SYNDICATE
AEI Team 01-2019

Final Design of the Jack H. Miller Center for Musical Arts

2019 AEI Student Design Competition
# TABLE OF CONTENTS

## Codes and Standards

### Integration
- Executive Summary
- Report: 1-15
- Supporting Documents: 16-20
- Supporting Drawings: 21-30

### Structural
- Executive Summary: 31
- Report: 32-45
- Supporting Documents: 46-50
- Supporting Drawings: 51-60

### Mechanical
- Executive Summary: 61
- Report: 62-75
- Supporting Documents: 76-80
- Supporting Drawings: 81-90

### Lighting/Electrical
- Executive Summary: 91
- Report: 92-105
- Supporting Documents: 106-110
- Supporting Drawings: 111-120

### Construction
- Executive Summary: 121
- Report: 122-135
- Supporting Documents: 136-140
- Supporting Drawings: 141-150
CODES & STANDARDS

**Structural**
- 2015 International Building Code
- ASCE 7-16, Minimum Design Loads for Buildings and Other Structures
- 2018 NDS, Supplement and SDPWS
- CLT Handbook by FPInnovations
- ACI 318-14, Building Code Requirements for Structural Concrete
- ASTM E1300—04, Standard Practice for Determining Load Resistance of Glass in Buildings
- Kawneer 1600 LR Wall—Curtain Wall System Product Information

**Mechanical**
- ASHRAE Standard 62.1 - 2016
- ASHRAE Standard 90.1 - 2016
- ASHRAE Standard 55 - 2017
- International Energy Conservation Code (IECC) - 2009
- National Fire Protection Association (NFPA) 13 & 14

**Lighting/Electrical**
- 2012 International Building Code
- ASHRAE 90.1 2013
- NFPA 72 – National Fire Alarm and Signaling Code - 2011
- The IES Lighting Handbook – 10th Edition

**Construction**
- Occupational Safety and Health Administration (OSHA)
- RS Means
Syndicate is a multidisciplinary integrated design-build firm consisting of construction, lighting/electrical, mechanical, and structural teams. For the AEI Student Design Competition, Syndicate designed and engineered a high-performance center for musical arts, known as The Miller Center. The Miller Center is on the campus of Hope College located in Holland, Michigan. Throughout the duration of the project, team members were assigned to the major disciplines and to specialty multidisciplinary teams including building integration, enclosure, acoustics, and architecture. Syndicate collaborated to surpass building standards for mechanical and electrical systems, design a sustainable wood structure, and develop an overall budget of $23,926,850. Syndicate’s Optimized Design falls $1,073,150 below the given budget. By rotating the building on the site and reordering various spaces, Syndicate was able to increase the percentage of commonly occupied spaces receiving daylight, significantly reduce the amount of solar heat gain entering the lobby and create an acoustical buffer zone for the central symphonic concert hall. Syndicate focused on integrating high quality acoustics in each type of space by meeting or surpassing the desired acoustical sound transmission class (STC) and impact isolation class (IIC) levels for wall and floor assemblies, as well as falling within optimum reverberation times (RT) for each space of the building. Areas of critical integration are shown:

**CONCERT HALL**
- 72’ long steel truss
- Displacement ventilation underground ducts integrated with foundations
- Fiber optic DMX lighting scheme coordinated with acoustical ribbons
- Solar photovoltaic rooftop array
- High quality and adaptable acoustics
- 300-ton 2250 series 3 Manitowac crawler crane for precast panel installation

**OCCUPIABLE ROOF**
- Usability Occupancy: 100 people
- Enclosed space: 1500 SF
- Heating system for winter use
- Sliding glass doors to open the space and allow natural ventilation
- Programmable time schedule for electric lighting
- Provides fundraising opportunity for the owner
- Showcasing sustainability through exposed wood beams, columns, and floor system

**WEST CORRIDOR**
- Allows for ample daylight into all three classrooms
- Connection between north and south lobbies
- High performance enclosure
- Utilizes solar heat for heat recovery in winter, exhausts warm air in warmer months
- Reduces yearly utility cost by 7%
- System modularized for constructability

**SUSTAINABILITY PLAN**
- Incorporated a sustainability display to showcase dynamic and static building statistics
- Categories:
  - Waste Reduction
  - Indoor Environment
  - Materials and Resources
  - Energy Conservation

**NORTH LOBBY**
- Reduced direct sunlight levels into the atrium by 70%
- Reduced solar heat gain in space by 85%
- Hanging balcony design to limit obstruction of view
- Cross-beam wood design accented by wall grazers

**MECHANICAL SPACE**
- Fully isolated structure
- Mechanical equipment isolation springs and concrete inertia pads
- Isolation joints within slab on grade and CLT floor system
- Reduce structural borne sound and vibrations
Integration Table of Contents

1.0- Project Overview
2.0- Vision Statement
3.0- Integrated Project Goals
4.0- Integrated Design and Delivery
5.0- AEI Team Challenges
6.0- Design Facilitation and Communication
7.0- Early Design Development
8.0- Integrated Final Design
9.0- Hope College Sustainability Plan
10.0- Integrated Acoustics
11.0- Lessons Learned
12.0- Conclusion

1.0 PROJECT OVERVIEW

The Jack H. Miller Center for Musical Arts (The Miller Center) is a proposed building project for Hope College located in Holland, Michigan. Syndicate is an integrated design-build team that produced a high-quality design and construction plan for this project. The project site is situated in the northeast corner of campus across from downtown Holland, near Lake Michigan. The Miller Center acts as an investment for the future of Hope College and as a showcase pilot for a new sustainability plan on campus. The addition of an occupiable roof and south lobby allows this building to act as a gateway space for connecting Hope College campus to downtown Holland. The Miller Center can be seen in Figure 1.

Figure 1: Syndicate’s Design

Syndicate’s final design is a three-story building designed for serving the educational and performance requirements of Hope College. Totaling 70,000 square feet (SF), The Miller Center includes an 800-seat symphonic concert hall, a smaller recital hall for intimate chamber performances, and two large rehearsal spaces for choirs and orchestras. The building also includes classrooms, faculty studios, and student practice rooms distributed throughout the three stories.

2.0 VISION STATEMENT

Through a multidisciplinary team strategy, Syndicate produced a high-quality center for musical arts that met the goals and mission of Hope College. As a team, Syndicate chose to pursue this project with a vision statement that would contain individualized team and discipline goals. The vision statement is HOPE and the goals are to:

- Enhance Hope College Campus
- Maximize Occupant Experience
- Create Premier Performance Spaces
- Minimize Energy Impact

Refer to Integration SD-A for details about the vision statement.

3.0 INTEGRATED PROJECT GOALS

To achieve HOPE, Syndicate created specific integration goals for these four vision statements.

3.1 Enhance Hope College Campus

Syndicate set one of their goals as enhancing Hope College campus through design iterations and promoting sustainability. Metrics to evaluate this goal are:

- Developing a sustainability plan that optimizes the goals of Hope College
- Designing a CHP Plant with room for expansion of the campus by at least 400,000 SF of building
- Developing a construction schedule of 16 months
- Fall below the given budget of $25,000,000
- Adding a rooftop amenity space for 100 people
- Generating a captivating aura through the night time lighting design that will draw in occupants

3.2 Maximize Occupant Experience

After studying the given design of the building’s architectural features, Syndicate chose to set metrics to maximize the occupant experience:
• Reduce the building’s solar heat gain by 50%
• Reduce the amount of annual sunlight exposure (ASE) entering the lobby to IES acceptable levels
• Increase amount of commonly occupied spaces receiving daylight to at least 90%
• Achieve STC and IIC values greater than 50 to increase quality of acoustics for floor and roof assemblies
• Minimize perceived floor vibrations transmitted throughout the building using equipment isolators and an isolated structure for mechanical space
• Design a versatile concert hall

### 3.3 Create Premier Performance Spaces

The Miller Center is diverse because it contains classrooms, faculty studios, a recital hall, rehearsal spaces, and a grand concert hall. It is imperative that the studios and practice spaces allow for world-class acoustics. Refer to Integration Drawings I-4.0 and I-5.0 for acoustical data. To create premier performance spaces, the following criteria needed to be met or exceeded:

- Achieve acceptable reverberation times at various frequency values and noise criterion for each space (Figure 2)
- Achieve optimum music clarity index (C) 80 for the concert and recital halls, as well as optimum speech clarity index (C) 50 for the concert hall
- Achieve STC values greater than 65 for acoustical quality of wall assemblies in performance spaces
- Reduce transfer of noise through ducts
- Achieve optimum lateral energy fraction for the concert and recital halls
- Properly coordinated LED fixtures with the appropriate drivers to mitigate noise generation

**Figure 2: Reverberation Times and Noise Criterion**

<table>
<thead>
<tr>
<th>Type of Space</th>
<th>Reverberation Time Acceptable (seconds)</th>
<th>Reverberation Time Optimum (seconds)</th>
<th>Acceptable Noise Criteria (NC) Value (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orchestral, chours, or organ</td>
<td>1.9 - 3.4</td>
<td>2.6 - 3.4</td>
<td>30</td>
</tr>
<tr>
<td>Symphony (romantic)</td>
<td>1.6 - 2.2</td>
<td>1.7 - 2.1</td>
<td>20</td>
</tr>
<tr>
<td>Secular choral works</td>
<td>1.6 - 2.2</td>
<td>1.7 - 2.0</td>
<td>30</td>
</tr>
<tr>
<td>Contemporary orchestral works, recitals, and chamber music</td>
<td>1.2 - 1.9</td>
<td>1.4 - 1.7</td>
<td>30</td>
</tr>
<tr>
<td>Semi-classical concerts and choral groups using sound system</td>
<td>1.1 - 1.9</td>
<td>1.2 - 1.6</td>
<td>20</td>
</tr>
<tr>
<td>Small Theatres</td>
<td>1.1 - 1.5</td>
<td>1.2 - 1.4</td>
<td>40</td>
</tr>
<tr>
<td>Lecture and conference rooms</td>
<td>0.6 - 1.4</td>
<td>0.9 - 1.3</td>
<td>25</td>
</tr>
</tbody>
</table>

### 3.4 Minimize Energy Impact

Hope College expressed its goal for total-building sustainability of The Miller Center through a design challenge. Syndicate chose to set the following metrics that go beyond current standards to positively impact the environment:

- Develop a customized sustainability plan for Hope College
- Incorporate 25% minimum structural renewable wood products by volume into the design of the building
- Reduce building energy usage by 40% when compared to ASHRAE 90.1 2016 baseline building
- Reduce carbon content of structural system by 25% when compared to a steel construction baseline
- Properly coordinate all lighting, HVAC, and plug load controls to reduce energy demands by 20%
- Reduce building’s carbon footprint by providing alternate electric systems that allow for clean energy production
- Exceed ASHRAE 90.1-2013 for lighting control standards by 20%

### 4.0 INTEGRATED DESIGN AND DELIVERY

*Syndicate* operates under an integrated design-build delivery method. This delivery method allows streamlined communication between the owner and the project team, as seen in Figure 3. *Syndicate* wants to ensure that Hope College is an integral part of the design and construction processes when providing this premier space for its occupants. Through this delivery
method, Hope College will only have one project contract and one point of contact for the designers and construction professionals.

This method ensures that the team is providing the best quality while budgeting reasonably. The designers and construction professionals will be delivering on a fast-tracked timeline because they are under one roof and collaborate from project conception.

4.1 Stakeholder Analysis

Syndicate performed a stakeholder analysis in order to determine how each stakeholder should be incorporated into the project and at what stage, as seen in Figure 4. The Hope College Administration has the highest level of influence over this project because they control the funds and programming but will not experience the day to day performance of the building like the students and faculty. Therefore, Syndicate will include the Hope College Administration heavily at the beginning of the project and keep them informed throughout the project at a high level. The faculty and students will be involved at a more detailed level, such as classroom layout and storage spaces. They will participate in design reviews with Syndicate at various times throughout the design process to ensure the spaces are meeting their needs. Refer to Construction Report Section 4.1 for details.

4.2 Prevention Through Design

Prevention through Design (PtD) is an initiative that aims to anticipate and remove safety hazards, both during the construction and operation of the facility, in the early design phases of the project. This level of detail requires a highly integrated team. Therefore, an integrated design-build team like Syndicate is the perfect candidate to implement this up-and-coming concept. Refer to Construction Report Section 5.5.1 for more detail.

5.0 AEI TEAM CHALLENGES

Syndicate was commissioned to design The Miller Center systems concurrently with these three challenges: high performance/adaptive acoustics, engineered wood design, and a rooftop amenities space.

5.1 High Performance/Adaptable Acoustics

The Miller Center is versatile by design through its adaptability to various types of performances, public events, and ceremonies using moveable curtains and several wall finishes. Syndicate’s disciplines collaborated and incorporated an acoustical software program known as ODEON, shown in Figure 5, to go beyond industry standard levels of STC and IIC of 65. Noise criterion (NC) levels and reverberation times were also analyzed in all spaces within The Miller Center. Refer to Integration Report Section 10.0 for acoustical design and Integration Drawings I-4.0 and I-5.0 for acoustical analysis and enhancements.

5.2 Wood, Timber, and Engineered Wood

Syndicate was tasked with incorporating a minimum of 25% wood into the design of The Miller Center. In conjunction with Syndicate’s sustainability plan and the wood challenge, the team incorporated heavy timber
products within the structural system to promote sustainable and environmentally conscious practices. Glued-laminated (glulam) and cross-laminated timber (CLT) members were used in all spaces. Refer to Structural Report Sections 8.3 and 8.4 for details. The team also incorporated wood finishes throughout the building where applicable for acoustics and aesthetics. The end design surpassed the 25% minimum by volume of structural material and utilized 86% wood products for the structural system. The use of wood products reduced the carbon content of the structural system by 27% of a comparative baseline steel building, as seen in Figure 6. This is highlighted in the Materials and Resources category of the Hope College Sustainability Plan. Refer to Structural Drawing S-10.0.

"Figure 6: Carbon Content of Structural System
Reference: Inventory of Energy and Carbon (ICE) Version 2"

5.3 Rooftop Amenities Space

Our team created a solution for Hope College’s expressed interest in adding a rooftop amenities space that could accommodate up to 100 people and be accessible for both university and public events. Syndicate incorporated architectural elements such as sliding door systems and exposed wood features to encourage sustainable thinking (Figure 7). To accommodate both public and campus events, Syndicate utilized Revit to evaluate the existing architectural layout of The Miller Center and create a plan to allow user flow to our amenity space. Syndicate’s design is accessible throughout the full year and adaptable to the various seasonal climates in Michigan. More is discussed in Integration Report Section 8.1.

6.0 DESIGN FACILITATION

Syndicate set up several important approaches to encourage integration among disciplines to ensure the goals were attainable, as discussed below.

6.1 Multidisciplinary Team Emphasis

Syndicate is comprised of ten members across four disciplines including three lighting/electrical designers, two mechanical designers, three structural designers, and two members of the construction team, as displayed in Figure 8. At the start of the design process, Syndicate discussed roles that would be crucial in the design of The Miller Center. Acoustics became an additional essential discipline to consider alongside architecture and building enclosure for this project. Members of the team volunteered to take on these roles in addition to their own discipline through collaborative multidisciplinary teams. These teams aided in the improvement of interdisciplinary coordination, collaboration, and total building performance. Refer to Integration SD-D for details.

6.2 Decision-Making

Decision-making was a core component of design throughout the duration of the project. Syndicate incorporated decision matrices to assist in making...
unbiased decisions across all disciplines for the betterment of the project over a sole discipline. Design decisions were constantly measured against the goals of the project. One example of a decision matrix being adopted was in deciding whether to rotate The Miller Center on site, as seen in Figure 9. For the decision, the sound quality was a major consideration for the building and therefore was weighted a three, whereas construction schedule was minimally impacted by this decision and therefore was weighted a lower weight of two. This interdisciplinary process of decision making is further explained in Integration SD-C.

6.3 Collaborative Environment

An open, multidisciplinary work environment promoted Syndicate’s integration and communication. Syndicate designated their workspace by discipline, but kept the plan open to allow for cross-disciplinary communication and collaboration, as seen in Figure 10. Whiteboards were used during discussions and decision-making to further visualize integrated design solutions. Large-scale monitors were provided at all work stations to utilize BIM software, such as Revit and Sketchup, to promote collaboration. The setup of this collaborative environment is explained further in Integration SD-B.

6.4 Virtual Reality

Syndicate implemented the use of an HTC Vive virtual reality system. This system allowed the team to delve into details of each space aiding in the integration of disciplines for clash detection, design review, and team approval of architecture. Revit Live coupled to the HTC Vive allowed Syndicate to visualize the different architectural features of various spaces, as seen in Figure 11.

6.5 Team Planning

Syndicate utilized a program known as Trello to keep track of tasks and deadlines among disciplines. Each discipline created their own board to set up and check off responsibilities per person, as seen in Figure 12 on the next page. These boards allowed team members to see what parts of the project were completed by other
disciplines and therefore be able to identify any key areas of integration or participation. Trello also allowed disciplines to assign tasks to other team members to be completed with specified due dates. Refer to Integration SD-A for more information.

6.6 Team Meetings

Early decisions were made that the entire group would meet formally twice during the week. The first meeting would take place at the beginning of the work period on Mondays to discuss tasks to be accomplished in the week and to discuss any upcoming action items. The second weekly meeting would be at the end of the work period on Fridays to discuss the progress made through the week. Whenever the team received feedback, all options sat down to discuss the critiques provided. This created additional meetings when necessary to ensure the team stayed on track. Not only was verbal communication important for team organization, but nonverbal communication was equally vital.

6.7 Nonverbal Communication

Syndicate employed technological programs for nonverbal communication including GroupMe, Trello, Bluebeam Studio, Google Drive, Revit, and Google Calendar, as seen in Figure 13.

