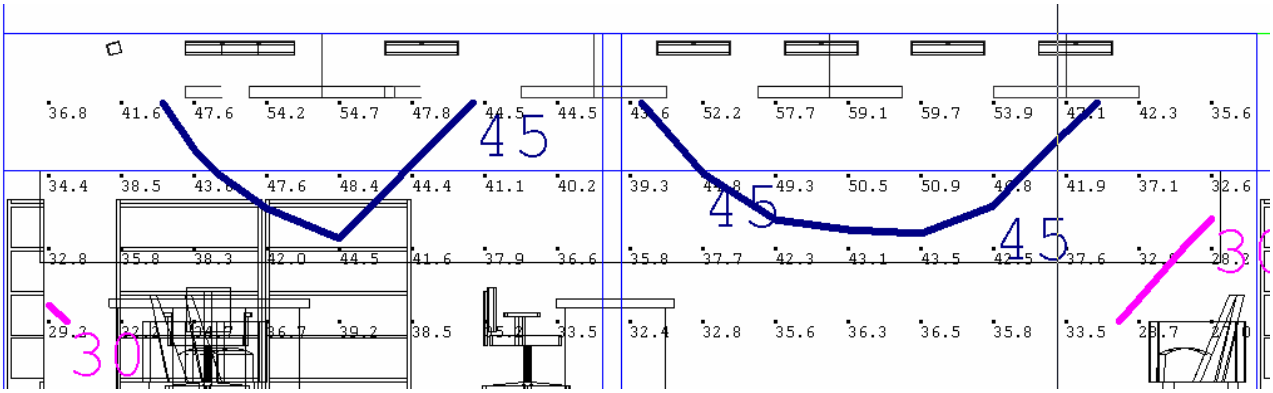
Final Report

Calculation:

Vertical Calculation Grids
Office walls for highlighting/illuminating artwork.



This calculation shows the performance of varied spacing for the wall washers.

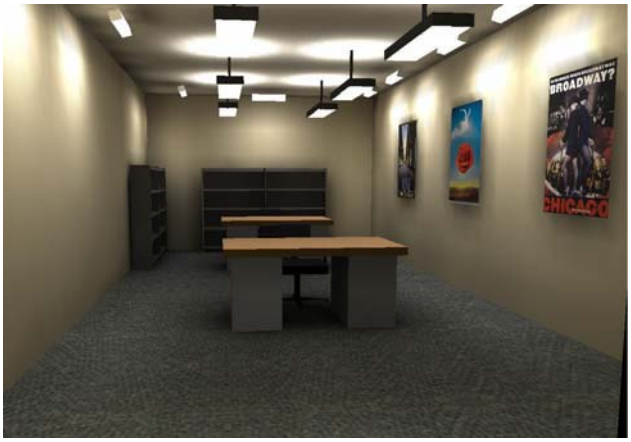


Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

AGI32 Renderings



Discussion

The system works well over the 2.5′ calculation grid to create a uniform working environment. Because the systems are dimmable, if so desired the levels of light over the work plane can be reduced to a more residential feel. The wall lighting system is to accent artwork as well as open up these very enclosed offices. The lighting level is higher than anticipated so this group of fixtures would be dimmed about 25% to reach a vertical illuminance level of closer to 20-30fc instead of +40fc. The lighting layout and fixture choices add to a contemporary setting in the offices. This is quite an improvement compared to the existing lighting system of industrial type fluorescent fixtures.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Electrical Depth

Introduction

The overall design ideas for the electrical design are to plan an efficient and well organized system. This includes control plans, circuiting and also distribution plans. There are two distinct plans to integrate these three systems. The first is to plan the controls and circuiting to coordinate directly. Then the secondary item is to make the distribution panels feeding these smaller items just as well planned and organized.

The new lighting design requires a level of detail for controlling and circuiting the number of different types of fixtures. This design has changes to the controls for the lobby, offices, and house light. Using Lutron's Grafik Eye system the lighting system is controlled through a number of zones in each larger space. The details to this system are specified in the following pages. There are a few exceptions to this main use for control which is for specific accent lighting that works better with DMX controls. There is an existing DMX control point at the stage area for stage and house lighting combined. So, the lighting system utilizes a few of those existing circuits for halogen fixtures in the theater and a specialty spot light in the entrance area.

Also, there was a potential to reduce the number of electrical distribution panels. There are a total of 13 distribution panels that are sized smaller than what is typical. After reviewing the existing panels, it was determined that two sets of two distribution panels can be consolidated. Each panel is 600A and was consolidated to be (2) 1200A panels instead of (4) 600A panels. This would have saved time for installation and also material costs as seen in the following electrical section of the report.

Lindsey Beane

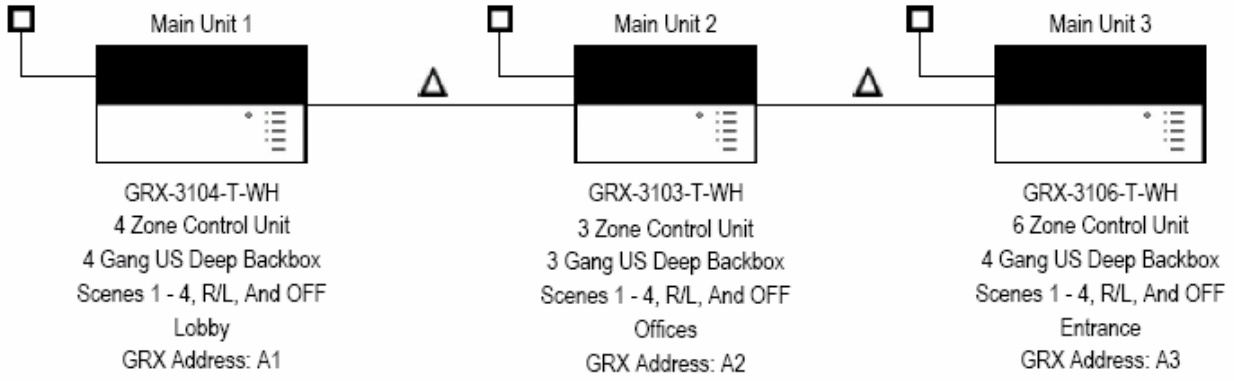
Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

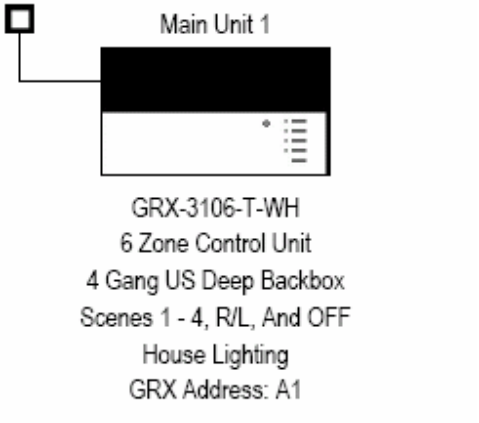
Final Report

Lighting Controls Details

The controls for all lighting systems are a combination of Grafik eye controls and a few DMX controls. The details to the DMX controls are not included, because there is an existing system to accommodate those controls. The following pages will include a discussion of the Lutron Grafik Eye controls for all four spaces. The zone analysis for the lighting controls was designed using Lutron's Designer software. This designer software provided control diagrams and a list of the zones required to fit the given design loads.

The diagrams below show the delineation between one set of controls in the entrance, lobby and offices. These systems were designed separately because the group of (3) spaces will be controlled from the main offices while the theater control point will be on the stage. This way the house lighting controls will be next to the house lighting accent and stage lighting controls for use by the director. These two systems will be called front of house and back of house controls. The front of house controls refers to the lobby, offices and entrance system while the back of house controls refers to the theater house lighting controls.





Lindsey Beane

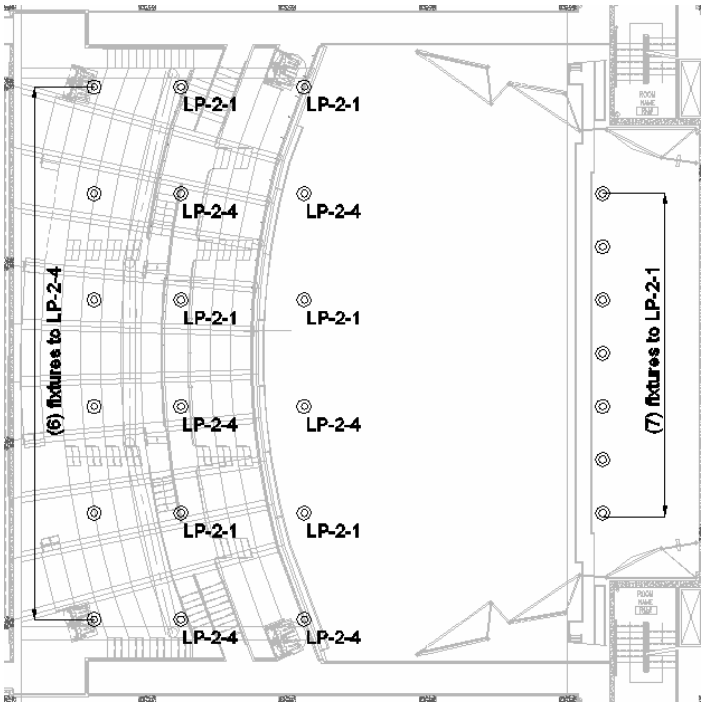
Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

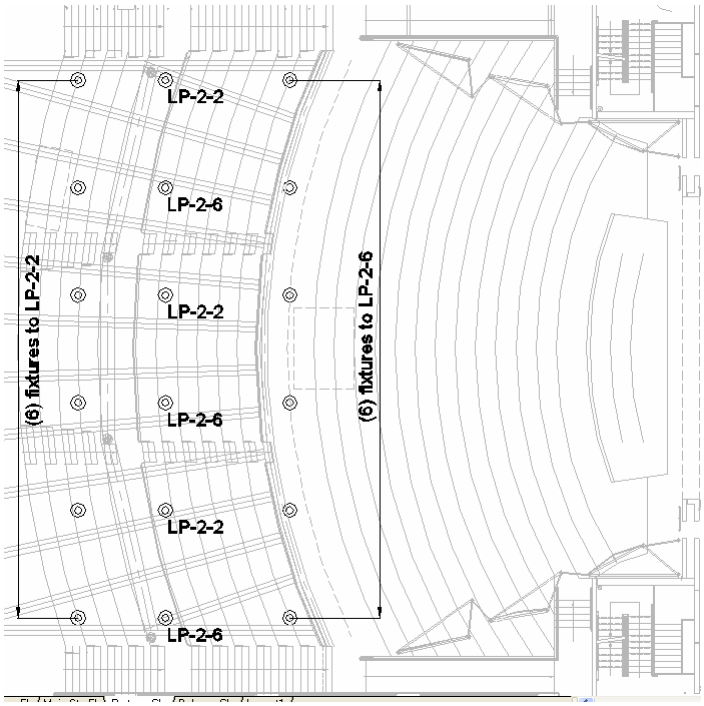
Control System Details

The zones for controls were chosen by circuit. All of the circuiting groups were planned for dimming/switching purposes. This page and the following page show circuiting plans which in effect relate to the listed zones described on the load schedules in Appendix B. There is some redundancy built into this system by overlaying circuits between house lighting rows.