GroupMe was used to discuss meeting times, deadlines, and any inspirations that group members chose to share with one another. Google Calendar allowed members to find times that worked best to meet within everyone’s schedules. Bluebeam Studio, Revit, and Google Drive were the main platforms for team collaboration and integration. These programs allowed for multiple members of the team to be working on the same presentation, document, or model simultaneously and acted as storage for documentation, as well as electronic file backup. Refer to Integration SD-B for further detail about software collaboration.

7.0 EARLY DESIGN DEVELOPMENT

Syndicate analyzed the given design of The Miller Center through integrated software and collaborative analysis. This analysis drove multiple iterations for architectural layout optimization and constructability. Refer to Integration Drawing I-1.0 for details.

7.1 Construction Type

In pursuit of The Miller Center’s design, Syndicate had to decide which IBC construction type they would implement. The team originally was designing for Type 2A based on the given design, but this construction type did not allow for the use of wood construction, which would limit sustainability efforts.

The team went through multiple consultations and team discussions regarding this construction type as discussed in Structural Report Section 7.0. In the end, Syndicate chose to design with construction Type IIIA that allows for the concealment of wood structural members using their char rate as the fire-rating. This helped with the integration of disciplines by:

- Allowing the team to decide space-by-space if the structure would be exposed
- Improving acoustical properties of each space by varying material finishes
- Adjustability of room heights to improve acoustical intimacy
- Allowing the team to conceal mechanical and electrical equipment within a plenum space
- Enhancing sustainable design using wood material

7.2 Layout Evaluation

After analyzing the given building design (see Figure 15 on next page) for performance evaluation, it became clear that there were areas for improvement relative to our team goals:

- Lobby facing towards the west allowed a lumen level 87% ASE into the space and 34 tons of solar gain into the lobby
• 25% of commonly occupied spaces not receiving daylight
• Amtrak route running behind The Miller Center causes undesired vibrations and sound transmittance
• Mechanical room located directly behind the large concert hall

Refer to Lighting/Electrical Report Section 4.3 for information on daylighting redesign.

7.3 Layout Enhancement

To enhance these areas for improvement, Syndicate incorporated the following design optimizations:

• Building rotation on site
• South lobby and west corridor addition
• Third floor addition
• Vibration and sound transmittance mitigation

7.3.1 Building Rotation

A 90º clockwise rotation was performed to reduce ASE and solar heat gain in the lobby (Figure 16). With this rotation, an opportunity for a buffer zone was presented using the solid mass on the east and south facades to limit the acoustical issues. This action allowed for the following benefits:

• Reduced the light levels entering the north lobby from 87% to 1.8 % ASE
• Created a larger buffer zone to mitigate sound transmission through wall assemblies rated at an STC of
• Reduced solar heat gain entering the building, as seen in Figure 14

<table>
<thead>
<tr>
<th>Solar Heat Gain (TON)</th>
<th>Current Orientation</th>
<th>Rotated</th>
<th>Percent Change %</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Lobby</td>
<td>34</td>
<td>5</td>
<td>85% reduction</td>
</tr>
<tr>
<td>Rest of Building</td>
<td>4</td>
<td>9</td>
<td>25% increase</td>
</tr>
<tr>
<td>Total Building</td>
<td>38</td>
<td>14</td>
<td>63% reduction</td>
</tr>
</tbody>
</table>

Figure 14: Solar Heat Analysis

This site rotation presented a challenge for Syndicate to assess the acoustical transmission into the recital hall, as well as the choral and orchestral rehearsal spaces along the east façade. To address this challenge, the team implemented acoustical treatment in the recital hall for live performance and felt that the rehearsal spaces were sufficient. Refer to Integration Drawing I-1.0 for further information about the building rotation.

7.3.2 South Lobby and West Corridor Addition

To create a link between campus and downtown Holland, Syndicate designed a south lobby that promotes student and patron interaction. A stronger connection between The Miller Center and the campus itself was achieved by Syndicate taking inspiration from The Martha Miller Center for Global Communication’s rotunda, located directly south of The Miller Center.

Further analysis of the new south lobby design showed the connection to the north lobby had become indirect and congested allowing people to walk through a hallway with classrooms and faculty studios. Syndicate reconfigured the floor plan layout to mitigate this by introducing a west corridor along the exterior façade. Refer to Integration Report Sections 8.3 and 8.4 for details about the west corridor and south lobby. Refer to Lighting/Electrical Report Section 4.3 for south lobby daylighting analysis.

7.3.3 Third Floor Addition

To incorporate an occupiable roof space per the competition challenge into the design of the building, a third floor was created above the north lobby. This additional floor would allow for better flow to the
occupiable roof space, as well as providing the opportunity for daylight optimization. The third floor also allowed Syndicate to move the exterior row of faculty studios from the first floor to this level. The team further added skylights onto the third floor that would allow 9 additional spaces to receive daylight. A major benefit from this addition was the reduction of commonly occupied spaces without daylight from 25% to 4%. Refer to Integration Drawing I-1.0 for Syndicate’s optimized floor plans and daylighting breakdown.

The team pursued an iterative process in the design of the occupiable roof space and upon further consideration of the AEI challenges, Syndicate designed a versatile, partially enclosed space. The rooftop is designed as a 1500 SF pre-function and post event area for both private and public parties. The addition of a green roof with this space was also highly considered, but the additional weight of the assembly would increase the structural depth by 19% and increase the cost of the roof assembly by $25/ SF. Therefore, Syndicate opted to not include a green roof within their design. Refer to Mechanical Report Section 7.2 for the green roof analysis.

7.3.4 Vibration and Sound Transmittance Mitigation

To accommodate the issue of the Amtrak route, Syndicate considered different wall assemblies for the recital hall and symphonic concert hall. These walls were designed to go beyond the industry standard of an STC level of 65 for performance spaces. Refer to Structural Drawing S-8.0 for more information.

Syndicate aimed to decrease the structural borne noise and vibration from the mechanical space behind the concert hall. The addition of an isolated structure, as seen in Figure 17, along with mechanical equipment isolators mitigates structural borne vibrations to ensure no vibrations will disturb performances. The implementation of an isolated structural system allowed the team to reduce the cost of mechanical equipment by not needing to design mechanical equipment isolation as standard isolators instead of designing for stealth equipment (extra quiet). The team also decided to include an option on mitigating train vibrations by using a neoprene isolation mat under the footings and slab on grade within the concert hall.

Syndicate not only considered the negative effects of the vibrations throughout the building, but also discovered an opportunity to utilize these vibrations. While small, the structure has natural vibrations caused by factors such as wind or foot traffic. While completely unnoticeable to occupants, equipment known as Vibration Energy Harvesters (VEH) are sensitive enough to pick up these vibrations. Syndicate implemented these energy harvesters to power all low voltage sensors in The Miller Center, including wireless lighting control sensors and automatic lavatory fixtures. This energy will be used to power the 128 lighting control sensors and 70 automatic fixture sensors that would normally require wiring or disposable batteries. Over the course of a 15-year time period, the VEH devices are able to reduce the building’s CO₂ emissions by 700,000 kg, which is equivalent to removing 168 passenger vehicles from the road. Refer to Lighting/Electrical SD-D for more details.

8.0 Final Integrated Design

Within the following sections, Syndicate focuses on the final design of the following areas of integration:

- Occupiable Roof
- North Lobby
- West Corridor
- South Lobby
- Concert Hall

8.1 Occupiable Roof Final Design

Syndicate collaborated to design an occupiable roof that would act as a gathering space between downtown Holland residents and Hope College community. The space is versatile to a multitude of events and designed to be used year-round. A hybrid ventilation system,
exposed wood structure and optimized lighting controls allowed Syndicate to create a space to be utilized by the community and campus that showcases sustainable design.

8.1.1 Occupiable Roof Systems Integration

Syndicate designed the occupiable roof structure with deep glulam beams and drop panels with recessed linear lighting to create depth and variability within the space, as shown in Figure 18. Minimal disruption on the ceiling was achieved by an exposed wood structure and optimized mechanical system. This unobstructed view allowed for cove lighting to highlight the exposed wood members and bring a warm aesthetic to the space. The team integrated the glulam columns and curtain wall facade with the lighting controls to maximize natural indirect daylight into the space.

Syndicate integrated sliding glass doors into the facade along with overhead fans to encourage air movement and maximize comfort during the warmer months. A heating ventilation system was designed to allow for winter use so that the occupiable roof can be used year-round, while acting as an additional thermal barrier. The space adds an additional R-value of 20 to the roof of the north lobby, saving 90 MMBTU/hr in energy usage. Refer to Structural Report Section 11.0.

The team was able to include the occupiable roof in their budget but saw the space as an opportunity for promoting a fundraising initiative to allow donors to assist in the expense of this versatile space. Options for fundraising presented to Hope College include holding a performance gala for school of music students, advertising for local business sponsorship, and naming opportunities for the rooftop space. To assist with this fundraising initiative, Syndicate will provide free design of models, renderings, and virtual reality walkthroughs of the space to allow potential donors to experience the design, while also matching donations up to $50,000.

8.2 North Lobby Final Design

Syndicate’s multidisciplinary team designed the north lobby of The Miller Center to showcase sustainability while welcoming occupants from both the Holland community and campus. This was accomplished using vertical lighting techniques to accent exposed glulam and CLT systems to emphasize the curtain wall’s transparency at night (Figure 19). Lighting and HVAC controls synced with Lutron’s Quantum software are to be displayed along with static building data on an interactive dashboard. The north lobby is further designed for sustainability through an integrated high-performance façade and underfloor displacement ventilation to reduce mechanical equipment present in the space.

8.2.1 North Lobby Systems Integration

The team integrated through multiple iterations of an exposed wood roof structure to showcase sustainable design that aligns with the materials and resources category of the sustainability plan. This structure incorporates deep wood glulam cross beams supporting a CLT floor system with double story glulam columns integrated along the exterior facade. Refer to Structural Report Section 11.0. In order to ensure quality of these glulam members, the team designated a special laydown area for the heavy timber that is larger than normal, elevated, and protected from weather.

The team collaborated through constructability of glazing layouts and façade connections to meet thermal
and solar capacity enabling a high-performance façade. The team designed the glass and mullions of the north lobby façade for structural capacity based off controlling wind pressures. Refer to Structural Report Section 13.1. Once the minimum glass size was chosen based off loading, the team analyzed the daylight and thermal penetration to find acceptable coatings and glass thicknesses. This façade faces north, therefore, sun coatings were not necessary, but the team’s final design did incorporate laminated glass for safety of occupants (Figure 20). Syndicate’s design enhances the campus by providing views from the building and into the building to maximize occupant experience. Refer to Integration Drawing I-7.0 and Structural Drawing S-6.0 for details regarding this façade. The façade was analyzed for the practicality of incorporating a ventilated double wall façade but had a payback period of 30 years.

As mentioned earlier in Integration Report Section 7.3.1, Syndicate optimized the north lobby orientation to reduce ASE coming into the space, while also reducing the solar heat gain by over 50%. Time schedules are incorporated to allow for full light on between 7 AM and 7 PM but can be overwritten through daylight sensors to conserve energy. Accent lighting was also incorporated in key areas, such as the custom clock designed by Jack H. Miller and the exposed wood members of the ceiling, to showcase the features of the space. The use of lighting controls along with the amount of daylight entering the north lobby allowed Syndicate to reduce the kwh/year by 86% which aided in a total building energy reduction of 53% when compared to the baseline model.

The team collaborated to place duct runs along the first and second story heights, as well as underfloor ventilation displacement to efficiently cool and heat the high-volume space. Syndicate altered the layout of the balcony in the north lobby to allow a stairwell to take occupants to the occupiable roof space. The staircase in this space was offset from the concert hall wall in order to allow for mechanical return ducts running at the second story height. The balcony was extended out 16 feet into the lobby and then hung using steel rods from the structure above. The hanging balcony along with displacement ventilation minimized the presence of mechanical and structural systems by eliminating the need for columns.

8.3 West Corridor Final Design

Syndicate designed a hallway along the first-floor west façade in order to act as a grand corridor between the north and south lobbies. Refer to Integration Drawing I-1.0 for optimized floor plans. This space was designed with a glass curtain wall along the exterior façade to provide ample daylight into the three classrooms.

8.3.1 West Corridor Systems Integration

When analyzing this space, the team realized that the design had allowed 75.5 MMBTU/hr of unwanted solar heat gain into the west corridor. Syndicate researched ways to utilize this solar heat gain and implemented a ventilated double wall façade along the west corridor (Figure 21 on the next page). This system efficiently utilizes the solar heat gain for heat recovery in the colder months, while exhausting the heated air to cool the space in the warmer months. This wall will be constructed on site to modularize the system and then installed into the building to improve quality of construction. Operable glass panels were designed in the ventilated double wall façade to open to the building’s interior to allow for maintenance. The team incorporated continuous insulation above and below the system to enhance thermal performance by mitigating thermal bridges. Refer to Mechanical SD-D for further information.
Syndicate encountered that the interior glass wall of the classroom would create glare challenges. To mitigate sunlight and daylight penetration, the team incorporated a smart tint adhesive film to block any direct sunlight while still allowing for a partial view. An electrochromic tint film by Smart Tint was chosen that varies from 3% to 97% transparent. An additional blackout shade from Lutron’s Serena Shades for situations where the lecturer would be using the projector was implemented. This self-adhesive electronic film can be controlled through switches that provide the ability to dim the transparency. As seen in Lighting Drawing L-6.0, Syndicate was able to increase daylight autonomy within the classrooms to 82% while limiting the ASE to 23% through the addition of the smart tint glazing. This system allowed the team to recover 8.4 MMBTU/hr through heat recovery utilizing the unwanted solar heat gain.

After analyzing the practicality of this system, it provided a reduction in annual utility services by 7%, or $6600 annually, and a payback period of 8 years, which Syndicate deemed to be acceptable to implement into design.

8.4 South Lobby Final Design

Syndicate designed the south lobby to provide a direct connection between campus and The Miller Center to be used primarily by students and faculty. The team created a space that felt both open and flexible, as seen in Figure 22. This was accomplished through all disciplines optimizing designs for the space’s potential. Within the south lobby there are two functions, a comfortable lounge space for students to sit and study and a transition space to encourage visitors to move through the building.

8.4.1 South Lobby System Integration

A combination of CLT, glulam beams and columns, and pendant fixtures resulted in an open design that framed out a lounge space to be used by students and faculty. The uninterrupted double height space benefitted from a minimal structure, displacement ventilation, as well as mounting all track lights to the beams rather than the ceiling.

Mentioned in Integration Report Section 7.3.2, the façade mimics the Martha Miller Center rotunda, providing a balance between natural light and occupancy comfort by alternating the large high-performance windows with solid brick walls. This allowed Syndicate to maximize the views from the south lobby but presented a challenge of solar heat gain and direct sunlight penetration entering the space.

To overcome this challenge, horizontal louvers were incorporated along with 70% tinted glazing to limit the ASE from 84% to 48%. Refer to Lighting Drawing L-6.0. The glass layup for the façade of the south lobby incorporates laminated glass and an argon filled space along with the above-mentioned louvers and tint glazing to enhance thermal, daylight, and safety criteria for the façade. The use of displacement ventilation allowed the team to minimize mechanical presence in the space and provided a more open, exposed structural system. Displacement ventilation was incorporated to provide superior indoor air quality or “well-being” for occupants when compared to ceiling supplied distribution systems. The integration of all systems resulted in a south lobby that met the goals of Hope College and the team, while still providing an open and flexible space for occupants. Syndicate analyzed the practicality of designing the façade of the south lobby as a ventilated double wall façade to utilize the solar heat gain, but like the north lobby, the payback period was not deemed acceptable at a period of 15 years.

8.5 Concert Hall Final Design

Syndicate designed a world class symphonic concert hall (Figure 23) that enhanced the occupant experience while creating a premier performance space through a collaboration of disciplines. This was achieved through the design of concrete precast panels, coordination
between underground ventilation displacement and footings, as well as a steel truss roof structure integrated with catwalk layouts, fiber optic lighting, and acoustical ribbon coordination.

### 8.5.1 Underground Ducts

This large volume space incorporated a displacement ventilation system to efficiently cool and improve air quality to occupants. The system directly cools the utilized space and allows for stratification in the upper zones that can be exhausted instead of cooled. The Blue Duct system runs a 48” duct from the mechanical room to the concert hall below the slab. Refer to Mechanical Drawing M-3.0 for details about displacement ventilation, *Syndicate* collaborated heavily using clash detection in *Navisworks* and *Revit* for a below-grade with the strip footings surrounding the concert hall. The concrete strip footings surrounding the concert hall were lowered by 6’ in order to accommodate a frost depth of 42” and the additional depth for the size of the underground ducts. The concrete shear walls were then designed to be prefabricated with holes to allow for duct travel into the space as seen in *Figure 24*. During construction, the team properly sequenced the concert hall to efficiently install and protect each system. Refer to Construction Drawings C-1.0 for details.

### 8.5.2 Concert Hall Roof

The concert hall roof incorporates all disciplines within the final design. A catwalk layout was determined to correspond with the layout of the structural roofing system to allow for access to performance equipment and maintenance. *Syndicate’s* structural and construction teams collaborated to perform and analyze, respectively, three iterations of the roof structure. After further consideration for budget, *Syndicate* selected the roof structure as a steel truss system to reduce the cost of large wood members with expensive connection details. For more detail about the roof structure options refer to Structural Report Section 10.1.