Ceiling Lighting Circuiting Plans



Balcony Ceiling



Parterre Ceiling

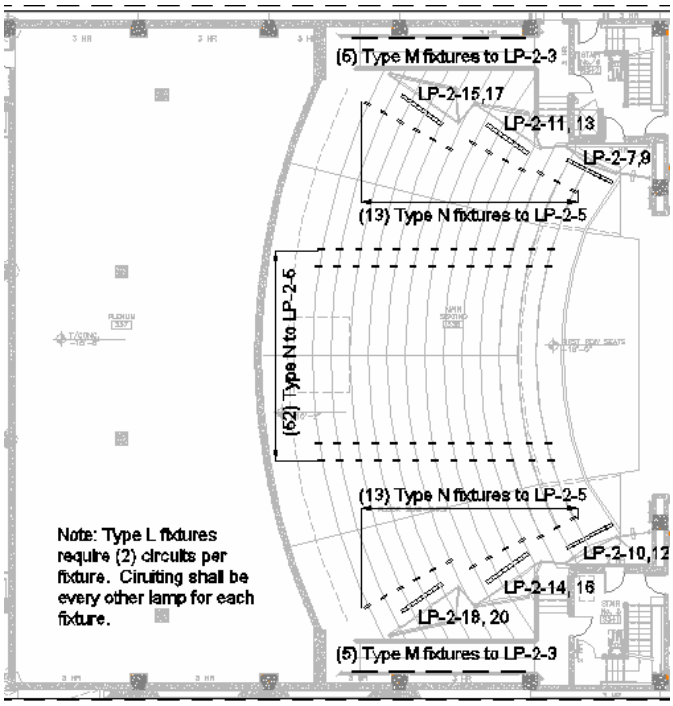
Symbol	Type
◎	K
▭	L
▬	M
▪	N
▬▬	P

Lindsey Beane

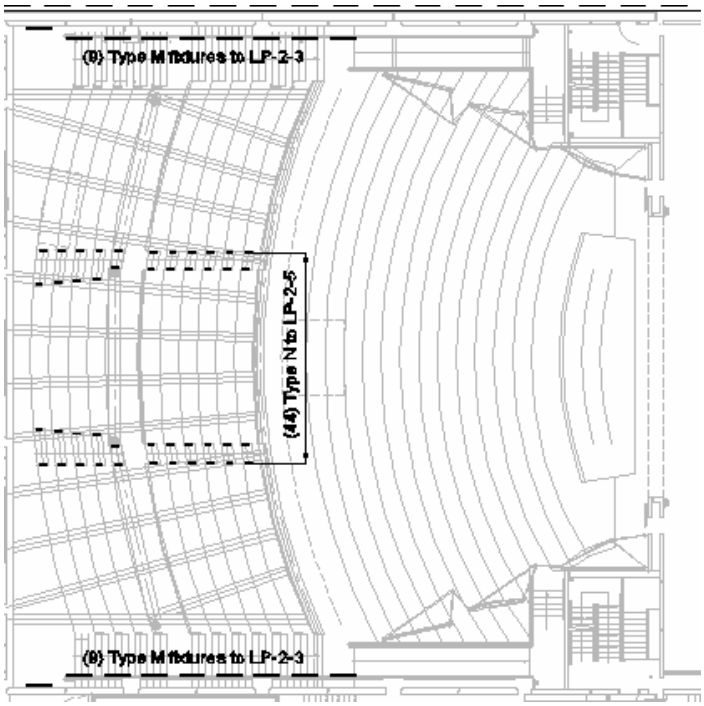
Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

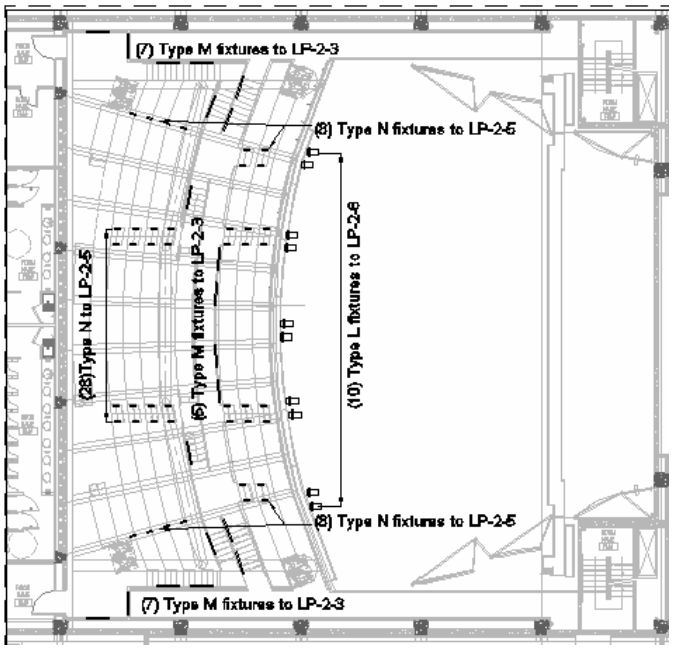
Floor Level Lighting Circuiting Plans



Main Seating Area



Parterre Seating Area



Balcony Seating Area

Symbol	Type
◎	K
▭	L
▬	M
▬	N
▬	P

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Control Load Schedules

To further describe the zones and their purpose please see the load reports below and how they correlate to the load requirements on the given panel boards on the next page. To see how the zones were chosen and grouped please reference these load schedules next to the circuiting plans on the previous two pages or in Appendix A. The first three schedules describe the front of house lighting and the fourth covers the back of house lighting.

Front of House Controls

Entrance GRAFIK Eye 3000 Load Schedule

Main Control Unit Name: Main Unit 3
Lutron Model No.: GRX-3106-T-WH
Control Address / Location: 3 /

Lutron Zone	Customer Zone	Zone/Circuit Description	Customer Circuit #	Voltage	Load Type	Actual Load (W/VA)
A3-1	Accent Flood Lights		5	120V	-	GRX-TVI*
A3-2	Cove Lighting		1	120V	-	GRX-FDBI-16A-120*
A3-3	Cove Lighting -2		2	120V	-	GRX-FDBI-16A-120*
A3-4	Large Pendants		3	120V	-	GRX-FDBI-16A-120*
A3-5	Railing Lights		4	120V	-	GRX-FDBI-16A-120*

Lobby GRAFIK Eye 3000 Load Schedule

Main Control Unit Name: Main Unit 1
Lutron Model No.: GRX-3104-T-WH
Control Address / Location: 1 /

Lutron Zone	Customer Zone	Zone/Circuit Description	Customer Circuit #	Voltage	Load Type	Actual Load (W/VA)
A1-1	Cove Lighting		1	120V	-	GRX-FDBI-16A-120*
A1-2	Cove Lighting -2		2	120V	-	GRX-FDBI-16A-120*
A1-3	Large Pendants		3	120V	-	GRX-FDBI-16A-120*

Offices GRAFIK Eye 3000 Load Schedule

Main Control Unit Name: Main Unit 2
Lutron Model No.: GRX-3103-T-WH
Control Address / Location: 2 /

Lutron Zone	Customer Zone	Zone/Circuit Description	Customer Circuit #	Voltage	Load Type	Actual Load (W/VA)
A2-2	Workstations		1	120V	-	GRX-FDBI-16A-120*
A2-1	Wall Washers		2	120V	-	GRX-FDBI-16A-120*
A2-3	Conference Pendant		3	120V	-	GRX-FDBI-16A-120*

Back of House Controls

House Lighting GRAFIK Eye 3000 Load Schedule

Main Control Unit Name: Main Unit 1
Lutron Model No.: GRX-3106-T-WH
Control Address / Location: 1 /

Lutron Zone	Customer Zone	Zone/Circuit Description	Customer Circuit #	Voltage	Load Type	Actual Load (W/VA)
A1-1	Main - Balcony House Lights	Main Seating area and front of balcony	1	120V	-	GRX-FDBI-16A-120*
A1-2	Railing	All Railing Lights	6	120V	-	GRX-FDBI-16A-120*
A1-3	Balcony House Lights	Rear of balcony	2	120V	-	GRX-FDBI-16A-120*
A1-4	Parterre House Front	Front of parterre	4	120V	-	GRX-FDBI-16A-120*
A1-5	Parterre House Rear	Rear of parterre	3	120V	-	GRX-FDBI-16A-120*
A1-6	Aisle Lights	All aisle lights	5	120V	Incandescent	160

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Circuiting Information

Lighting System Load Requirements

The circuiting information below describes the design loads of the lighting system. The design loads were divided by spaces. As mentioned before there are two separate controls the front of house and back of house. The lobby, offices and entrance were located on LP-1 (referring to front of house) with the exception of the automated fixture (Type J) in the entrance. The automated circuit was separated to the LP-2 (referring to back of house) panel so that it can be located closer to the stage DMX controls which also control this specialty fixture. Panel LP-2 was organized such that the Grafik Eye controlled fixtures are circuits 1-6 and DMX controlled fixtures are circuits 7-18. To see total load information and wire sizes for the panel boards, please reference Appendix B.

Description	LOAD (VA)			Brk. Trip (A)	LP 1				LOAD (VA)			Brk. Trip (A)	Description
	A	B	C		Cond. Size	Ckt. #		Cond. Size	A	B	C		
Off - Pendants	1048			20	#12	1	2	#12	1254			20	Lby1 - Cove
Off - Wall washer		1245		20	#12	3	4	#12		1320		20	Lby1 - Cove
Lby2 - Cove			1584	20	#12	5	6	#12			1056	20	Lby1 - Lg Pendant.
Lby2 - Cove	1518			20	#12	7	8	#12	636			20	Lby1 - Railing
Lby2 - Lg Pendant		1452		20	#12	9	10	#12		644		20	Ent - Track
Lby2 - Sml Pendant			732	20	#12	11	12	#12			644	20	Ent - Track

Description	LOAD (VA)			Brk. Trip (A)	LP 2				LOAD (VA)			Brk. Trip (A)	Description
	A	B	C		Cond. Size	Ckt. #		Cond. Size	A	B	C		
HL - CFL Downlight	1607			20	#12	1	2	#12	1113			20	HL - CFL Downlight
HL - Railing		1527		20	#12	3	4	#12		1484		20	HL - CFL Downlight
HL - Aisle			665	20	#12	5	6	#12			1113	20	HL - CFL Downlight
HL - Borderlight Accent	1000			20	#12	7	8	#12	1000			20	HL - Hal Downlight
HL - Borderlight Accent		1000		20	#12	9	10	#12		1000		20	HL - Borderlight Accent
HL - Borderlight Accent			1000	20	#12	11	12	#12			1000	20	HL - Borderlight Accent
HL - Borderlight Accent	1000			20	#12	13	14	#12	1000			20	HL - Borderlight Accent
HL - Borderlight Accent		1000		20	#12	15	16	#12		1000		20	HL - Borderlight Accent
HL - Borderlight Accent			1000	20	#12	17	18	#12			1000	20	HL - Borderlight Accent
Ent - Automated Spot	700			20	#12	19	20	#12	1000			20	HL - Borderlight Accent