The roof structure was designed to support lighting and mechanical equipment loads. The use of underground ducts minimized the necessity for mechanical equipment in the ceiling plenum and allowed the team to only need three return ducts sized up to 30”x42”. Collaboration among disciplines allowed *Syndicate* to strike a balance between a fiber optic lighting scheme, general snooted house lighting, and the placement of acoustical ribbons. These ribbons enhance the acoustics of the space and therefore, require specific placement in the ceiling and a specific height to maximize reverberation times. The fiber optic lighting was then coordinated to be hung from the truss above and placed in between these ribbons to create the feeling of a starry night while aiding to blacklist the equipment above. Refer to the Lighting/Electrical Report Section 5.2 for details on the lighting scheme.

The team further collaborated to incorporate a photovoltaic array system on the concert hall roof. The minimal disruptions in sunlight allows the array to ultimately generate 3.26 GWh of energy resulting in a total net savings of $350,000 over its 35-year lifespan. Refer to Lighting/Electrical Report Section 6.1. When originally analyzing site conditions, *Syndicate* discovered that Michigan’s average annual snowfall is 70 inches, compared to the United States average annual snowfall is 26 inches. This allowed the team to incorporate a snowmelt system into their roof assembly with a water storage capacity of 5000 gallons to be used for grey water. Refer to Mechanical Report Section 10.2.
The installation of this snowmelt system along with low flow options for toilets allowed Syndicate to reduce the water consumption of The Miller Center by 30%. The roofing assembly is further optimized to mitigate moisture transmittance and heat loss through a sustainable roof design including 4” polyiso rigid insulation and other materials as seen in Figure 25, that surpasses ASHRAE 90.1 standards.

8.6 Faculty Studios Final Design

The faculty studios serve as a space for professors to work and meet with students throughout the day. Syndicate wanted to create areas for the faculty that optimizes workflow and comfort (Figure 26). Every faculty studio has windows or skylights to provide natural light for improved mental health of the users. The acoustics of the space was important during design considerations since many faculty and students will be meeting and rehearsing in these studios. Integrated acoustical lighting fixtures were intermixed with radiant panel modules to create a dynamic ceiling that provided thermal comfort, artificial light, and proper acoustical qualities. The radiant panels and acoustical lighting fixtures are designed in 2’x2’ and 2’X4’ modules for easier constructability. In addition, the CLT structure above the dynamic ceiling provides an air space to trap in unwanted sound reflections and further improve the acoustics of the space. By integrating all the systems together, Syndicate was able to eliminate extra acoustical paneling on the walls. Refer to Integration Report Section 10.1 for further acoustical analysis.

9.0 Hope College Sustainability Plan

Rather than follow standards, such as LEED or Well, that focus on point accumulation rather than technical goals, Syndicate created a unique sustainability plan personalized to Hope College. This sustainability plan would allow Syndicate to aspire to Hope College’s goal of sustainable design by using The Miller Center as a pilot for future projects.

The team chose to focus on waste reduction, indoor environment, materials and resources, and energy conservation. Refer to Construction Report Section 7.0. Syndicate incorporated a Senseware interactive dashboard display that will showcase the dynamic sustainability aspects of the design during operation (Figure 27).

Behind the scenes, the Lutrons Quantum™ will talk to the Senseware system to portray all savings made by the lighting controls, HVAC controls, and electrical systems. The Senseware system will also manage the savings from water consumption and solar payback. Statistics such as cost and reduced carbon footprint through the utilization of a wood structure will be on the dashboard, as well. Figure 22 provides an example of the dashboard display and portrays the analysis of carbon content based off volume of building structural materials compared to passenger vehicles on the road. This system will be used in lieu of a “plaque” for The Miller Center to proudly present to the community and encourage their contribution to a more energy efficient future. Refer to Integration Drawing I-10.0 for integrated use of this plan and dashboard display boards.
10.0 Integrated Acoustics

Syndicate collaborated in the design of The Miller Center to incorporate world class, adaptable acoustics. This was achieved through analyses using a program, known as ODEON, to measure acoustical criteria of each area, as well as analyzing the enclosure of the critical performance spaces. The team analyzed reverberation time (RT), lateral energy fraction, musical clarity, early decay time (EDT), and speech clarity within the various performance, rehearsal, and faculty spaces. (Figure 28).

<table>
<thead>
<tr>
<th>Definitions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverberation Time</td>
<td>The time it takes for sound to decrease by 60dB</td>
</tr>
<tr>
<td>Clarity</td>
<td>implies a shorter RT and is best for rapid passages</td>
</tr>
<tr>
<td>Early Decay Time</td>
<td>A short EDT is a good indicator of speech clarity</td>
</tr>
<tr>
<td>Lateral Energy Fraction</td>
<td>Measure of the spaciousness of a room</td>
</tr>
<tr>
<td>Sound Transmission Class</td>
<td>Rating of how well a building partition reduces airborne sound</td>
</tr>
<tr>
<td>Impact insulation Class</td>
<td>Rating of how well a building floor reduces impact sound</td>
</tr>
</tbody>
</table>

10.1 ODEON Results

The concert hall is the main feature of The Miller Center and entertains various performance types. After analysis, it was found that no changes were required because the given design already provided acoustical excellence. Commencement ceremonies and other spoken events will take place in this space, so a specific metric to the concert hall was the speech clarity, which is how well speech is interpreted by the listener. By drawing the curtains on the side of the hall, there is an improvement in speech clarity that provides adaptability. The recital hall is similar to the concert hall except that it is a smaller, more intimate performance space for soloists and chamber ensembles. Speech clarity was not considered because there are no spoken events. When considering the other metrics, again, there were no changes necessary.

The practice rooms, faculty studios, and orchestra and choir rehearsal rooms were analyzed using only RT. This single metric is used because these spaces are specifically for practice and a low RT will better allow the instructors and students to hear each distinct note length and intonation. The choir and orchestra rooms did not require any changes, but the practice rooms and faculty studios did. The practice rooms analysis resulted in a low RT, therefore some of the acoustic panels were able to be removed. Integration with all disciplines led to the development of the radiant panel and acoustic light fixture grid in the faculty studios. The acoustical panels within this fixture are good low frequency absorbers for sound while the lighting fixture itself is a great high frequency absorber. This custom fixture allowed for acoustic wall panels to be removed, and premier acoustics to be maintained. Refer to Integration Drawing I-4.0 for ODEON results and Construction Drawing C-3.0 for cost savings.

10.2 Sound and Vibration Transmittance

A multi-disciplinary approach was critical when addressing the sound and vibration in the building. A large portion of this sound and vibration comes from the mechanical equipment. Syndicate’s solution to the vibrations included isolating the structure for the mechanical room. The team designed a system that implements isolation pads between the columns and piers along with isolation joints in the floor system to mitigate vibration transmission from the mechanical room. Equipment specific vibrational isolation includes a varying combination of spring isolators and concrete inertia pads. The equipment also creates airborne noise that travels through the ducts. To prevent this sound from disturbing sound sensitive spaces, duct silencers, duct lining, long duct runs, and multiple mitered elbows were implemented. Refer to Mechanical Report Section 9.0 for details on equipment acoustics.

The concert hall was an acoustically critical space due to the performances that would be taking place. Therefore, the team further isolated this system using isolation padding between embed plates and beams framing into the concrete precast panels. To further improve the acoustical quality of the concert hall, the team built-up the wall assembly of the concert hall to meet STC 65. The floor assembly was built-up as well to surpass STC and IIC values of 50. See Structural Drawing S-8.0 for details. Throughout construction, the team will ensure acoustical quality through reminders at weekly foremen meetings and utilizing QR code tracking system in each space. Refer to Construction Drawing C-2.0 for more detail.
11.0 Lessons Learned

During the design of The Miller Center, Syndicate grew as a team to improve on the individual and collaborative levels, as well as the overall design process resulting in these valuable lessons to be taken away:

- **Communication is the foundation for collaboration**, without it the team will fail along with the design.
- **Every design choice has the potential to bring both seen and unseen results** for other disciplines.
- **Building Information Modeling (BIM)** is the catalyst for coordination between disciplines, spanning all lifecycle phases of design.
- **Cross-disciplinary interactions provide a unique perspective** that can refine solutions.
- **Consultation with experts and professionals can lead to a better understanding** of the end user’s needs and wants.

- **A good design is revealed through** mistakes, innovations, and integration.

12.0 Conclusions

*Syndicate* utilized iterative and integrative design approaches to sustainably and economically create a combined design of The Jack H. Miller Center for Musical Arts. The team operated under an integrated design-build delivery method to streamline communication between the owner and their project team, while providing the best quality of work on a fast-tracked timeline. *Syndicate* was able to complete the project within a 16-month schedule and successfully develop a budget of $23,926,850 with donations covering the cost of the occupiable roof. Refer to Integration Drawing I-6.0. The final design of The Miller Center provided Hope College with an educational and performance center that improved the campus and downtown Holland with numerous benefits as shown in Figure 29.

<table>
<thead>
<tr>
<th>OWNER DEFINED GOALS</th>
<th>SYNDICATE DEFINED GOALS</th>
<th>IMPROVEMENT</th>
<th>BENEFIT</th>
<th>DISCIPLINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection</td>
<td>Enhance Hope College Campus</td>
<td>Layout optimization</td>
<td>Create a connection between downtown Holland and campus</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Occupiable roof addition</td>
<td>Space versatile to a multitude of activities and events for the school, public, and a combination of both</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotation of building</td>
<td>Reduces solar heat gain entering the lobby by 63%</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reduces annual sunlight exposure of large lobby by 85.2%</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td>Versatility</td>
<td>Maximize Occupant Experience</td>
<td>High Performance/Adaptable Acoustics</td>
<td>STC standards met or exceeded for each roof and wall assembly</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skylight on third floor roof</td>
<td>Increases amount of commonly occupied spaces receiving daylight by 13%</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Finish material selection</td>
<td>Wet or exceeded evaporation times for each type of performance materials</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moveable curtains in central performance hall</td>
<td>Spaces designed for educational and performance activities</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td>Performance</td>
<td>Create Premier Performance Spaces</td>
<td>Ventilated double wall facade</td>
<td>Decreases annual utility cost by 34% on $6600 annually</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-performance wall assemblies</td>
<td>Meets required R-value for thermal barrier by at least 38%</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concert Hall room finishes and acoustical ribbons height</td>
<td>A broad range of acoustical materials, interfacial energy fraction, and musical clarity</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>QIC coated during construction</td>
<td>Increase quality control and assurance</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolated structure for Mechanical Space</td>
<td>Minimize structural borne vibrations</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td>Sustainability</td>
<td>Minimize Energy Impact</td>
<td>Implementation of a Lumen Quantum display system</td>
<td>Provides a pilot for sustainable design for future projects</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incorporating wood engineered products into structural system</td>
<td>Reducing carbon content of the building by 27% when compared to steel structure</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PV array system on concert hall roof</td>
<td>Total net savings of $550,000 over a 35-year lifespan, generates 0.1569 MWh of energy</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHP system option</td>
<td>Capability for 90% further expansion of campus connection</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low flow toilets</td>
<td>Reduce water consumption by 30%</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Snowmelt and rainwater collection system</td>
<td>Can hold up to 2400 gallons of water to be used for grey water</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall energy reduction</td>
<td>Reduced overall building energy usage by 44%</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skylight on third floor</td>
<td>Overall net energy reduction of 2,647 kWh/year</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring construction waste on a biweekly basis</td>
<td>Reduce carbon footprint impact</td>
<td>Architecture &amp; Engineering, Construction Management, Interior Design</td>
</tr>
</tbody>
</table>

*Figure 29: Team Conclusions*
Syndicate utilized Trello to allow the team to function in a dynamic manner. Throughout design, all disciplines had their own tasks to complete along with information and tasks to complete for other disciplines. To keep track of these tasks, as well as deadlines throughout the project, boards were set up for the different disciplines and subcommittees. As seen to the left, these boards were broken down by category into different checklists. This software program allowed the team to maximize their collaborative efforts and efficiently follow strict deadlines.
COLLABORATIVE SPACE

An open, multidisciplinary work environment promoted integration and communication more readily. As shown below, Syndicate designated their workspace by discipline, but kept the plan open to allow for cross-disciplinary communication and collaboration. Each team member had their own work station with two monitors as seen below. Within the space, two white boards separated the work space from a conference space. These white boards were used during discussions and decision making to sketch graphics and further visualize ideas for integration. Syndicate chose to utilize the conference space for consultations with industry professionals and advisors.

An interactive large-scale monitor was placed in the center of the work room. Syndicate chose to set up two tables in front of this monitor to create a meeting space so that the monitor could be utilized to bring up models and meeting minutes. This interactive monitor also acted as a tool to assist in discipline collaboration and integration.

Intradisciplinary Collaboration
To create as successful of a work space as possible, Syndicate chose to designate work station location for each member based on discipline. This allowed for the best intradisciplinary communication and collaboration. The success of the intradisciplinary interaction led to success within the interdisciplinary interaction as well.

Interdisciplinary Collaboration
Syndicate found that interdisciplinary collaboration was key in creating a successful project. The open plan for the work space assisted in open communication among disciplines. The interactive tables, whiteboards, and technology also aided Syndicate creating and discussing graphics to further discuss and visualize integrated aspects of the project.

INTEROPERABLE SOFTWARE USAGE

Interoperable software became a key component to collaboration among all disciplines. Each discipline used the software programs listed above for information storage, design, analysis, and planning. Syndicate utilized a central model within the building information modeling (BIM) software of Revit to assist with clash detection, layout optimization, and visualization of spaces. This program allowed the team to input their own discipline specific design into the building and promoted easier team communication. The team created storage locations for shared files and information within Google Drive and Bluebeam Studio for easy access among team members. Trello also became a main collaborative platform for sharing deadlines and tasks required for each team member to complete.
DECISION MATRICES

Syndicate utilized a decision matrix to make unbiased decisions that connected back to their vision statement of HOPE. The use of decision matrices was necessary when making decisions for the design as it aided in a faster decision being made, as well as, an easy way for all members of the group to be integrated and involved.

DECISION MAKING PROCESS

The four overarching goals that Syndicate incorporated into the matrix from the vision statement of HOPE were broken down into design based criteria. These criteria were kept consistent throughout all disciplines in order to connect all decisions to the original four overarching goals.

When choosing the weight of the specific criteria, one member would weigh all criteria and then at least three other members of the team would analyze the weights and give their input. If there were any discrepancies, the team would have a group discussion regarding the weighting of the criteria. This was the procedure not only for decisions that had cross-disciplinary criteria, but also for decisions that were discipline specific. For example, one discipline would have at least one member from every other discipline review their matrices and provide feedback. This interdisciplinary process ensured that the design decisions were constantly measured against the goals of the project.

The weighting of the criteria varies from a weight of one through three, with a three being very important to the project goals and a one being the least important. The specific rating is then based on a one to three scale with a one being the worst option for that criteria and a three being the best option.
Syndicate is comprised of ten members with the following breakdown by discipline:

- Three structural designers
- Two mechanical designers
- Two construction members
- Three lighting/electrical designers

The team was then broken down into multidisciplinary teams based off the goals of the project. The multidisciplinary teams include acoustics, architecture, and building enclosures. All members of Syndicate took part in the architecture decisions being made throughout the design. Each team consisted of one member of each discipline to promote collaboration and integration among disciplines, as seen above.

Within the multidisciplinary teams, design iteration and decisions were made. Each member of each discipline was responsible for discussing the decision with their own discipline members and the decisions were then brought up in full team meetings as well. These teams allowed Syndicate to optimize integration and collaborative thinking while mitigating biased design decisions.

### DOMINANT PERSONALITY MATRIX

From the time of forming the team, Syndicate realized that analyzing and understanding each member’s personality would be crucial for creating a cohesive and trustworthy group. Every team member took a personality test known as the Personality Matrix which uses a more generalized range of personal qualities, allowing for simpler comparisons within a smaller team. The construction team used these results to plan for situations like team bonding, conflict mediation, and indicating stress amongst other members. As seen to the right, the Analyzer, Controller, and Supporter were all equally represented in Syndicate. Overall, Syndicate felt that the team was well-rounded and allowed every member to grow throughout the duration of the project. Seen to the left is a grid displaying where members from each discipline fell into each personality type. Since the individual disciplines are required to divide their work amongst two or three people, understanding each person’s strengths and weaknesses becomes crucial to delegating tasks. Somebody with a dominant “Owl” personality is more likely to be more detail oriented and organized, whereas somebody with a dominant “Koala” personality may have the ability of reflective thinking and therefore expressive writing and speaking.

### VIRTUAL REALITY

The team utilized Virtual Reality (VR) to aid in systems integration, space visualization, and decision making. The ability to walk through a space, experience the architecture, and witness the features allowed the team to optimize their design.
MILESTONE SCHEDULE
Syndicate created a 26-month total design and construction schedule for the Jack H. Miller Center for Musical Arts. Sixteen of those months consist of the construction phase of the project. Shown to the left is the milestone schedule for the project that was created to give the owner a high-level summary of the project activities. This also aids in determining the overall duration of construction and ensures any major conflicts with campus events are mitigated. Due to Syndicate's design-build delivery method, the project can be fast-tracked, meaning the construction period begins before the design is complete. The notice to proceed for construction happens in the early second quarter of 2020, and construction of the project ends in the third quarter of 2021. Further schedule detail can be found on Drawing C-4.0 and Drawings C-5.0.

TEAM DESIGN PROCESS
Syndicate's design process neatly categorized into three main phases: discovery, design, and develop. With this movement of collaboration, Syndicate was able to better their integration skills and keep all team members on the same pace. During the first few months of meeting the discovery phase occurred. By taking the time to better understand the challenges given to us, one another's personalities and working skills, defining the overall end goals for the project, and setting core hours to meet, Syndicate's disciplines were able to better design with common mindsets. Moving through the design phase, large amounts of integration occurred, finding key spaces to expand on together, implementing decision matrices that would incorporate all disciplines, and constantly reiterating designs to make sure all disciplines were thought of. Once all designs were finished with contentment, Syndicate took feedback from all teammate as well as outside voices to catch anything that could use some final adjustments. Detailed designs, explanations, and final deliverables were then created to make sure anybody viewing the project could fully understand the intent that Syndicate put forward.
The project site for The Miller Center is located on the northeast corner of Hope College campus and south of downtown Holland, as seen below. There is an Amtrak route approximately 100 feet behind the site, as well as a highly trafficked east 9th street and a less frequented east 10th street.

The addition of the third floor required Syndicate to design fire-rated stairs based off of the IBC 2018 requirements.

= Fire Rated Stairwell
WOOD CHALLENGE

Syndicate took on Hope College’s challenge to use a minimum of 25% wood products in the design of The Miller Center. To accommodate this, the team collaborated to design and showcase glued-laminated timber beams and columns, as well as, a cross-laminated timber floor system. The team measured the wood challenge through volume of material designed within the Miller Center’s superstructure. At the completion of design, Syndicate calculated the volumes of concrete, steel, and wood used in the superstructure and found that they had completed the wood challenge by designing 90% of the superstructure by volume of material as wood products as seen below.

CARBON CONTENT ANALYSIS

Syndicate analyzed the carbon content associated with the materials incorporated into the structural system. As seen below, through the use of sustainable materials, the team was able to decrease the kilograms of carbon dioxide of The Miller Center by 27%. This is equivalent to removing about 86 cars from the road for a year.

CARBON CONTENT COMPARISON

Baseline Steel System: 1,427,487 kg CO₂
Timber System: 1,043,019 kg CO₂

27% Reduction in kg CO₂

= 10 CARS

SYNDICATE
PROJECT
JACK H. MILLER CENTER FOR MUSICAL ARTS
HOLLAND, MICHIGAN

SCALE: NOT TO SCALE
NOT FOR CONSTRUCTION
01-2019
The Faculty Studios are utilized by Hope College professionals to train a wide variety of music students. Syndicate was able to improve the reverberation times of these spaces at several frequencies by installing custom radiant panels and acoustic lighting fixtures, while saving money by removing the original wall panels.

The Choir Rehearsal Room allows choirs of all sizes and voices to rehearse. A lower reverberation time is desired here as well so vocalists may hone on their technical skills. As with the orchestra rehearsal Room, Syndicate deemed this space acoustically acceptable and chose not to modify the given design.

The Orchestra Rehearsal Room provides a space for instrumental ensembles of all sizes to rehearse. A lower reverberation time is desired here so that instrumentalists and conductors can focus on precision along with musicality. The given design met Syndicate’s standards and was not modified in any way.

The Practice Rooms are crucial to Hope College students enrolled in the music department, as they are designed specifically for individual vocal and instrumental practice. Syndicate found that by removing half of the given acoustic wall panels, the reverberation times at most frequencies shifted closer to an ideal value.

The Recital Hall offers a more intimate performance space for soloists and chamber ensembles. In order to ensure quality musical performances, acoustical qualities such as lateral energy fraction and musical clarity were observed in addition to reverberation times and early decay times. Given that the only variation Syndicate introduced was the exposed CLT ceiling structure, it was determined that the given design could be deemed adequate.

The Concert Hall, being the main feature of the Miller Centre, required the highest degree of acoustical analysis from Syndicate. Since Syndicate made no design changes that directly affected the Concert Hall, the original design was modeled in ODEON. The reverberation times were found to be within an ideal range for almost all frequencies, as well as the early decay times for most frequencies. These two values are critical in large performance spaces as they relate to how much musical sound “rings” in a space, which creates the sense of liveliness that audiences crave. Lateral energy fraction, which quantifies the spaciousness of a room, was also shown to be within range of the ideal values for a typical concert hall. Musical clarity is also an important quality in large performance spaces as it defines how well the intricacies within an ensemble can be heard. Once again, the original design proved to be more than adequate within this criteria. Since the concert hall will also house commencement ceremonies, speech clarity was also analyzed and was found to be within an acceptable range when the side curtains of the hall are drawn. See Drawing C-3.0 for all cost-related impacts to acoustical changes.
Cross Talk
Cross talk, which is defined as when sound travels from one space to another space, through ductwork is mitigated by increasing the length of duct between the spaces and adding elbows.

Duct Acoustical Treatment
The team implemented various techniques to mitigate sound travel through ducts:
- Long duct runs
- Duct silencers
- Duct lining
- Mitered elbows
- Round ducts
- Duct attenuators

ACOUSTICAL TREATMENT OF WALL AND FLOOR ASSEMBLIES

The isolated structure consists of a double column along the perimeter to frame out the space. An isolated pad was placed between the wood column and concrete pier on the mechanical side to further reduce the vibrations entering the footing. Within this isolated structure, the team also incorporated isolation joints into the slab on grade, as well as the CLT floor assembly to further isolate the mechanical vibration and structural borne sound transmittance.

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Although the cost of the occupiable roof was covered within the Optimized Design budget, Syndicate would like to offer Hope College with another way to cover the cost of an occupiable roof for their patrons, rather than including it in the project budget. We suggest that the college pursues a fundraising strategy for this feature. Some options for this could include:

- Program advertising for local business sponsorship
- “Patron Levels” program with incentives for donors
- Performance gala for school of music students
- Naming opportunities for rooftop space

As the construction team, Syndicate’s role would be to provide a free design of the roof, provide models, renderings, and virtual reality walkthroughs for the potential donors, and match the donations up to $50,000.

The placement of the occupiable roof on the north side was advantageous for natural ventilation because of the light summer breezes coming from the north. To encourage air movement during the summer months, fans were placed throughout the space. The simplicity of the occupiable roof mechanical system increases constructability and ceiling coordination. With minimal mechanical equipment and flat CLT ceilings, a drop-ceiling panel was able to be placed in three bays to house recessed lighting and an LED tape-light cove.
1. **Shading and Glazing System**

   - VLT = 44%
   - SHGC = .58
   - U-Value = .48

2. **Flexible Space**

   - Student/Faculty Lounge Area
   - Transition to Educational Spaces
   - Gateway to West Corridor and North Lobby

3. **Connecting Campus to Downtown**

4. **Ventilated Double Wall Facade**

   - VLT = 4-98%
   - SHGC = .71

5. **Project Information**

   - JACK H. MILLER CENTER FOR MUSICAL ARTS
   - HOLLAND, MICHIGAN
   - Sheet Title: South Lobby, West Corridor, and Classroom Integration
   - Scale: Not to Scale
   - Date: February 18th, 2019
   - Drawing No.: I-8.0
   - Page No.: 28

6. **Syndicate Information**

   - Project: Jack H. Miller Center for Musical Arts
   - Holland, Michigan
   - Sheet Title: South Lobby, West Corridor, and Classroom Integration
   - Scale: Not to Scale
   - Date: February 18th, 2019
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   - Page No.: 28
1. **BELOW SEAT DISPLACEMENT VENTILATION INTEGRATION**

2. **BALCONY COORDINATION**

3. **ACOUSTICAL RIBBON/ FIBER OPTIC INTEGRATION**

4. **CRANE SELECTION AND PRECAST PANEL LAYOUT**

5. **CATWALK LAYOUT COORDINATION**

6. **LONG SPAN STEEL ROOF TRUSS**

7. **PHOTOVOLTAIC ARRAY**

8. **SYNDICATE**

   **PROJECT**

   **JACK H. MILLER CENTER FOR MUSICAL ARTS**

   **HOLLAND, MICHIGAN**

   **DATE**

   **SCALE**

   **DRAWING NO.**

   **PAGE NO.**
THE HOPE COLLEGE SUSTAINABILITY PLAN

Syndicate, after considering aspects of the LEED and WELL plans and the efforts that Hope College is already making, has created a customized sustainability plan for Hope College. This plan allows Hope to pursue environmentally-minded goals without sacrificing their academic objectives. There are four main canons that encompass large sustainability aspects, and those four are broken down into several implementation categories (shown below). The objectives that were considered during the integration design in The Miller Center are highlighted below.

DASHBOARD DISPLAY

Syndicate analyzed criteria across all disciplines to incorporate throughout design within the sustainability plan. This information will be provided to the public and Hope College through a dashboard system located in the north and south lobbies that tracks dynamic building statistics along with static information. As seen in the dashboards, this information has been presented within a user friendly interface through simplified graphics.
0.0 STRUCTURAL EXECUTIVE SUMMARY

**GRAVITY SYSTEM**
- CLT panel floor system supported by glulam girders and columns
- Superstructure composed of 86% engineered wood products by total structural volume
- Fire-resistance rating achieved through char design

**LATERAL SYSTEM**
- 8” & 12” precast concrete wall panel system serving as the main lateral force-resisting system
- Precast panels enclose acoustically sensitive spaces
- Building drift limited to H/400

**ROOF SYSTEMS**
- Long-span glulam beams in recital hall, rehearsal rooms and organ faculty studio
- Pre-fabricated steel truss in the main concert hall
- CLT panels used as structural roof decking

**NORTH LOBBY**
- Exposed, heavy-timber framing system creates a sustainability statement
- Integrated and high-performing curtain wall system
- Steel rods used to hang the balcony to minimize view interference

**FOUNDATION**
- Concrete spread footings under all columns
- Continuous strip footings under all precast wall panels
- 5” slab-on-grade throughout the building
- Special slab-on-grade system in the concert hall consisting of 4” slab, 2” *Regupol vibration* 200 pad and 6” slab to mitigate vibration disturbance

**ISOLATED STRUCTURE**
- Vibration isolators under columns of the mechanical space to prevent vibration transmittance
- Separate structure housing the building system equipment to prevent noise transfer
1.0 PROJECT OVERVIEW

The Jack H. Miller Center for Musical Arts (The Miller Center) is a proposed building project for Hope College located in Holland, Michigan. Syndicate is an integrated design-build team that produced a high-quality design and construction plan for this project. The project site is situated in the northeast corner of campus across from downtown Holland, near Lake Michigan. The Miller Center acts as an investment for the future of Hope College and as a showcase pilot for a new sustainability plan on campus. The addition of an occupiable roof and south lobby allows this building to act as a gateway space for connecting Hope College campus to downtown Holland. The Miller Center can be seen in Figure 1.

Figure 1: Syndicate’s Design

Syndicate’s final design is a three-story building designed for serving the educational and performance requirements of Hope College. Totaling 70,000 square feet (SF), The Miller Center includes an 800-seat symphonic concert hall, a smaller recital hall for intimate chamber performances, and two large rehearsal spaces for choirs and orchestras. The building also includes classrooms, faculty studios, and student practice rooms distributed throughout the three stories.

2.0 VISION STATEMENT

Through a multidisciplinary team strategy, Syndicate produced a high-quality center for musical arts that met the goals and mission of Hope College. As a team, Syndicate chose to pursue this project with a vision statement that would contain individualized team and discipline goals. The vision statement is HOPE and the goals are to:

- Enhance Hope College Campus
- Maximize Occupant Experience
- Create Premier Performance Spaces
- Minimize Energy Impact

Refer to Integration SD-A for details about the vision statement.

3.0 PROJECT GOALS

To achieve HOPE, Syndicate created specific integration goals for these four vision statements. Below are the objectives for the structural team to meet the integrated team goals.

3.1 Enhance Hope College Campus

The structural team worked closely with other disciplines to produce a structure that is economical, efficient and accommodating of the other building systems within The Miller Center. Furthermore, Syndicate showcased and optimized the wood structure. To accomplish this, the structural team set out to:
• Minimize the cost of a wood structural system through mindful member placement, resulting in reduced member quantities.
• Target a SF cost that is within 15% of a comparable steel system.
• Optimize gravity members to be within 85%-95% of capacity with respect to their controlling limit state.
• Reduce erection schedules through prefabrication, construction engineering and integration of wood and precast concrete.
• Develop early integration efforts to establish each discipline’s design intentions at the start of the project, allowing for a strategically laid out structure.

3.2 Maximize Occupant Experience

The structural design team strategically exposed the building’s structure in the double story north lobby and the occupiable roof space with the intent to:

• Create prominent spaces of interest and drama in areas that serve as a display for a unique system.

These spaces are framed by large, glued-laminated (glulam) timber members with cross-laminated timber (CLT) panels left exposed to create a wood-finish ceiling. The natural rhythm of the structure echoes throughout these spaces and strives to compliment the sensory experience of musical arts.

The team also recognized that limiting structural borne noise and building movement was significant. To address these concerns and further enhance occupant experience, the team set forth to:

• Achieve and surpass the minimum sound transmission class (STC) and impact insulation class (IIC) of 50 for the structural floor system.
• Mitigate floor vibrations by designing the gravity system to minimize perceived walking floor movement.
• Isolate mechanical equipment to prevent incidental vibrations from being transferred to occupiable areas.

3.3 Create Premier Performance Spaces

Superior acoustical performance was the primary metric that influenced all design decisions throughout the project, including structural. For each performance space, Syndicate aimed to:

• Design concert hall and recital hall wall assemblies that achieve a minimum STC value of 65.
• Structurally design the balcony for unobstructed views.
• Provide flexibility in the roofing system for flexible catwalk placements or future modifications.

To ensure that the building performs acoustically as intended, the structural and construction teams will work together to create details and construction procedures that exceed acoustical standards.

3.4 Minimize Energy Impact

Energy impacts resulting from the built environment are substantial. As such, endeavors to create a building that embodies sustainability was crucial. We set forth with the following goals in mind:

• Design a structural system composed of at least 25% engineered wood products by structural volume.
• Reduce the structure’s embodied carbon content by 25% as compared to a traditional steel system.
• Source materials from a manufacturer that is conscious of sustainability.
• Limit the number of individual members through numerous layout iterations and optimize their efficiency to be within 15% of the controlling limit state.

4.0 BUILDING STRUCTURE OVERVIEW

To achieve these goals, the structural team of Syndicate conducted an iterative and multidisciplinary design process that produced a superior final design. The team’s final design is shown in Figure 2.
Syndicate surpassed its original goal of incorporating engineered wood products into 25% of the structure’s volume by delivering 86%. The primary products used to achieve this 86% are CLT panels as the floor system, along with glulam members serving as the beams and columns. A precast concrete wall panel system was designed to serve as the main lateral force resisting system that is also load bearing to assist with gravity loads. These walls surround the concert hall, recital hall, two rehearsal spaces, organ faulty studio, elevator shaft, and stairwells and act conjunctially as acoustical barriers to reduce sound transmission into or out of the various performance spaces. The foundation system consists of cast-in-place reinforced concrete spread footings and continuous strip footings under columns and walls, respectively. These foundations are able to effectively distribute the building loads on the soil while also remaining above the water table. This reduced the cost and simplified the construction processes.

5.0 DESIGN AND ANALYSIS SOFTWARE

No single program could analyze every system. The team utilized multiple programs to aid in efficiently designing the gravity, lateral and foundation systems. These programs include ETABS, SAP2000, Woodworks Sizer, RAM, RISA, and Microsoft Excel. See Structural SD-A for a flowchart explaining how the structural team designed and verified our systems with these technologies.

6.0 CODES AND STANDARDS

The structural design of The Miller Center was completed in accordance with the 2015 Michigan Building Code, which adopts the 2015 International Building Code (IBC 2015) with amendments. The following publications were most notably referenced as well throughout the duration of the project.

- ASCE 7-16
- 2018 NDS, Supplement and SDPWS
- CLT Handbook

A more extensive list of the publications utilized during the project can be found in in Structural SD-A.

7.0 CONSTRUCTION TYPE

As a collective, an interdisciplinary collaboration was established to put sustainability forward in the overall design of The Miller Center, including structural. The given design was classified as Type IIA Construction, which does not allow for combustible structural, this limits utilizing the highly renewable structure material, wood. To forward focus on a wood structure, Syndicate studied three construction types to maximize their opportunity for wood implementation (Figure 3).

7.1 Limitations of Type IV Construction

Syndicate initially planned to design The Miller Center according to Type IV Construction requirements. While a Type IV classification does allow the use of heavy timber elements in structures, it requires that they be left exposed for fire safety concerns. As a result, the team was not able to conceal unsightly mechanical, electrical, and plumbing equipment with closed ceiling plenums. This inability to conceal equipment took away from the team’s architectural vision to align with the rest of Hope College. In addition to the concerns over appearance, the exposed equipment would have diminished the acoustical performance of the spaces as well.

7.2 Type IIIA Construction

To achieve our desired vision for The Miller Center, Syndicate researched further into construction type requirements and found that Type IIIA does allow for the concealment of combustible structural systems.

To attain a Type IIIA classification, several criteria had to be met for this change to be permissible. The two primary areas of concern were the building size and the
To present a conservative structural design for The Miller Center, both methods were used for the CLT analysis, with the more stringent condition of the two ultimately being selected. The schematic shown in Figure 4 displays the theory behind designing a beam for char. The same basic concept is similarly applied to all other wood structural elements in The Miller Center.

To achieve the mandated IBC 1-hour char fire-rating for glulam beams, an effective area of 1.8” deep on all exposed sides is not considered to contribute to capacity. For example, Figure 4 shows a beam exposed on three sides. This would reduce an 11”x23.5” member to an effective cross section of 7.4”x21.7”. Due to their initial size, the controlling limit state for many of the longer span CLT and glulam beams are vibration and deflection, respectively, instead of char design. However, when smaller initial cross-sections are considered, like for many of the columns, it often becomes the controlling limit state. Due to the highly specialized nature of these construction materials, the structure was designed to exceed basic code-level requirements. Given that this design strategy was only recently adopted, Syndicate’s approach may require special approval from the governing code official and/or certification from our Engineer of Record (EOR).

8.0 GRAVITY SYSTEM DESIGN

Numerous materials and systems were investigated and refined to arrive at the final design of heavy timber glulam framing with CLT for the gravity system. The engineered wood products are sourced from Nordic Structures. This manufacturer was chosen due to their sustainability efforts. Nordic is environmentally-focused and has a strict forest management system to ensure that all trees that are used for their structures are immediately replaced. See Structural Drawing S-10.0 for more details.