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Electrical Distribution Panels

Consolidation

The electrical distribution system is spread over 13 smaller panels with an average size of 600A. To reduce the complexity and material costs of the system the following design has consolidated (4) 600A panels into (2) 1200 A panels. To support that this is a cost-wise decision there is also a cost analysis of materials and installation.

To view the load information for the existing and designed distribution panels please reference Appendix B. The cost information listed below is compiled from Eaton Electrical for materials and RSMeans for installation and labor information.

RSMeans #	Size	Quantity	Crew	Output	Hours	Unit	Material	Labor	Total
8600270	600 A	4	2 elec	1.2	13.33	ea	$24,200.00	$2,180.00	$26,380.00
86002090	1200 A	2	2 elec	0.92	17.39	ea	$22,502.00	$1,420.00	$23,922.00
								Savings	**$2,458.00**

Electrical Depth Discussion

Providing a more straightforward approach to the electrical distribution and lighting controls creates a cost saving and efficient building system. An organized and well-sized distribution system makes the design less complicated and easier to install. The design for lighting controls, circuit loads, and distribution panels are also a straightforward and efficient approach to the situation. And organized and well planned electrical system adds to the success of the integrated building systems as well. The efficient electrical design supports a lighting system that follows the same plan for organization. The design plans for these electrical portions of this report meet the plans for an efficient and well organized system.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Acoustical Breadth

The reverberation time in a live theater is very critical to a patrons experience during a performance. My lighting design has affected an architectural element in the theater space, so I deemed it necessary to see how this change may effect the reverberation time. I proposed to change the length of horizontal hanging clouds at the ceiling. For my lighting design I planned to have the ceiling dark with the exception of the hanging down lights. My reducing the length of the clouds by a total of 6' this allows the light to upright the towers without interfering with the dark ceiling I had planned for the lighting design. By leaving an extra 3' on each end there isn't spill light from the plighting accent fixtures.

The following lighting study to determine the new length of the ceiling clouds:

Existing design

Study #1: A 6' length reduction on all three ceiling clouds.

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Study #2: From left to right 6', 8' and 10' length reductions.

Study #2 was used to compare the reverberation time, because the light spill is minimal and suitable to work with the tower accent plighting.

To calculate the reverberation time Sabine's formula can be used. To determine the value "a" you must compile the quantities of surface area for each type of material within the space. The details for Sabine's calculation are on the following page. The absorption coefficients used to calculate the reverberation time, T, were taken David Egan's Architectural Acoustics textbook.

$$T = 0.05\frac{V}{a} \qquad (16)$$

where T = reverberation time, or time required for sound to decay 60 dB after source has stopped (s)

V = room volume (ft^3)

a = [see formula (11)]

Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Reverberation Time Calculation:

Surface Name	Surface Area
Floor	14,976 sf
Seating	5147 sf
Towers, Clouds	5,690 sf
Ceiling	14,976 sf
Walls	12,626 sf
Volume	724,672 cf

Coefficients for absorption used for Sabine's Reverberation calculation:

		Sound Absorption Coefficients					
Description	**Surface Name**	**125**	**250**	**500**	**1000**	**2000**	**4000**
Concrete Floor	Floor	0.01	0.01	0.02	0.02	0.02	0.02
Audience, seating	Seating	0.39	0.57	0.8	0.94	0.92	0.87
Acoustical Reflectors	Towers, Clouds	0.15	0.1	0.05	0.04	0.07	0.09
Concrete Ceiling	Ceiling	0.01	0.01	0.02	0.02	0.02	0.02
Concrete Block	Walls	0.01	0.02	0.04	0.06	0.08	0.1

Existing Calculation:

S * alpha						
125	**250**	**500**	**1000**	**2000**	**4000**	
149.8	149.8	299.5	299.5	299.5	299.5	
2,007.4	2,933.9	4,117.8	4,838.4	4,735.5	4,478.1	
896.0	597.3	298.7	238.9	418.1	537.6	
149.8	149.8	299.5	299.5	299.5	299.5	
126.3	252.5	505.0	757.6	1,010.1	1,262.6	
3,329.2	4,083.3	5,520.5	6,433.9	6,762.7	6,877.3	
				Sum of S* alpha		**33,006.9**
				Reverberation time (T)=		**1.098**

With cloud length reductions:

S * alpha						
125	**250**	**500**	**1000**	**2000**	**4000**	
149.8	149.8	299.5	299.5	299.5	299.5	
2,007.4	2,933.9	4,117.8	4,838.4	4,735.5	4,478.1	
853.5	569.0	284.5	227.6	398.3	512.1	
149.8	149.8	299.5	299.5	299.5	299.5	
126.3	252.5	505.0	757.6	1,010.1	1,262.6	
3,286.7	4,055.0	5,506.4	6,422.6	6,742.9	6,851.8	
				Sum of S* alpha		**32,865.4**
				Reverberation time (T)=		**1.102**