The CLT chosen has a stress grade of E1 with a 267-9I layup combination that has a thickness of 10.5”. The CLT panels were carefully designed to limit vibrations, as discussed later in Structural Section 8.4.1, “Vibration Analysis”. The glulam members have a stress grade of 24F-ES/NPG. Additionally, the precast wall panel system is utilized for load bearing throughout the structure.
8.1 Gravity Loading

Gravity loads were determined in accordance with IBC 2015, and ASCE 7-16. Typical dead loads and live loads are shown on Structural SD-B and Structural Drawing S-2.0 respectively.

At the roof levels, snow loads controlled. The flat roof load was 35 psf with areas subject to drift had additional loads varying between 17 psf and 95 psf. See Structural SD-B for a sample drift calculation. The structure was designed to withstand the full snow loads of the region even though a snow melt system was incorporated into the roof assembly. This was done to provide added redundancy in the event it goes offline. Refer to the Mechanical Section 10.2 for more details regarding the snow melt system.

8.2 Design Progression

During the early stages of design, Syndicate’s structural team researched a wide variety of gravity systems. The system analysis table on Structural Drawing S-1.0 gives a complete list of all the systems considered and was used to weigh the pros and cons of each option.

During preliminary system selection, the team aimed to establish relatively square bays typically ranging between 20'-0” and 30'-0” for architectural and MEP system coordination.

A typical bay for three systems (composite steel beams with concrete on metal deck, glulam beams with concrete on metal deck and glulam beams with a CLT floor) was designed for a more in-depth evaluation (Table 1). The information was analyzed with the decision matrix, found in Structural SD-A, to compare all three systems using criteria such as embodied carbon content, cost, MEP coordination and acoustical performance.

After a thorough review of the itemized table, the structural team determined that glulam beams with CLT floor was the best system for Syndicate’s vision and sustainability goals. Early identified drawbacks of this system were:

- An increased cost of 14% compared to the glulam beams with concrete on metal deck.
- Bays with glulam beams have an approximately 172% increase in system depth compared to steel beams.

However, our decision to choose the glulam beam and CLT system was driven by:

<table>
<thead>
<tr>
<th>Steel Beams with Concrete on Metal Deck</th>
<th>Benefits</th>
<th>Trade Offs</th>
<th>Goals Met</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Concrete slab is non-flammable and acts as fire barrier between levels at certain thickness</td>
<td>• Cast in place concrete slabs have long durations and are labor intensive</td>
<td>• Create Premier Performance Spaces</td>
<td></td>
</tr>
<tr>
<td>• Fast erection time with steel</td>
<td>• Steel has highest construction noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Concrete acts as sound insulator</td>
<td>• Greatest possibility for structural borne noise and noise transfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Concrete slabs require infill beams every 8-12 feet</td>
<td>• Steel members require separate fireproofing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Glulam Beams with Concrete on Metal Deck</th>
<th>Benefits</th>
<th>Trade Offs</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Concrete slab is non-flammable and acts as fire barrier between levels at certain thickness</td>
<td>• Cast in place concrete slabs have long durations and are labor intensive</td>
<td>• Maximize Occupant Experience</td>
<td></td>
</tr>
<tr>
<td>• Glulam char acts as fire protection on members</td>
<td>• Heavy slabs will result require considerably larger members than steel solutions</td>
<td>• Minimize Energy Impact</td>
<td></td>
</tr>
<tr>
<td>• Glulam can be left exposed for aesthetics</td>
<td>•</td>
<td>• Create Premier Performance Spaces</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Glulam Beams with Cross Laminated Timber Floor</th>
<th>Benefits</th>
<th>Trade Offs</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lightest structure</td>
<td>• Most expensive structural system</td>
<td>• Minimize Energy Impact</td>
<td></td>
</tr>
<tr>
<td>• High strength per unit area</td>
<td>• Larger member sizes as compared to steel</td>
<td>• Maximize Occupant Experience</td>
<td></td>
</tr>
<tr>
<td>• 20% less carbon dioxide emissions compared to steel</td>
<td>• Most expensive unit</td>
<td>• Enhance Hope College Campus</td>
<td></td>
</tr>
<tr>
<td>• Absurdent prefabrication opportunities</td>
<td>• Infill beams not required with CLT panels</td>
<td>• Create Premier Performance Spaces</td>
<td></td>
</tr>
<tr>
<td>• Fastest erection schedule</td>
<td>• Timber can be left exposed for aesthetics</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Typical Bay Analysis
- A cost within 1% of the system of steel beams with concrete on metal deck
- Achieving the building program goal of a sustainable system and reduced overall carbon content
- Decreasing the schedule
- Easier framing connections
- Limiting the number of individual members. Due to the spanning capacity of CLT panels, no infill beams are required, which takes the beam count down from 7 to 2 per bay.

Within the many early framing layout iterations, a column was added near midway along one of the longest beam spans. This addressed the drastic increase in beam depth between the wood and steel systems. The now improved design created an extra 21.5” of uninterrupted ceiling space to coordinate with the MEP system. This negative component determined through the typical bay analysis no longer existed allowing for smooth integration between the systems. This can be seen below in the cross section shown in Figure 5.

![Figure 5: Structural Depth Optimization](image)

The time spent on early iterations also allowed us to refine our lay-out design, which continually resulted in reduced member quantities, and therefore, reduced cost. Once the architectural changes were complete, the current framing plans shown on Structural Drawing S-3.0 were finalized, which optimized efficiency and serviceability requirements under the given architectural and structural constraints.

### 8.3 Beam and Column Design

The final design of the gravity system resulted in glulam beams typically ranging from 7.25”x23.5” to 11”x54.5” in size. The wood framing elements were sized using NDS’s procedures for the ASD design. Beams were appropriately sized to meet the criteria for strength, serviceability and char. For deflection allowances, live load deflections were limited to L/360 and total load deflections to L/240. The only exception to these criteria were at exterior beams, where the total load deflection was limited to L/600 to uphold the brick veneer. Syndicate’s efficiency target of being within 15% of the controlling limit state was achieved for each individual member.

Typical columns were selected as square or near-square sections to optimize their biaxial performance. As a result, the typical columns ranged between 11”x11” and 11”x12.5”. With constructability concerns over placing the large CLT panels, columns are spliced at every level to minimize crane obstructions. To simplify construction and connection detailing, columns have the same cross section from the ground to the roof.

### 8.4 Cross-Laminated Timber (CLT) Design

A CLT floor system was chosen to minimize energy impact and promote sustainability. The CLT panels were designed as one-way slabs spanning between simple end supports. The panels are arranged with a typical width of 8’-6”, which can be easily altered in the fabrication shop for geometric constraints. The team evaluated several limit states when designing the system, including flexural strength, shear strength, deflection, char and vibrational effects.

To address Syndicate’s goal of maximizing occupant experience, the floor assembly was specifically designed to exceed ASTM E90 and ASTM E492 standards, which specify a minimum STC and IIC rating of 50. Because music will be played throughout the building, a higher focus was placed on attaining the proper STC rating, which helps to prevent sound transmission between rooms. The final assembly, seen on Structural Drawing S-8.0, has an STC value of 60 and an IIC rating of 54, both of which do exceed the ASTM standards.

#### 8.4.1 Vibration Analysis

To achieve Syndicate’s goal of maximizing the occupant experience, special attention was taken with the gravity system to limit the amount of structural borne noise and occupant discomfort caused by excessive vibrations. The structural team followed the design procedures presented in the CLT Handbook by FPInnovations since neither the AITC or NDS publish design guides for vibrations.
Transient vibration responses are the preferred of the two forms because they disappear quickly while resonance responses can become amplified and last for some time. Achieving the transient response behavior was largely dependent on a proper mass and stiffness proportion in the system, which are represented as \( E_{I\text{eff}} \) and \( G_{A\text{eff}} \) respectively. The team was ultimately able to use the handbook’s procedures to find a span and section combination that performed within the acceptable vibration limits. The selected CLT floor system has a limiting span of 25’-6” to not be vibration controlled. This condition ensures that we achieved our goal of maximizing occupant experience by mitigating floor vibrations as our largest span is 25’-3”.

8.5 Gravity Summary

By implementing an all-wood gravity system, the carbon content of the structure was reduced by 27% as compared to the team’s baseline steel system (Figure 6). Additionally, Syndicate’s design obtained 86% engineered wood products by structural volume (Figure 7), which surpassed our goal of 25%.

This gravity system does have an increased cost of roughly $3 per SF when compared to a more traditional steel system. This small difference was possible because the CLT floor panels only require support on two opposite sides, which significantly reduced the quantity of beam members in the building. In all, the total cost of the building’s gravity superstructure was estimated at $21 per SF, which is only slightly higher than the $19 per SF that a similar steel system would have cost. These numbers come from material and labor costs. This hit the team’s goal of remaining within a 15% difference.

9.0 LATERAL SYSTEM DESIGN

The structural design team chose a loadbearing, precast concrete panel shear wall as the lateral system. To mitigate vibrations from the mechanical rooms to the concert hall, the building is split into two separate structures (each with its own lateral system). This separation is created from an expansion joint along the CLT panels and slab on grade with the wall segments via double column lines. Syndicate designed the precast panels to act as a versatile wall that meets flexural strength and building drift, while maximizing acoustical properties of the wall assembly.

9.1 Lateral Loading

Syndicate performed initial wind and seismic loading calculations based on ASCE 7-16 to determine the controlling loads. Wind loading was calculated in accordance with MWFRS, and seismic loading was calculated according to ELFP for SDC B. Refer to Structural Drawing S-2.0 for loading summaries. Wind
loading governed the lateral system’s design, although seismic drift was verified. *Etabs* models were analyzed for in- and out-of-plane strength, mandated by ACI 318-14. *Syndicate* designed the reinforced concrete precast panels according to ACI 318-14 for flexural strength, shear capacity, and a building drift of H/400 for brick cladding and non-structural components.

9.2 Design Progression

When considering all options for the lateral system, acoustical sound transmittance became an integrated driving factor for the decision to use concrete shear walls for the lateral system. Due to concrete’s mass, it has a significantly higher acoustical STC level when compared to steel or wood. The team decided early on that due to the desired 16-month construction schedule, a faster installation system would be optimal for the lateral system, which meant that masonry and cast-in-place concrete were deemed as non-optimal. The team analyzed further system drawbacks and benefits as shown below (Table 2).

<table>
<thead>
<tr>
<th>System</th>
<th>Benefit</th>
<th>Drawback</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLT</td>
<td>Sustainable material</td>
<td>Expensive</td>
</tr>
<tr>
<td></td>
<td>Quick installation</td>
<td>Sourcing</td>
</tr>
<tr>
<td></td>
<td>Wood contractors already on site</td>
<td>Connection between panels</td>
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<tr>
<td></td>
<td></td>
<td>Connections to members framing in</td>
</tr>
<tr>
<td>Cast in Place Concrete</td>
<td>Mass acts as great sound insulator</td>
<td>Slow installation</td>
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<tr>
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<td>Local Sourcing</td>
<td>Connections to members framing in</td>
</tr>
<tr>
<td>Precast Concrete</td>
<td>Mass acts as sound insulator</td>
<td>Expensive to prefabricate</td>
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<tr>
<td></td>
<td>Quick installation</td>
<td></td>
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<td></td>
<td>Local sourcing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Connections prefabricated</td>
<td></td>
</tr>
</tbody>
</table>

*Table 2: Lateral System Comparison*

9.3 Final Lateral Design

*Syndicate’s* construction and structural teams collaborated heavily in the design of the panels. The team considered two options for the height of the panels. Due to the precast manufacturer being located 20 miles away with limited turns along the route, the team decided that designing the panels for the main concert hall to be 64’ tall would be more efficient than mid-height connections.

The large concert hall was a main concern for undesired sound transmitting into or out of the space. To accommodate this concern, shear walls were designed to have a thickness of 12”. To achieve an STC of 65, *Syndicate* chose a built-up wall assembly, shown in Structural Drawing S-8.0. Furthermore, special attention was provided to the joints in the panels to maximize construction as well as acoustic isolation, discussed in Structural Drawing S-9.0. Due to the uneven loading on either side of the walls for the central concert hall, the walls were further analyzed for out-of-plane loading. The northern shear wall was found to have the highest load irregularity coming from two balconies along with the north lobby and occupiable roof structures (Figure 9). To analyze this out-of-plane loading, *Syndicate* utilized SPWall to create an interaction diagram for the wall section. End reactions and moments were then calculated. The results were then plotted in the interaction diagram to verify that the section was within capacity (Structural SD-E). For the erection sequence of the precast panels, refer to Construction Drawing C-1.0.

The east and south facades also became important components to mitigate sound transmittance and were designed as 8” thick precast panel shear walls. *Syndicate* also designed the stairwells and elevator shafts as concrete precast panels to increase sound insulation from outside sources into the performance center. The precast shear wall panels sizes are designed to be between 6’ and 11’ in width and between 32’ and 64’ in height for the main building with thicknesses varying from 8” to 12”.

During analysis it became important to limit drift in the isolated area of the building to avoid unwanted collision with the rest of the building. These shear walls were placed strategically within interior wall partitions or along an exterior façade. The panels in the isolated
structure are two-stories tall and vary between 11’ and 13’ in width with a thickness of 8”.

9.4 Lateral System Summary

The design thickness was governed by ACI and acoustical performance requirements with coordinated constructability input. These panels are prefabricated in shop to include embed plates for the connection of glulam beams spanning into the walls. The design of the lateral system assisted in meeting Syndicate’s goals by reducing sound transmittance to create premier performance spaces. The shear walls also promote versatility because they act as thermal and acoustical barriers in exterior locations.

10.0 ROOF DESIGNS

CLT panels were used as the primary roof decking. The heavy snow loads, combined with long spans between supporting beams, made this option the most viable and it was more economical to carry the same system throughout the entire building.

10.1 Performance Spaces Roofs

In order to span 72’-0” for the concert hall roof, Syndicate developed a custom steel truss design to accommodate special loading, such as the catwalk and lighting equipment (Figure 10). The rehearsal and recital spaces required a shorter span, the longest being 41’-3”, which allowed the structural team to continue to use glulam beams for the roofing systems there.

10.1.1 Design Progression

The structural team considered several different options that could be used in the main concert space, such as long-span glulam beams, long-span wooden trusses, and steel joists (Structural Drawing S-1.0). Due to complexities with hanging the catwalk, steel joists were not pursued in the design iterations. Syndicate’s structural team first designed multiple iterations of wooden trusses, as well as glulam beams to span these distances. However, both systems were eventually ruled out due to fabrication issues and the inability to ship full-length members without significant shipping costs. Shipping the members in pieces was ruled out due to complex field splices in wood.

After ruling out all three previous ideas, a new design had to be developed. A custom steel truss would be easier to fabricate, could be transported in halves and spliced on site, was accommodating of the unique catwalk loading and required the least number of individual trusses. All connections are welded in the shop except for the splices, which are bolted on site. The catwalk may be placed in any combination that allows one branch per truss.

10.1.2 Final Design

The final trusses are 8’-0” deep with nine 8’-0” panels and are spaced at 20’-0” o.c.. The panel points also align with the connection intervals of the hanging catwalk (Figure 11). Additionally, the top cord of the truss is braced by steel purlins at the same interval, allowing for further flexibility in the catwalk placement. Finally, 4-1/8” thick CLT panels make up the roof deck.
The rehearsal and recital spaces utilize glulam beams spaced in 10’ intervals with a CLT deck that has a stress grade E1 and a 105-3s layup combination. Due to the shorter span, shipping was not an issue and mid-span moment connections are not required. The deepest roof beam in either area is 29”.

The team had to compromise on using a sustainable material in favor of a recyclable material in the concert hall in order to accommodate the budget and design requirements. However, glulam beams were still a viable option for the smaller recital and rehearsal spaces.

10.2 Occupiable Roof

Syndicate considered four occupiable roof designs. These iterations are described and can be seen in Structural Drawing 5-5.0.

The third and fourth iterations developed simultaneously in response to concerns regarding the beam depth in the second design to evaluate if a shallower beam depth was preferred. After consultations with an industry professional, Syndicate saw the beams in the second iteration as a way to break up the space, add dimension and showcase sustainability. Ultimately, the team decided that the second iteration was the best for the vision of The Miller Center.

11.0 NORTH LOBBY DESIGN

A key feature of The Miller Center is its grand north lobby. Syndicate immediately identified the north lobby as a space that could leave a lasting impact on visitors of The Miller Center. To promote sustainability and minimize energy impact, Syndicate created a structural system for the lobby that showcases the wood structure. This area was heavily coordinated with mechanical, construction and lighting/electrical to achieve our vision of HOPE.

11.1 Design Progression

The best way to maximize the occupant experience was by exposing the structure to make not only an architectural statement, but also a sustainability statement. Four iterations were performed, discussed in Table 4, to determine the best way to achieve the desired atmosphere.