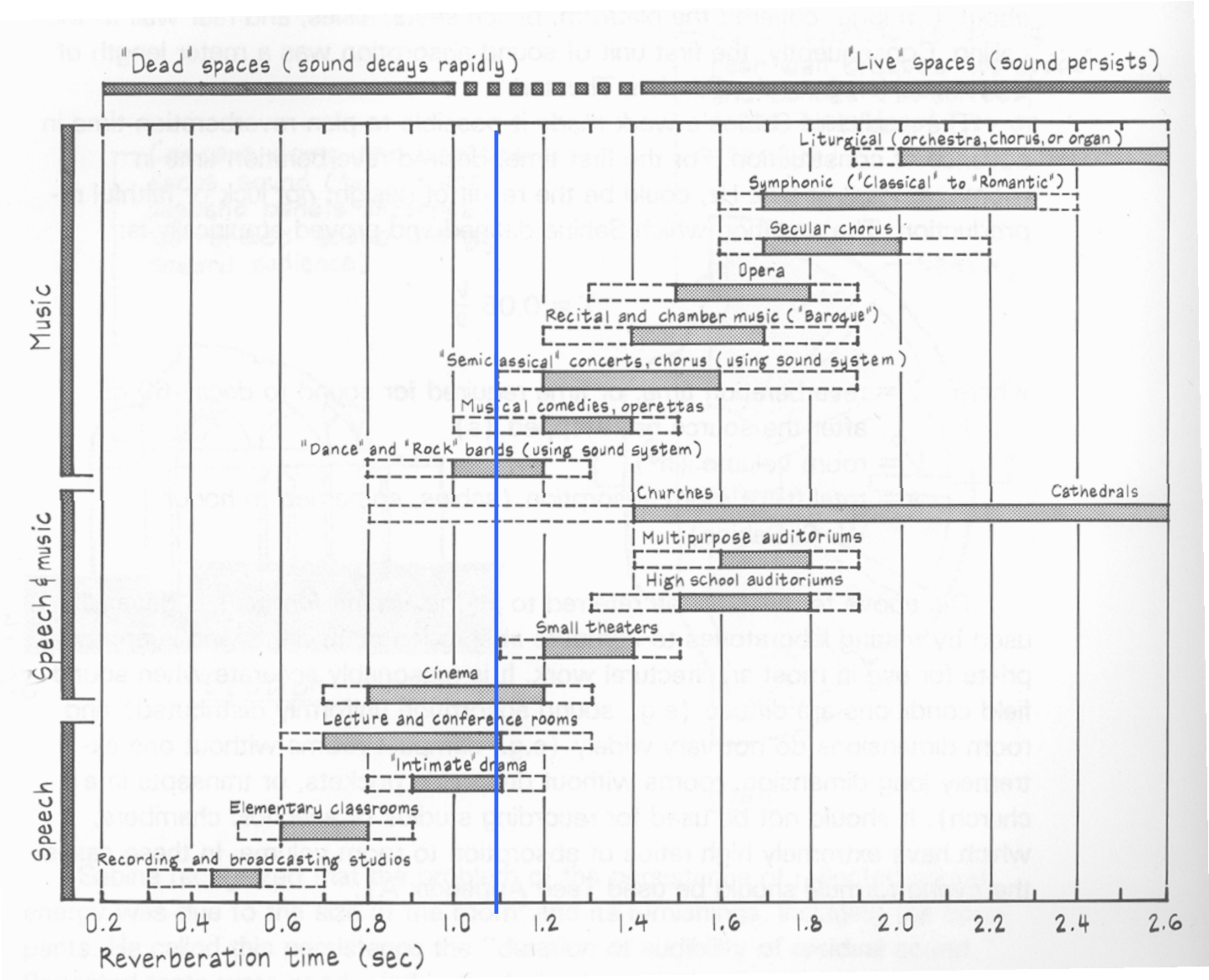
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Discussion

The line plotted below shows where both calculations would fall on the reverberation time scale. The change in reverberation time was so small on the scale shown below that the change in reflector length is recommended. This will enhance the lighting design while maintaining acoustical performance.



Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Cost Analysis Breadth

After completing the design scheme that could be implemented on all lobby floors I studied the existing lighting installation cost to my design. The comparison included costs of material and labor. When this comparison was considered I had not planned to have a cove fixture, but instead to surface mount fixtures on the existing beams. After careful consideration I decided that the design need to be cleaner cut then a surface mounting design could provide. So, I have proposed to add a cove as well as the ceiling washing fixtures. So, the pricing for this new installation is significantly more expensive.