<table>
<thead>
<tr>
<th>North Lobby Design</th>
<th>Iteration Description</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24’ x 35’ rectangular bay girders spanning 35’ CLT running one-way in the 24’ direction</td>
<td>Girders resist a large moment of 750 k-ft More efficient &amp; impactful layout</td>
</tr>
<tr>
<td>2</td>
<td>Design of two cross beams within existing bays Queen stud designed at center of cross with cables spanning back to supports</td>
<td>Reduced depth of main girders Created depth and rhythm in the space Constructability issues and high cost Cables did not reduce beam depth significantly</td>
</tr>
<tr>
<td>3</td>
<td>Two cross beams within existing bays Column supported balcony</td>
<td>The structure is efficient Broken line of view and separation from columns</td>
</tr>
<tr>
<td>4</td>
<td>Two cross beams within existing bays Balcony is hung from by rods from the main girders above</td>
<td>Main girder increased by 37% Unobstructed space on the ground level Iteration that is best suited for Syndicate’s vision</td>
</tr>
</tbody>
</table>

Table 3: North Lobby Design Iterations

Due to the complexity of the tributary area in the iterations, RISA was implemented. Four bays were modeled to determine the maximum forces that occur at any point in the system, since the glulam properties were not in the database. After verifying the forces from the model, they were compared to the allowable capacities calculated using Excel. To determine the increase of member sizes due to hanging the balcony, hand calculations were performed to determine the max moment and shear. These forces were superimposed with the model forces and compared, once again, to the allowable capacities calculated using Excel.
11.2 Final Design

The final design of the North Lobby utilizes the same glulam species and grades as the rest of building for consistency. The same design methodology and limiting criteria were also used to select proper beam and column members within the spaces. This resulted in the main glulam roof girders being 11”x54.5” while the intermediate crossing members are 11”x39.75”. Member sizes were governed by either deflection or flexure. While deep, the sizes allow for a robust statement to be made about the prominence of sustainability throughout the structure. It further allows for depth and dimension throughout the ceiling.

All roof members are attached directly to the concert hall walls on the south end and attach to 11”x23.5” columns about the strong axis. Rectangular column cross-sections are used because lateral bracing is only present in the weak-axis direction from the supporting structure of the curtain wall. These columns also serve as the main attachment point for the full-height curtain wall enclosure (discussed later in Structural Section 13.0). The CLT floor spanning the girders is continued into this space to span the 24'-0" which carry the load of the occupiable roof above the lobby. The underside of the panels is left exposed to reveal the wood-finish that matches the framing members. As for the balcony, 1” diameter F1554 Grade 55 steel tension rods were used to suspend the structure from the roof members, see Structural Drawing S-5.0. This created a floating appearance that kept the lobby’s open feel.

The north lobby required coordination between the structural, mechanical and lighting/electrical teams. The structure remained exposed on the second level with a duct place against the concert hall wall. Wall grazers were placed on the beams to highlight the structure and the space below. See Figure 12 for more details.

11.3 Summary

The structural design of the north lobby achieved our initial goal of maximizing the occupant experience by creating a structural rhythm within the room, while also providing added interest to the building’s most prominent gathering space. The attention of viewers is immediately drawn to the monumental wood members, showcasing our unique design and making Hope College’s sustainability efforts very clear.

12.0 FOUNDATION SYSTEM DESIGN

The soil profile is topsoil, brown to dark brown sand with trace silt, and very loose to loose, light brown, fine to medium sand. Groundwater was encountered from 8.8’-12.3’ below grade with a frost line at 42”. Following the suggestions of the geotechnical report, the structural design team pursued spread and strip
footings for the foundation system below The Miller Center. Vibro-compaction must be applied to the native sand to improve the allowable bearing capacity.

After compaction, Syndicate utilized the soil bearing capacity of 4,500 psf by picking a shallow foundation that allows for higher cost savings and simpler construction procedures.

Syndicate utilized a slab-on-grade system to shape the concert hall floor. Following the geotechnical report’s recommendation, the final slab assembly consists of a 6” slab, 2” Regupol vibration 200 mat and then another 4” slab on top. The high mass of the assembly, along with the isolation pad, will help reduce the vibrations of the nearby train from entering the space. For the remainder of the building, a typical 5” slab was deemed acceptable.

The spread footing plan dimensions ranged from 6'-0”x8'-0” to 9'-0”x7'-6” and thickness varied between 16” to 20”. Column loads on the footings range from 184 to 324 kips. For all foundation elements, a concrete grade of 4,000 psi was used. For further information on the spread and strip footings refer to Structural Drawing S-4.0. A short concrete pier, matching the dimensions of the columns above, was placed on the footing up to the top-of-slab to prevent the wooden columns from being in contact with the ground. The connection places a steel base plate between the wood column and concrete pier to prevent the wood from absorbing any moisture.

The foundations between the isolated mechanical space and the rest of a building were shared. Much of the vibrations from the mechanical equipment were reduced through springs and concrete inertia pads under the equipment. To further diminish the vibrations before it reaches the footing, an isolation pad was placed between the wood column and the concrete pier. With these provisions, the benefit of placing two separate footings did not outweigh the extra costs. To prevent the transfer of vibrations in the superstructure an isolation joint was implemented between the two structures.

Special foundation coordination was implemented with the mechanical team to avoid clashing between the structural footings and the underground blue ducts. The ducts had to enter the main spaces, such as the concert hall, recital, choral and orchestral rooms. These spaces are enclosed by the precast shear walls that extend below grade to a strip footing. To allow the blue ducts through, openings are preformed slightly larger than the duct passing through. Furthermore, the footings are moved down an extra 2'-6” to ensure they are below the plane of the largest duct, which is 48” in diameter. This was only performed at locations where the blue ducts interacted with footing which can be seen in Figure 14.

12.1 Summary

Syndicate’s structural team applied the information and recommendations provided in the geotechnical report. The foundation system accommodated the blue ducts passing below grade while also reducing the train vibrations. The spread and strip footings withstand the loads from The Miller Center in a cost-efficient system.

13.0 BUILDING ENCLOSURE DESIGN

13.1 Sustainable Curtain Wall

The north lobby curtain wall was a multidisciplinary design effort involving the entire team. After finalizing the architectural changes of The Miller Center, the structural team determined wall loadings based on ASCE 7-16 components and cladding (C&C) procedures. A schematic showing the different building zones and respective pressures can be found on Structural Drawing S-6.0. The north lobby was specifically designed to withstand a pressure of 25 psf.

In coordination with architecture and lighting/electrical, the structural team began preliminary sizing calculations for the glazing panels under geometric constraints. The final glazing design is composed of
insulated glass units (IGU’s) with the following layers: ¼” monolithic glass, ½” argon space and 3/8” monolithic glass. All glass is fully tempered for safety reasons.

Due to the relatively low wind pressure, the design was an iterative process largely governed by achieving the proper combination of U-value and VLT percentage. To ensure that our glazing configuration was of sufficient strength, ASTM E-1300 was used to verify that the system’s load capacity was adequate. While the 3/8” lite is not required for structural purposes, it does improve the curtain wall’s acoustical performance because IGU’s with panes of dissimilar thickness absorb a greater range of sound frequencies. The STC of this glazing assembly is 39.

As an architectural preference, Syndicate opted to select a uniform mullion size for the entire wall. The window mullions are a traditional stick-built system produced by Kawneer for low-rise building applications. Manufacturer product data provided tables to size mullions based on applied loads, span length and spacing. The resulting design is a 5.75”x2.5” mullion to resist the worst-case C&C loading. A separate FEM model was also built in SAP2000 to verify that all strength and deflection criteria of L/175 were successfully met. Schematics and calculations relevant to the curtain wall design can be seen on Structural Drawing S-6.0.

### 13.2 Curtain Wall Connection

![Figure 15: Curtain Wall Assembly Detail](image)

To support the curtain wall, horizontal HSS 4 ½x4 ½x½ tube sections span between the exterior columns along two horizontal mullion lines (14’-10 ½” spacing vertical). Connections are provided at every vertical mullion along the HSS that were sized for curtain wall self-weight and wind loads. Slotted bolted connections accommodate for both construction tolerances and building drift. HSS blind bolts are used for constructability. The connection between the tube and mullions is shown in Figure 15 while a detailed model of the curtain wall can be seen on Structural Drawings S-6.0.

### 14.0 SPECIALTY DESIGN

#### 14.1 Concert Hall Balcony Design

The balcony of the main concert hall presented a unique challenge for the structural team because of the large cantilever. Initially entirely wood solutions were explored but member sizes became too large to fit in the balcony cross section as there are large mechanical ducts, explained in Mechanical Section 8.2.1, running through the balcony, further limiting allowable depth.

Under these constraints, a steel solution was the most practical. The final design is composed of a series of four steel raker beams. The two outside members are supported by the precast walls on one end and steel columns on the other. For the interior raker beams, they are connected to the walls but are propped by columns 10’-0” inward of the wall. This reduced the cantilever length from 24’-0” to a manageable 14’-0”. All the raker beams are W21x111 shapes, which fit within the geometric constraints. Like the rest of the building, CLT floor panels serve as the structural floor system of the balcony. The balcony structure can be seen on Structural Drawing S-7.0.

#### 14.2 Isolated Mechanical Structure

With the mechanical equipment room located along the stage side of the concert hall and near faculty offices, there was a team concern over accidental vibration transmittance into these spaces through the structure. To reduce the source vibrations, the pumps were placed on spring mounted concrete inertia pads and the chillers and air handling units are on springs. Furthermore, due to the sensitive nature of the adjacent spaces, Syndicate decided to isolate this section of the building that houses the mechanical equipment via double column lines and expansion joints. These joints are carefully detailed to dissipate any incidental vibrational energy. See Structural Drawing S-8.0 for more information.
14.3 Heavy-Timber Connections

The structural team designed two of the typical wood connections in the project. The first of which was the beam-to-wall connection. *Syndicate* initially pursued dowel-type connections here, but after considering the large member sizes and end reactions, found that a bearing-type connection was optimal. A seated, saddle-like configuration made from built up ½” A36 steel plates are used to set the beams while two ¾” through-bolts restrain movement. This “saddle” assembly would be welded to embed plates in the precast panels prior to setting the beam. Isolation pads line the saddle to add acoustic isolation from the concert hall.

For the standard beam-to-column shear connection, a similar methodology was used. The same saddle configuration is present at each column face supporting a beam but they are joined to a steel plate bearing directly on top of the column section. This top plate is then used as the surface to build the column splice on. This provides a single built-up section that serves as both a beam connection and column splice. These prefabricated elements can be attached to columns on the ground prior to erection, allowing for a simpler and thus faster structural erection.

Alternative knife-plate configurations were developed as well using the same principals, giving the supplier multiple options to best fit their fabrication preferences as well as architectural ability to hide the saddles. The saddle beam-column connection can be seen below in Figure 16, while the knife plate types can be seen on Structural Drawing S-3.0.

![Figure 16: Beam-Column Connection](image)

15.0 LESSONS LEARNED

Through the design process, the structural team learned to coordinate and adapt to the ever-changing design. Out of the box thinking had to be employed in order to accommodate the specific needs of The Miller Center, such as maximizing acoustical performance, developing an eye-catching structure, creating sustainability and versatility. The team developed throughout the process to maximize the collaboration effort and efficiency.

16.0 CONCLUSION

The team enhanced Hope College through an optimized gravity system, which in turn reduced the cost of the structure. Furthermore, the wood enabled a faster construction process which minimized the impact on students and residents of Holland, Michigan.

Special attention was given to mitigating structural borne vibrations and to creating assemblies with STC and IIC ratings that exceed industry standards. In addition to this, the exposed structure in the north lobby and occupiable roof showcased the sustainability aspects of the building as well as brought warmth and dimension to the spaces.

The roof structure is designed to allow for flexibility in the layout of the catwalk and for future additions. Also, the shear walls are sized to ensure an STC of 65 was met and the balcony in the back of the hall was cantilevered to reduce the use of columns allowing for an unobstructed view.

Throughout the project, a focus was placed on providing the owner a sustainable building. The structural team was able to achieve this using engineered wood structural members sourced from a sustainable manufacturer, for 86% of the building. This, in turn, reduced the carbon content by 27% in comparison to a steel system.
Syndicate used the decision matrix below to select design solutions that best aligned with the project goals. More information regarding the design iterations shown in the matrix can be found in the structural report.

<table>
<thead>
<tr>
<th>Structured Codes and Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 2015 International Building Code</td>
</tr>
<tr>
<td>- ASCE 7-16, Minimum Design Loads for Buildings and Other Structures</td>
</tr>
<tr>
<td>- 2018 NDS, Supplement and SDPW5</td>
</tr>
<tr>
<td>- CLT Handbook by FPInnovations</td>
</tr>
<tr>
<td>- ACI 318-14, Building Code Requirements for Structural Concrete</td>
</tr>
<tr>
<td>- ASTM E1300—04, Standard Practice for Determining Load Resistance of Glass in Buildings</td>
</tr>
<tr>
<td>- Kawneer 1600 LR Wall—Curtain Wall System Product Information</td>
</tr>
</tbody>
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### Structural Decision Matrix

<table>
<thead>
<tr>
<th>Design Matrix Structure</th>
<th>Wood Works</th>
<th>Excel</th>
<th>Sap2000</th>
<th>Revit</th>
<th>Bluebeam</th>
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Additional Comments: Syndicate decided to pursue the glulam frame with CLT deck system. Even though the system was predicted to be the highest cost, it provided many benefits that outweighed the cost. This system allows for a significantly smaller water table, carbon footprint, and lifecycle, as well as improved aesthetics to the space which will improve the occupant experience.

### Software Use

- Preliminary sizing of long-span glulam system
- Final sizing of long-span glulam system
- Basic load calculations
- CLT roof deck design
- Member forces in heavy timber truss system
- Design of final steel truss system in main concert hall

<table>
<thead>
<tr>
<th>Software Use</th>
<th>Wood Works</th>
<th>Excel</th>
<th>Sap2000</th>
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<tr>
<td>3D Risa</td>
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<td>Integration</td>
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<td>SAP2000</td>
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<td>Forces and deflections</td>
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<td>SAP2000</td>
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<td>Final member sizing</td>
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<td>SPECIALTY DESIGN</td>
<td>C &amp; C wind pressures</td>
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<td>SAP2000</td>
</tr>
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</table>

### Process

Syndicate utilized multiple programs throughout the project because no single program could be used to design every system. The structural team implemented an iterative process between programs to verify and optimize the design.
### DEAD LOAD CALCULATIONS

#### Floor Superimposed Dead Load

The superimposed dead load is to provide an additional load allowance for the weight of miscellaneous building components. These include, but are not limited to: floor/ceiling finishes, ducts, light fixtures, plumbing, electrical equipment and partitions.

<table>
<thead>
<tr>
<th>Floor Finishes</th>
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<tbody>
<tr>
<td>ACT</td>
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</tr>
<tr>
<td>MEP</td>
<td>10 psf</td>
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<tr>
<td>Partitions</td>
<td>15 psf</td>
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#### CLT Floor + Acoustic Topper Assembly Weight

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½” Concrete Topper</td>
<td>20.5 psf</td>
</tr>
<tr>
<td>Regupol Sonuswave</td>
<td>2 psf</td>
</tr>
<tr>
<td>OSB</td>
<td>2.2 psf</td>
</tr>
<tr>
<td>Battens + Insulation + Membrane</td>
<td>0.50 psf</td>
</tr>
<tr>
<td>CLT Panel (10.5”)</td>
<td>28.1 psf</td>
</tr>
<tr>
<td></td>
<td>53.3 psf</td>
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#### Roof Superimposed Dead Load

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
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<td>15 psf</td>
</tr>
<tr>
<td>Roofing Materials</td>
<td>2 psf</td>
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<td>Rigid Insulation</td>
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<td>Snow Melt System</td>
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<td>MEP</td>
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<td></td>
<td>35 psf</td>
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### SNOW LOAD CALCULATIONS

\[
p_d = 0.7C_eC_tI_s P_g\]

#### Parameters

- \(C_e\) (Partially Exposed Terrain Category B) = 1.0
- \(C_e\) (Heated Building) = 1.0
- \(I_s\) (Risk Category IV) = 1.0
- \(P_g\) (Holland, MI Building Code) = 50 psf
- \(P_I\) = 35 psf

There are no drifting effects from surrounding buildings, however, The Miller Center has significantly varying roof heights and parapets that create localized areas of drift build-up. The most severe case occurs at the interface between the main concert hall wall and the southern roof. A sample calculation utilizing the ASCE 7-16 procedures is provided below for this space.

\[
h_d = 0.43 \sqrt{\frac{P_d}{h_d}} + 10 - 1.5
\]

\[
\text{Snow Density (pcf): } \gamma = \min\left\{ \frac{0.13P_d + 14}{h_d} \right\}
\]

\[
\text{If } h_d \leq h_c, \text{ then } \gamma = h_d
\]

\[
W = 4 \times 4.68 = 18.7'\]

\[
P_d = 20.5 \times 4.68 = 96 \text{ psf}
\]

### WIND LOAD PARAMETERS

#### Holland, MI Wind Loading Parameters

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>P</th>
<th>E-W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50 psf</td>
<td>35 psf</td>
</tr>
<tr>
<td>2</td>
<td>25 psf</td>
<td>15 psf</td>
</tr>
</tbody>
</table>

### SEISMIC LOAD PARAMETERS

#### USGS Report Data

| Ss | 0.087 |
| S1 | 0.045 |
| Sm | 0.139 |
| Sm1| 0.117 |

#### Seismic Data

<table>
<thead>
<tr>
<th>Seismic Site Class</th>
<th>Building Class</th>
<th>R</th>
<th>Cd</th>
<th>Dc</th>
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</thead>
<tbody>
<tr>
<td>D</td>
<td>III</td>
<td>3</td>
<td>3</td>
<td>2.5</td>
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#### ASCE 7-16 Data

<table>
<thead>
<tr>
<th>Lateral System</th>
<th>Bearing Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>3</td>
</tr>
<tr>
<td>Cd</td>
<td>3</td>
</tr>
<tr>
<td>Dc</td>
<td>2.5</td>
</tr>
</tbody>
</table>

#### Calculated Values

| PGA | 0.042 |
| Seismic Design Category | B |

Reference Structural Drawing S-2.0 for further information on lateral loading.
Typical Connections

Diaphragm CLT Connection
Syndicate’s structural team designed the CLT floor system to act as a rigid diaphragm. To do so, the panels had to be joined together so that the entire floor plate moves uniformly as a single element. Multiple methods for panel-to-panel connections were considered, with the team ultimately selecting Option C. Option C was best suited for The Miller Center because the loads between panels were relatively low and it was the easiest to construct.

Beam to Column Saddle-Type Connection Limit States
Each saddle-type connection has two side plates, therefore, the limit states for each side plate failure mode need to be doubled. The controlling load for this connection is 55.6k. This particular connection can be seen on Structural Drawing S-3.0.

Foundation Coordination
At the locations that the blue ducts pass over the foundation, the spread and strip footings were moved from 3'-6" to 6'-0" below top-of-slab. The extra 2'-6" was determined to accommodate the largest of the underground blue ducts (48" in diameter). At the tightest point there is 6" of clearance on either side of the blue duct.

Concert Hall Slab on Grade
The built-up assembly shown below implements the use of a 2" thick Regupol Vibration 200 isolation mat to achieve an STC of 59 and an IIC of 70.

Spread Footing
Hand Calculation for an 12.875x12.875 Column

Loading/Sizing

Wide Beam Shear

Reinforcement

Punching Shear

Determined Depth

Bearing

Foundation Detail for an 11x11 Wood Column

<table>
<thead>
<tr>
<th>#3 Ties</th>
<th>11&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 #4 Dowels</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>3&quot; Clear Cover Type</th>
<th>(8) #9’s EQ Spaced</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Saddle Type Connection Limit States</th>
<th>11&quot; x 22.5 Saddle Type Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL=23k, LL=18k</td>
<td>Factored load to 39 k (ASD), 53 k (FBD), 6&quot; x 11&quot; bearing area recalculated as per 2014 MDO</td>
</tr>
<tr>
<td>Limit State</td>
<td>Applied Load</td>
</tr>
<tr>
<td>Bottom Plate Flexural Strength</td>
<td>4.96 kN</td>
</tr>
<tr>
<td>Saddle Flexural Strength</td>
<td>19.3 kN</td>
</tr>
<tr>
<td>Bottom Plate/Trim Plate Weld</td>
<td>26.6 kN</td>
</tr>
<tr>
<td>Side Plate Tension Yield</td>
<td>26.6 kN</td>
</tr>
<tr>
<td>Side Plate Horizontal Rupture</td>
<td>26.6 kN</td>
</tr>
<tr>
<td>Beater Plate Tension Yield</td>
<td>53.2 kN</td>
</tr>
<tr>
<td>Beater Plate Horizontal Rupture</td>
<td>53.2 kN</td>
</tr>
<tr>
<td>Top Plate Shear</td>
<td>53.2 kN</td>
</tr>
</tbody>
</table>

| 6" Concrete Slab | Noncohesive soil compacted to 95% of MDD |

| 2" Regupol Vibration 200 | | | 4" Concrete Slab |
| 59 | 70 | STC | IIC |
Typical Glulam

Beam Calculations

**Loading**
- Loads:  DEAD = 400 psf, LIV = 100 psf, MEM = 400 psf
- Member Length = 17 ft
- Thrust = 0.24 ft

**Deflection Check**
- $\Delta_{n} = \frac{1}{24} \times L^2 = 1.29$ in
- $0.75 = 0.75(0.5 \times 12 \times 4) = 24.72$ in
- $0.75 = 0.75(0.5 \times 12 \times 4) = 24.72$ in
- $\Delta_{n} = 0.75 \times 24.72 = 18.54$ in
- $\Delta_{n} = 0.75 \times 24.72 = 18.54$ in
- $\Delta_{n} = 0.75 \times 24.72 = 18.54$ in
- $\Delta_{n} = 0.75 \times 24.72 = 18.54$ in

**Cross-Laminated Timber**

The same design process was used to design the CLT members and the glulam beams/columns. The CLT panels were treated as a one-way system, simply supported on each end by a glulam beam.

**Column Capacity**

<table>
<thead>
<tr>
<th>Column Capacity</th>
<th>Variable</th>
<th>11 x 11</th>
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</thead>
<tbody>
<tr>
<td>Length (in)</td>
<td>192</td>
<td></td>
</tr>
<tr>
<td>Depth (in)</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Le/D</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Em (10^6)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fc</td>
<td>2564</td>
<td></td>
</tr>
<tr>
<td>Cc</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cm</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cm</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fc</td>
<td>2300</td>
<td></td>
</tr>
<tr>
<td>Fc*</td>
<td>2300</td>
<td></td>
</tr>
<tr>
<td>Fc/Fc*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cp</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fc</td>
<td>1837</td>
<td></td>
</tr>
<tr>
<td>Width (in)</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Depth (in)</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>P allow</td>
<td>222220</td>
<td></td>
</tr>
</tbody>
</table>

**Allowable Area For Type IIIA Construction**

<table>
<thead>
<tr>
<th>Allowable Number of Stories</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE 304-4</td>
</tr>
</tbody>
</table>

**Frontage Calculation**

Minimum Width of Public Way (W)

<table>
<thead>
<tr>
<th>Building Parameter (ft)</th>
<th>Side</th>
<th>setback (ft)</th>
<th>Length (ft)</th>
<th>W (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>97.2</td>
<td>West</td>
<td>30</td>
<td>257.7</td>
<td>30</td>
</tr>
<tr>
<td>30</td>
<td>East</td>
<td>30</td>
<td>319.9</td>
<td>30</td>
</tr>
<tr>
<td>30</td>
<td>South</td>
<td>30</td>
<td>225.7</td>
<td>30</td>
</tr>
<tr>
<td>30</td>
<td>North</td>
<td>30</td>
<td>189.4</td>
<td>30</td>
</tr>
</tbody>
</table>

**Square Feet / Floor**

<table>
<thead>
<tr>
<th>Type</th>
<th>Group</th>
<th>At (sq. ft)</th>
<th>If</th>
<th>NS (sq. ft)</th>
<th>Aa (sq. ft/story)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIIA</td>
<td>A</td>
<td>42,600</td>
<td>0.75</td>
<td>14,000</td>
<td>52,500</td>
</tr>
</tbody>
</table>
When designing the precast panels for the shear wall, Syndicate considered the out of plane loading from members framed into the wall. The worst case scenario is shown to the right with loading from balconies, floor systems, a roof, and wind pressures.

The wall was analyzed using the unit strip method for the flexural and axial capacities at varying heights along the wall. After modeling the member in SAP2000, SPWall was utilized in order to obtain an interaction diagram. The various loadings were input as shown to the left. The points fell within the interaction diagram and verified that the current design has the capacity to handle the out of plane load demands.
System Analysis

<table>
<thead>
<tr>
<th>System</th>
<th>Benefit</th>
<th>Drawback</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLT</td>
<td>Sustainable material</td>
<td>Expensive</td>
</tr>
<tr>
<td></td>
<td>Quick installation</td>
<td>Distant sourcing</td>
</tr>
<tr>
<td></td>
<td>Wood contractors already on site</td>
<td>Connection between panels and members framing in</td>
</tr>
<tr>
<td>Cast in Place Concrete</td>
<td>Mass acts as great sound insulator</td>
<td>Slow installation</td>
</tr>
<tr>
<td></td>
<td>Local sourcing</td>
<td>Connections to members framing in</td>
</tr>
<tr>
<td>Precast Concrete</td>
<td>Mass acts as sound insulator</td>
<td>Expensive to prefabricate</td>
</tr>
<tr>
<td></td>
<td>Quick installation / connections prefabricated</td>
<td>Connections to members framing in</td>
</tr>
<tr>
<td></td>
<td>Local sourcing</td>
<td></td>
</tr>
</tbody>
</table>

General System Analysis

- Steel
  - Ability to span long distances
  - Available locally
  - Fire proofing is required and costly

- CIP Concrete
  - Available locally
  - Well insulated
  - Constructability issues during winter months
  - Large contributor to greenhouse gases

- CMU
  - Naturally fire resistant

- Precast
  - Naturally fire resistant
  - Requires skilled workmanship on site

- Heavy Timber
  - Reduces carbon dioxide emissions between 15-20% from steel
  - Manufacturers are far away

Lateral System Comparison

<table>
<thead>
<tr>
<th>System</th>
<th>Benefit</th>
<th>Drawback</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLT</td>
<td>Sustainable material</td>
<td>Expensive</td>
</tr>
<tr>
<td></td>
<td>Quick installation</td>
<td>Distant sourcing</td>
</tr>
<tr>
<td></td>
<td>Wood contractors already on site</td>
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</tr>
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<td>Cast in Place Concrete</td>
<td>Mass acts as great sound insulator</td>
<td>Slow installation</td>
</tr>
<tr>
<td></td>
<td>Local sourcing</td>
<td>Connections to members framing in</td>
</tr>
<tr>
<td>Precast Concrete</td>
<td>Mass acts as sound insulator</td>
<td>Expensive to prefabricate</td>
</tr>
<tr>
<td></td>
<td>Quick installation / connections prefabricated</td>
<td>Connections to members framing in</td>
</tr>
<tr>
<td></td>
<td>Local sourcing</td>
<td></td>
</tr>
</tbody>
</table>

Typical Bay Designs

- Iteration 1: A composite steel system with a W18x35 as the deepest beam. The deck is a 1.5VLI19 with 4 1/2" NWC topper.
- Iteration 2: Glulam beams and columns with the deepest beam being a 10.75x43.5. A CLT deck consisting of 1.5VLI19 with 4 1/2" NWC topper.
- Iteration 3: Glulam beams and columns with the deepest beam being a 10.75x40.5. A CLT deck with a E1 stress grade and a combination of 244-7s with 2" IWC.

North Lobby

- Foundation
- Lateral
- Selected Design
- Design Iterations

Occupiable Roof

- Selected Design
- Design Iterations

Structural Enclosure

- Selected Design
- Design Iterations

Concert Hall Roof

- Selected Design
- Design Iterations

SYNDICATE

Jack H. Miller
Center for Musical Arts
Holland, Michigan

Design Timeline

- Sheet Title
- Project
- Sheet No.
- Date
- Scale
- Not for Construction
- Not to Scale

Scale: 5-1.0

Page No.: 51

February 18, 2019
Syndicate’s structural team designed their diaphragm to act as a rigid diaphragm. To do so, multiple options for panel-to-panel connections for the cross-laminated timber were considered. The team opted to choose Option 3 for constructability purposes.
The four iterations above were performed to determine the optimum layout for the occupiable roof to maximize the occupant experience and create a statement of sustainability. For the final design Syndicate chose iteration 2. This structure, due to its depths, added dimension to the space, demonstrated sustainability and continued the same aesthetic that was developed in the north lobby.

### Occupiable Roof Design

<table>
<thead>
<tr>
<th>Iteration</th>
<th>Description</th>
<th>Conclusion</th>
</tr>
</thead>
</table>
| 1         | - Columns sit at the face of the curtain wall on the occupiable roof  
- Bay size: 24' x 24' - 6"  
- Girders span: 24' - 6"  
- CLT span: 24' | Applied point loads on the main girders in the North Lobby, increasing the member size by 13% |
| 2         | - Columns line up with the columns in the North Lobby below  
- Bay size: 24' x 35'  
- Girders size: 11 x 49.5 | Reduced load on the North Lobby beams below  
Increased beam size due to longer spans  
Columns and exterior beams are visible from the street level |
| 3a        | - Girders span 24' - 6" and a steel tension rods are used to tie back the roof overhang to the concert hall walls above  
- Bay size: 12' x 24' - 6"  
- Glulam beam: 11 x 21.5  
- CLT sits on the flat glulam beams | Reduced visual impact from street level due to the small size of the rod |
| 3b        | - Girders span 24' - 6" and are tied back by glulam members to the concert hall at a 30-degree angle  
- Bay size: 12' x 24' - 6"  
- Flat glulam beam: 11 x 11  
- Angled glulam beam: 11 x 29  
- CLT sits on the angled member | Angled roof line is visible from street level  
Vault ceiling visible from the interior of the space |
Glazing panel sizes ranged from 2'-0" x 3'-0" to 8'-0" x 3'-0". ASTM E-1300 tables for “4 sides simply supported” were used to design the glass for both strength and serviceability. The final IGU assembly is 1 1/8" thick with 1/4" and 3/8" monolithic lites separated by a 1/2" argon filled space. All of the glass is fully tempered in areas accessible to occupants.

The curtain wall mullion system chosen for the Miller Center is Kawneer’s 1600 LR Wall. Using the charts provided in the published product data, it was determined that a 5 3/4" mullion could withstand the given loads with a 10'-0" span. While the twin span condition did not directly apply to the project since there are two unequal spans (10' and 14'), the chart was beneficial for preliminary sizing. A model of the mullion and loading was created in SAP2000 and the 5 3/4" mullion was found to satisfy all deflection and strength criteria under the unequal span condition.

To carry the gravity and lateral loads from the curtain wall to the structure, HSS tubes spanning between the columns were used as support. Vertically and horizontally slotted holes were provided as well to allow ample room for both deflection and drift.

### IGU GLAZING CALCULATIONS

<table>
<thead>
<tr>
<th>L (in)</th>
<th>Lite no. 1 (1/4&quot; monolithic)</th>
<th>Lite no. 2 (3/8&quot; monolithic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W (in)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.375</td>
</tr>
<tr>
<td></td>
<td>1.45</td>
<td>3.4</td>
</tr>
</tbody>
</table>

### MULLION STRENGTH CHARTS BY KAWNEER

### TABLES FROM ASTM E-1300

<table>
<thead>
<tr>
<th>Zone</th>
<th>Load Case</th>
<th>Height</th>
<th>P(table)</th>
<th>Gust Factor (Gf)</th>
<th>P(table)*Gf</th>
<th>Kzt</th>
<th>P (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>70</td>
<td>53.4</td>
<td>0.85</td>
<td>-44.8</td>
<td>1</td>
<td>-33.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>66</td>
<td>57.7</td>
<td>0.85</td>
<td>-49.4</td>
<td>1</td>
<td>-39.2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>60</td>
<td>61.6</td>
<td>0.85</td>
<td>-50.6</td>
<td>1</td>
<td>-39.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>65</td>
<td>66.1</td>
<td>0.85</td>
<td>-56.2</td>
<td>1</td>
<td>-45.2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>60</td>
<td>64.8</td>
<td>0.85</td>
<td>-56.2</td>
<td>1</td>
<td>-45.2</td>
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### TABLES FROM ASTM E-1300

<table>
<thead>
<tr>
<th>Zone</th>
<th>Load Case</th>
<th>Height</th>
<th>P(table)</th>
<th>Gust Factor (Gf)</th>
<th>P(table)*Gf</th>
<th>Kzt</th>
<th>P (psf)</th>
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<td>-33.9</td>
</tr>
<tr>
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<td>57.7</td>
<td>0.85</td>
<td>-49.4</td>
<td>1</td>
<td>-39.2</td>
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<td>61.6</td>
<td>0.85</td>
<td>-50.6</td>
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<td>-39.2</td>
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<td></td>
<td>4</td>
<td>65</td>
<td>66.1</td>
<td>0.85</td>
<td>-56.2</td>
<td>1</td>
<td>-45.2</td>
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<tr>
<td></td>
<td>5</td>
<td>60</td>
<td>64.8</td>
<td>0.85</td>
<td>-56.2</td>
<td>1</td>
<td>-45.2</td>
</tr>
</tbody>
</table>
CONCERT HALL CATWALK
The above image shows the current layout of the catwalk that is hung from the purlins spanning the steel trusses in 8'-0" increments. Since the purlins line up with the rod supports for the catwalk it is able to be shifted seamlessly. Furthermore, the truss design allows the catwalk to be moved to any location within the concert hall. Additional catwalks may be added as long as the load is equivalent to one catwalk per truss.

CONCERT HALL BALCONY

TYPICAL RAKER BEAM

Steel Truss per Truss

<table>
<thead>
<tr>
<th>Member</th>
<th>Quantity</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3x5x3/14</td>
<td>2</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>L5x5x5/8</td>
<td>2</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>L6x5x3/16</td>
<td>2</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>L4x5x3/16</td>
<td>2</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>L3x5x3/14</td>
<td>2</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>L2x6x5/8</td>
<td>1</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>L2x2x1/4</td>
<td>2</td>
<td>8' - 11&quot;</td>
</tr>
<tr>
<td>L2x2x6/12</td>
<td>2</td>
<td>11' - 3.5&quot;</td>
</tr>
<tr>
<td>L3x2x6/12</td>
<td>2</td>
<td>11' - 3.5&quot;</td>
</tr>
<tr>
<td>L3x5x3/14</td>
<td>2</td>
<td>11' - 3.5&quot;</td>
</tr>
<tr>
<td>L5x5x3/14</td>
<td>2</td>
<td>11' - 3.5&quot;</td>
</tr>
<tr>
<td>WT10x39</td>
<td>6</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>WT10x25</td>
<td>3</td>
<td>8' - 0&quot;</td>
</tr>
<tr>
<td>WT10x17</td>
<td>3</td>
<td>8' - 0&quot;</td>
</tr>
</tbody>
</table>

Bracing

| W10x33       | 50       | 20' - 0" |

The 72'-0" truss poses an issue for transportation. To provide easier transportation, each truss was separated into two pieces consisting of a 32'-0" and a 40'-0" section. Both preassembled sections will consist of shop welded joints. At the splices, indicated by x's in the middle truss image, will be field bolted connections. A further breakdown can be seen in the bottom truss image.
The isolated structure consists of double columns along the perimeter. An isolation pad was placed between the wood column and concrete pier on the mechanical side to reduce the vibrations entering the footing. A single spread footing is used for each double column location along the perimeter.

Both the concert hall slab-on-grade and typical floor assemblies were tested for STC (how well a building system attenuates airborne sound) and IIC (how well a building system attenuates impact sound) values by Regupol.
ACOUSTICAL DETAILS FOR PRECAST PANELS

Syndicate is proposing to consider the following two details for panel to panel connection. The image on the left incorporates the use of acoustic sealant along with a staggered joint to mitigate sound transmittance from exterior sources coming into the acoustically sensitive space. The team suggests utilizing the detail on the left.