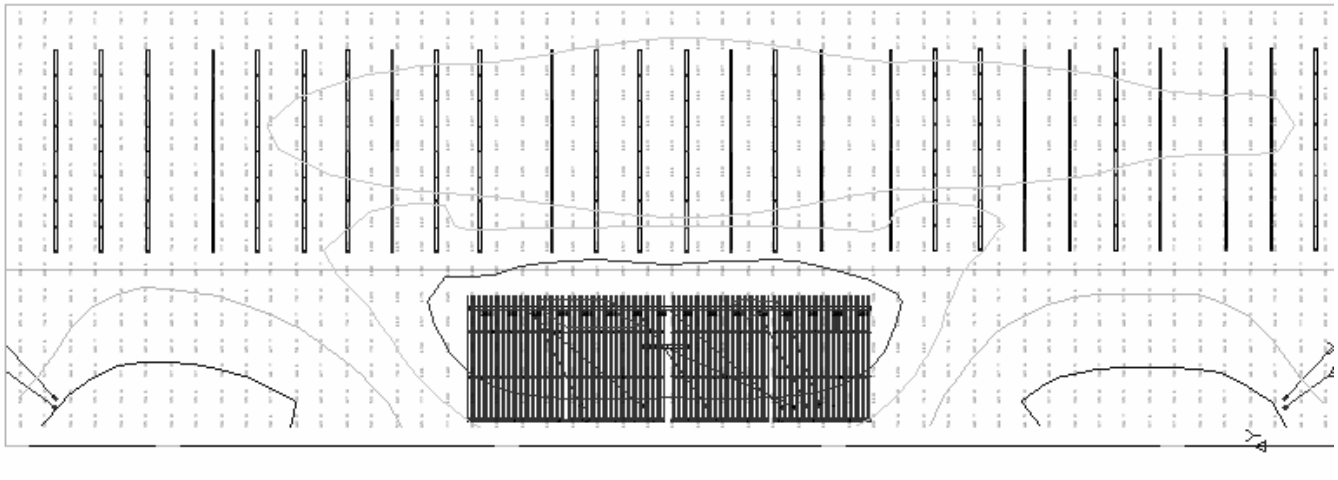
Existing Conditions

Lighting Schedule

VE-N	Fluorescent Strip Light (1) Lamp	Hubbell Lighting	Cleanroom-air Foil Series CR-X-8T-1-R-CL-A-1-CRS-1	(1) T8 Assumed 32W	120	34	0.666	L5725
VE-NC	Fluorescent Strip Light (1) Lamp 4' and 8' lengths.	Hubbell Lighting Duray	Cleanroom-air Foil Series CR-X-8T&40-1-R-CL-A-1-CRS-1 LS 96 or LS 48 Depending on	(1) T8 Assumed 32W Gel Fits T12 lamp	120	34	0.666	L5725

Lighting Layout

The layout is very uniform with the exception of colored strips used to define spaces between the columns. These are surface mounted strip fluorescents. This design provided a very economical approach to the lighting design. Half of the fixtures are 8′ in length which also greatly reduced the cost of labor for the installation.



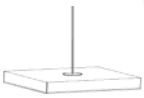
Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

New Design for Comparison

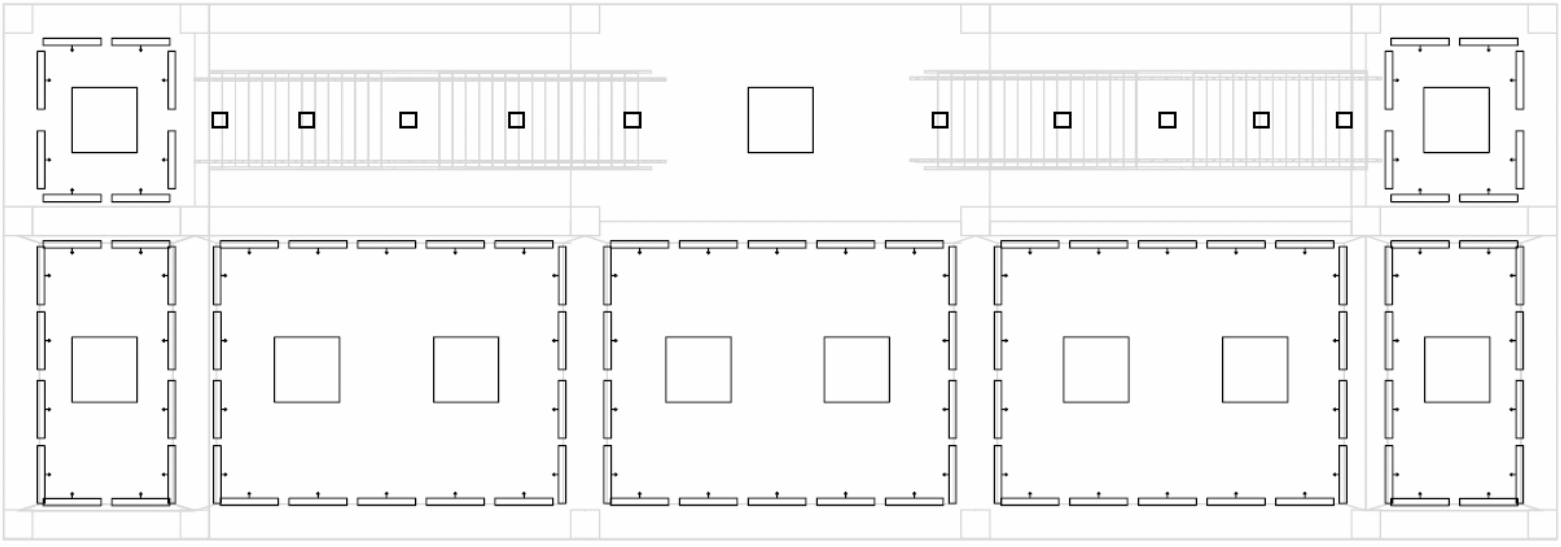
Lighting Schedule

D		**Winona Lighting P1-MC-*T5-*-MCVU-RA-*** Description: Fluorescent cove light with 1-28T5 lamp (in cross-section).	1-28T5 lamp (in cross-section)	Location: Lobby
F		**Custom Fixture 4.5' x 4.5' x 6" Square Pendant** Description: 4.5' x 4.5' x 6" Pendant with acrylic glass on sides and bottom. Top is opaque and reflective on inner side of fixture.	(4) 28T5 bi-pin linear	Location: Lobby
G		**Winona Lighting 5450-10-F-*-*-*-*MB-STD** Description: Suspended compact fluorescent decorative pendant with 4-FT40 lamps.	4-FT40 lamps	Location: Lobby

Symbol	Type
	D
	F
	G
	I
	J
	M

Lighting Layout

This design requires the installation of a cove to give a seamless approach to the uniform lighting of the space. Additionally, to keep the layout seamless there is a large custom fixture which added greatly to the expensive of the installation. The other two types of fixtures used were specified from Winona without modifications.



Lindsey Beane

Lighting/Electrical
Professor Mistrick
Harris Theater for Music and Dance
Chicago, IL

Final Report

Discussion

The spreadsheet below shows the initial cost analysis of the total installation. After reviewing these costs further a second analysis was needed to put the comparison into perspective.

Existing Design

RS Means #	Type	Quantity	Description	Crew	Output	Hours	Unit	Material	Labor	Total	O & P
2600	VE-N	52	(1) 8' Long Linear Fluorescent	2 Elec	13.4	1.194	ea.	$2,158.00	$3,016.00	$5,174.00	$6,916.00
2600	VE-NC	42	(1) 8' Long Linear Fluorescent with Sleeve and colored gel	2 Elec	13.4	1.194	ea.	$1,743.00	$2,436.00	$4,179.00	$5,586.00
2400	VE-NC	80	(1) 4' Long Linear Fluorescent with Sleeve and colored gel	1 Elec	8	1	ea.	$3,200.00	$3,920.00	$7,120.00	$9,360.00
										$16,473.00	**$21,862.00**

New Design

RS Means #	Type	Quantity	Description	Crew	Output	Hours	Unit	Material	Labor	Total	O & P
3565	D	94	4' Cove fixture and prefabricated steel cove	1 Elec	5	1.6	ea.	$17,014.00	$7,332.00	$24,346.00	$29,610.00
1600	F	11	4'-6" square pendant, acrylic, with (4) 4' T5 lamps	2 Elec	7.2	2.222	ea.	$4,565.00	$1,199.00	$5,764.00	$6,820.00
1060	G	10	CFL rectangular pendant	1 Elec	3	2.667	ea.	$5,500.00	$1,120.00	$6,620.00	$7,800.00
										$36,730.00	**$44,230.00**

Existing Design

Type	Quantity	Description	Material
VE-N	52	(1) 8' Long Linear Fluorescent	$2,158.00
VE-NC	42	(1) 8' Long Linear Fluorescent with Sleeve and colored gel	$1,743.00
VE-NC	80	(1) 4' Long Linear Fluorescent with Sleeve and colored gel	$3,200.00
Total	174	**Total**	**$7,101.00**
		$1.79 per s.f.	

New Design

Type	Quantity	Description	Material
D	94	4' Cove fixture and prefabricated steel cove	$17,014.00
F	11	4'-6" square pendant, acrylic, with (4) 4' T5 lamps	$4,565.00
G	10	CFL rectangular pendant	$5,500.00
Total	115	**Total**	**$27,079.00**
		$6.84 per s.f.	

Conclusions

The goals for this design were to create an appealing lighting design while maintaining an energy and maintenance efficient system. These goals were met by providing concealed fixtures where possible and using mostly fluorescent lighting sources. Fluorescent sources allowed the ability to be energy efficient while maintain the flexibility to be dimmed as well. To complete this design flexibility, a Grafik Eye system was specified for controls. The system design has the option to dim the different layers of light in each major space. The system has a straightforward plan for wiring because the circuiting plan reflects the lighting control zoning plans directly. This design is successful because the electrical layout plan was integrated into the lighting controls to simplify the installation.

Breadth studies provide a better understanding of the overall design. To improve the details of the lighting system other elements of the architectural design are affected. There are two architectural elements that would be modified by this design to avoid conflict with the lighting system plan. The first is the addition of coves in the lobby areas which was analyzed within the fixture cost installation analysis. The second conflict occurs in the auditorium space and affects the size of acoustical reflectors. The outcomes of both studies show that the results can either support the design or suggest modifications. As it turns out, the cost to install the cove lighting significantly adds to the lobby lighting installation costs. As a designer without a budget or limits to creativity, it is still recommended that the design be implemented as planned in this report. The added flexibility, aesthetics, and efficiency make the design a success.

References

Lighting
Rea, Mark S., ed. *The IESNA Lighting Handbook: Reference & Application.* New York: Illuminating Engineering Society of North American, 2000.

ASHRAE Standard: Energy Standard for Buildings Except Low-Rise Residential Buildings. Standard 90.1-2004. Pg 88.

Electrical
Hughes, David. *Electrical Systems in Buildings*. 1988.

General
Egan, David M. Architectural Acoustics. NY: McGraw-Hill Inc., 1998.

RSMeans 2005.

Image Sources for Renderings
www.whypop.net/janices/afrenchrailway1929.jpg
www.postersarts.com/Images/artposterssalvadordali.jpg
www.darknessandlight.co.uk/photos_misc/art_poster_cambridge_109fs.jpg
www.nationaltheatre.org/mainstage/art/Chicago/ChicagoFlyer350h.jpg

Acknowledgements

To Schuler Shook for guidance in not only choosing a thesis project, but also answering my numerous design questions all year long!

To Hammond Beeby Rupert Ainge Architects for their help in learning about this great architectural project and providing all the project documentation.

Thanks for your help with questions:
Ted Dannerth, Professor Mistrick, Professor Moeck and Steven Puchek

For your humor and support in the lab:
All the lighting kids and Courtney, too!

To my roommates for their patience over the last few weeks…