### Isolated Structure Lateral System

<table>
<thead>
<tr>
<th>Precast Panel Shear Wall Location</th>
<th>Thickness (in)</th>
<th>Longitudinal Reinforcement</th>
<th>Transverse Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-South Mechanical Space</td>
<td>8</td>
<td>(2) curtains #4 @18&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
<tr>
<td>East-West Mechanical Space</td>
<td>8</td>
<td>(2) curtains #4 @14&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
</tbody>
</table>

### Main Building Lateral System

<table>
<thead>
<tr>
<th>Main Building Lateral System</th>
<th>Thickness (in)</th>
<th>Longitudinal Reinforcement</th>
<th>Transverse Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stairwells</td>
<td>8</td>
<td>(2) curtains #4 @18&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
<tr>
<td>Elevator Shaft</td>
<td>8</td>
<td>(2) curtains #4 @18&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
<tr>
<td>Recital Hall</td>
<td>8</td>
<td>(2) curtains #4 @18&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
<tr>
<td>Orchestral Hall</td>
<td>8</td>
<td>(2) curtains #4 @18&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
<tr>
<td>Organ Hall</td>
<td>8</td>
<td>(2) curtains #4 @18&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
<tr>
<td>Choral Hall</td>
<td>8</td>
<td>(2) curtains #6 @18&quot;</td>
<td>(2) curtains #4 @18&quot;</td>
</tr>
<tr>
<td>Performance Hall</td>
<td>12</td>
<td>(2) curtains #6 @18&quot;</td>
<td>(2) curtains #4 @12&quot;</td>
</tr>
</tbody>
</table>

### Precast Panel Details

- **Precast Panel**: With Grout
- **Steel Reinforcement**: Embedded Plate, BOLTED PLATE CONNECTION OR WELD
- **Concrete Precast Panel**: ACOUSTICAL SEALANT
- **Backer Rod**: CONCRETE PRECAST PANEL
- **Embed Plate**:-grout
THE HOPE COLLEGE SUSTAINABILITY PLAN

Syndicate, after considering aspects of the LEED and WELL plans and the efforts that Hope College is already making, has created a customized sustainability plan for Hope College. This plan allows Hope to pursue environmentally-minded goals without sacrificing their academic objectives. There are four main canons that encompass large sustainability aspects, and those four are broken down into several implementation categories (shown below). The objectives that were considered during the structural design of The Miller Center are highlighted below.

JACK H MILLER PILOT PROGRAM

Syndicate has implemented this Sustainability Plan on the Miller Center project. Below are the specific aspects of the plan that are highlighted on this project, color-coded by responsible discipline.

Environmental Impacts

The structural system of The Miller Center is CLT and glulam, which emits significantly less greenhouse gas than concrete or steel. It also works to trap carbon dioxide that other systems emit. In total, choosing a wood structure reduced the carbon content by 70%. Below is a graphic depicting the carbon dioxide emissions of standard structural systems provided by Nordic Structures.

Construction Waste

There was a site wide effort on The Miller Center project to minimize waste. Prefabrication was heavily utilized to through the precast lateral system and the CLT assemblies.

Alternate Systems

Syndicate chose to implement a sustainable design by choosing a wood structural system over a steel structural system.

CARBON CONTENT

Designing the gravity system to be majority wood allowed Syndicate to achieve 80% wood by volume for the superstructure. The wood consisted of glulam beams and columns and CLT decking. Due to the factors, such as cost, constructability, acoustics and efficiency, steel was used for the balcony and truss in the concert hall and precast for the lateral system.

Sourcing/Production

The manufacturer chosen for the CLT and glulam members of The Miller Center is heavily involved in the forest operations where the wood is harvested. This company is cognizant of the amount of wood that they use and ensures that every tree is replaced to minimize the impact on the environment and the integrity of the forest.

CASE STUDY

An article published by Structure Magazine titled Mid-Rise Wood-Frame Buildings discusses safety, sustainability and cost of wood structures. It concludes that:

- **Safety:** Wood structures are just as safe as any other since it has to meet the same rigorous requirements outlined in the code.
- **Sustainability:** There is a smaller carbon footprint with wood, reducing the environmental impact.
- **Cost:** IIC Building Valuation Data compared the cost of buildings under different construction types. Wood is allowed, and often used, in Type IIIA and IIIB. However, noncombustible materials are not allowed in Type IIA and IIB. Below is a table listing their findings.

<table>
<thead>
<tr>
<th>Construction Type</th>
<th>Decrease in Cost/$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type IIA → Type IIIA</td>
<td>$20</td>
</tr>
<tr>
<td>Type IIB → Type IIIB</td>
<td>$18</td>
</tr>
</tbody>
</table>

ACOUSTIC PERFORMANCE

One of Syndicate’s primary goals is to create a world class acoustic space for premier performances. In the typical structure, the flooring system was developed to help mitigate vibrations and exceed the industry standards for STC and IIC. The concert hall has a slab-on-grade of high mass with an isolation pad in the middle to help diminish the vibrations from the train nearby. Also, the wall assembly, which is part of the lateral system, is thickened to achieve a higher acoustical performance. Through the mass and layout an STC of 65 was achieved. Furthermore, the mechanical section of the building was isolated to prevent vibrations produced by the mechanical equipment from transmitting into the rest of the building.

**PERCENT WOOD**

By changing the building system to use wood instead of steel the CO2 emissions were reduced by 27%. This is equivalent to taking 96.3 cars off the road for one year, see below.

**CARBON CONTENT COMPARISON**

The comparative CO2 emissions of different materials are shown in the figure below. Steel emits significantly more CO2 than wood, making it a more environmentally friendly choice.

**Material Volume vs. Carbon Content**

The figure below shows the relationship between the material volume and the carbon content. It can be observed that timber has the lowest carbon content, making it the most sustainable option.

**Volume of Cross-Laminated Timber, Glulam Columns & Beams**

The volume of cross-laminated timber used in the structure is shown in the figure. The usage of timber significantly reduces the carbon footprint of the building.

**Volume of Masonry, Precast Panels, Concrete Foundations, Steel Truss & Balcony**

The volume of other materials used in the structure is also shown in the figure. The usage of these materials is minimized to further reduce the carbon footprint.
### CENTRAL PLANT OPTION
- Contains a combined heat and power plant coupled with a chilled water plant.
- Provides Hope College the flexibility for to increase the campus building square footages by 900,000.
- The plant will be placed in an open site already on campus and allow for cleaner energy and electric production.

### SNOWMELT SYSTEM
- Located in both the roof and plaza.
- Uses free heating energy from steam condensate.
- Melted precipitation reused for building as grey water.
- Saves 200,000 gallons of water every year.
- Prevents snow from accumulating on horizontal surfaces.

### VENTILATED DOUBLE WALL FAÇADE
- An integrative glass façade that provides natural light with minimal added envelope load.
- Reduces heating and cooling cost by $6,600 per year.
- Modularized assembly allows for easier constructability.

### DISPLACEMENT VENTILATION
- Underground ducts serve large volume spaces to reduce plenum clutter.
- Direct supply of air to the occupants elevates indoor air quality.
- Saves energy by not conditioning upper unoccupied zones in high volume spaces.

### ACOUSTICS
- Ductwork was ensured to not transmit disruptive background noise by installing duct silencers and sound insulation.
- All mechanical equipment was assessed to provide proper vibration isolation.
- The mechanical rooms are structurally isolated from the building to mitigate vibrations.

### THERMAL STORAGE
- Reduces peak utility usage demand by load leveling the peak demands.
- Saves $16,200 per year with little additional first cost.
- The cooler chilled water for thermal storage also provides cool water for dehumidification in air handling units.
# 1.0 PROJECT OVERVIEW

The Jack H. Miller Center for Musical Arts (The Miller Center) is a proposed building project for Hope College located in Holland, Michigan. *Syndicate* is an integrated design-build team that produced a high-quality design and construction plan for this project. The project site is situated in the northeast corner of campus across from downtown Holland, near Lake Michigan. The Miller Center acts as an investment for the future of Hope College and as a showcase pilot for a new sustainability plan on campus. The addition of an occupiable roof and south lobby allows this building to act as a gateway space for connecting Hope College campus to downtown Holland.

*Syndicate*’s final design is a three-story building designed for serving the educational and performance requirements of Hope College. Totaling 70,000 square feet (SF), The Miller Center includes an 800-seat symphonic concert hall, a smaller recital hall for intimate chamber performances, and two large rehearsal spaces for choirs and orchestras. The building also includes classrooms, faculty studios, and student practice rooms distributed throughout the three stories.

# 2.0 VISION STATEMENT

Through a multidisciplinary team strategy, *Syndicate* produced a high-quality center for musical arts that met the goals and mission of Hope College found in. As a team, *Syndicate* chose to pursue this project with a vision statement that would contain individualized team and discipline goals. The vision statement is HOPE and the goals are to:

- Enhance Hope College Campus
- Maximize Occupant Experience
- Create Premier Performance Spaces
- Minimize Energy Impact

Refer to Integration SD-A for details about the vision statement.

# 3.0 PROJECT GOALS

To achieve HOPE, *Syndicate* created specific integration goals for these four vision statements. Below are the objectives for the mechanical team to meet the integrated team goals.

## 3.1 Enhance Hope College Campus

*Syndicate* wanted to ensure that the goals of Hope College as well as the individual goals of The Miller Center were not only met but exceeded. There was a push from the beginning to not only meet codes but also optimize the energy performance of the building as well as the entire campus. In addition to optimizing energy, a design should be proposed to allow for Hope College to expand the entire campus by an additional 400,000 of building square footage.

## 3.2 Maximize Occupant Experience

The Miller Center hosts numerous events every year that range from musical performances to graduation ceremonies. In addition to the performances, there are faculty and students in the building during the academic school year. With the various occupant uses come different thermal performance considerations that must be addressed to create an environment that is comfortable, healthy and meets the mission of the college.

## 3.3 Create Premier Performance Spaces

One major aspect of the building is the performances that bring together the campus and the community of Holland. One of *Syndicate*’s main points of focus from the start of the project was to ensure the building mechanical systems provide an NC level of 20
3.4 Minimize Energy Impact

Syndicate aims to reduce the amount of energy that The Miller Center uses. This reduction of energy begins with the optimization of the mechanical system to set a new standard for sustainability. The overall goal is to reduce the mechanical energy consumption by 40% when compared to the ASHRAE 90.1 baseline model. To help with this, advantageous architectural changes should be made in the design phase to reduce energy consumption from the start.

4.0 CODES AND SOFTWARE

The mechanical design team used IECC 2009, as required for projects in Michigan, ASHRAE 62.1 for ventilation requirements, and ASHRAE 90.1 for energy requirements. A full list of codes utilized by Syndicate can be found on the Codes and Standards page. By using these codes and standards as a baseline, mechanical design team was able to create a design that exceeds the requirements for this project type.

4.1 Design and Analysis Software

Syndicate used a variety of industry programs to complete the site analysis and design the mechanical system’s load profiles. Trane Trace 700 was the primary resource in determining the load profile of The Miller Center and in analyzing various parametric studies on the energy usage of the building. IES Virtual Environment was a supplemental tool to obtain detailed hour by hour profiles of multiple variables that affect energy consumption of the building. Syndicate also utilized Star-CCM+ to produce a CFD model, proving the effectiveness air movement in spaces. In addition, hand calculations, WUFI Pro, Bluebeam, Microsoft Excel, Revit, and AutoCAD were used throughout the design process to calculate and document the final mechanical design, seen on Mechanical SD-A.

4.2 Climate Zone

The Miller Center is in climate zone 5A according to the International Energy Conservation Code. This climate zone is characterized by typically having cold and humid weather. The Miller Center contains storage space for musical instruments that require a relative humidity level between 40-60%, so the high humidity levels in this climate would have to be addressed.

5.0 BUILDING AND SITE ANALYSIS

A site analysis was initially done to determine the weather variation, solar paths, and wind conditions that will influence the final design.

5.1 Proximity Factors

The Miller Center is located seven miles from Lake Michigan and a quarter-mile from Lake Macatawa. Both lakes are too far for access to heat rejection. In addition, the Holland Amtrak railroad is located 100ft to the east of our building, which posed acoustical and vibration concerns that Syndicate found important to address during the design process. Utility connections are located south of the site running along 10th street.

5.2 Solar Analysis

After running simulations in IES Virtual Environment andLicaso, a plugin of AGi32, Syndicate determined there was not an adequate amount of daylight in most spaces, while a large amount of direct sun comes in the given design’s lobby with an addition of 38 tons of solar gain during peak days. The lobby faces directly west, meaning throughout the year the sun penetrates into the space creating an uncomfortable space in regard to solar heat gain as well as direct glare with an average of 1200 lms/SF, see Lighting Drawing L-6.0. Syndicate decided to add daylighting with minimal solar heat gain as a priority when moving forward with design changes.

5.3 Climate Analysis

Using ASHRAE Fundamentals 2017, the design conditions for Holland, Michigan were estimated from Figure 1: Holland, Michigan IES Stresses
the nearby Muskegon Airport weather station as shown in Figure 1 on previous page.

Due to the dominance of cold stresses coinciding with the academic year, the envelope heating load needed to be addressed. Additionally, an analysis of Holland’s humidity levels, displayed in Figure 2, showed that only 554 hours out of the year would be appropriate to use natural ventilation.

This analysis constrained natural ventilation conditions to temperatures between 55-75°F for thermal comfort. In addition, to ensure humidity levels are maintained between 40%-60% relative humidity for instrument storage, a psychrometric chart and bin data were used to predict how often the humidity conditions were met. Due to the combination of tight temperature and humidity constraints, natural ventilation is not a recommended strategy for the portion of The Miller Center where instruments are used.

Holland, Michigan receives on average 36.75” of rain and 70” of snow per year. Most recently, Holland, Michigan received 15” of snow accumulation over a one-week span. These parameters were important in designing the stormwater conservation system. See Mechanical SD-B for further climate analysis.

5.4 Wind Analysis
The wind rose in Figure 3 indicates that the strongest winds come from the northwest from lake michigan during the winter months and shift to strong winds from the south during the summer months. The average wind speed is 12 mph, but can reach speeds up to 38 mph in the winter.

The wind speed and direction were considered when placing an occupiable roof on The Miller Center. To avoid strong, obtrusive winds from the south and west the occupiable roof was placed on the north side of the building to encourage light summer breezes to enter the space, see Mechanical Section 7.3.

6.0 ARCHITECTURAL DESIGN ANALYSIS
Syndicate created decision metrics to assist in determining the best alterations to make to the given design of the building.

6.1 Building Orientation
The first alteration Syndicate analyzed was the orientation of the building. The given design had the main lobby facing due west. However, Syndicate concluded the combination of harsh direct sunlight and high solar gain throughout the year warranted a redesign. The revised design involved rotating the building 90 degrees clockwise so that the main lobby faced north towards the town of Holland. The given design placed the emphasis on a single connection point between campus and the town. The redesign reduced the solar heat gain in the lobby space and the building overall (Table 1).

<table>
<thead>
<tr>
<th>Solar Heat Gain Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Orientation</td>
</tr>
<tr>
<td>North Lobby</td>
</tr>
<tr>
<td>Rest of Building</td>
</tr>
<tr>
<td>Total Building</td>
</tr>
</tbody>
</table>
To address the pedestrian relationship to central campus, an additional southern entrance is provided as a secondary connection point to the student-oriented spaces while maintaining a grand entry for the performance venue. As the given design intended, the southern entrance design draws inspiration from the surrounding buildings on campus. Between the south and north entrances, a one-story glass hallway was placed to act as a merging point between campus and the town of Holland.

Through the architectural modifications, the annual overall building mechanical energy load was reduced by 44% which surpasses the goal of 40%. See Mechanical SD-C for further energy analysis.

6.2 Third Floor Addition
Daylighting for the occupants was a major design driver when considering architectural changes. The building program requested the addition of an occupiable roof, presenting the need to extend the elevator and main stairwells. Due to the infrastructure already being implemented and desire to increase the number of spaces with daylight, Syndicate decided to reduce the footprint of the first and second levels on the west and add an additional third floor. This addition increased the façade area as well as the number of windows, so Syndicate had to ensure the building enclosure would mitigate any increase in envelope load from the given design.

7.0 BUILDING ENCLOSURE
Designing the enclosure required a highly integrative design process across all disciplines. A high-performance enclosure must be a balance of being an acoustical barrier, acting as a thermal air barrier, providing adequate daylight performance, being structurally sound, and providing an architectural statement for Hope College.

The facade is split into two wall assembly types as seen in Figure 4. Both wall assemblies are clad with 4” modular brick to maintain the aesthetic of Hope College’s Campus. 3” polyisocyanurate board is run continuously to mitigate any thermal bridging in both assemblies. For the shear wall assembly, 12” precast walls will be used as the structural component. See Structural Drawing S-9.0 for information on precast shear walls. For the typical wall assembly, 2”x4” metal studs filled with R-13 fiberglass insulation are placed to further increase the thermal resistance of the wall assembly (Table 2), see Mechanical SD-D for detail.

<table>
<thead>
<tr>
<th>Table 2: Wall Assembly R-Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Weight Framed Wall</td>
</tr>
<tr>
<td>Precast Concrete Shear Wall</td>
</tr>
</tbody>
</table>

Moisture control is addressed with the addition of a continuous vapor retarder on the interior side of the 3” polyisocyanurate board. This was purposeful since the polyisocyanurate board will not act as a proper vapor retarder. The interior foil-facing side cannot be sealed when installed against metal studs or concrete precast walls, creating holes where moisture can penetrate the wall. WUFI, which is a moisture transport analysis.
software, was used to analyze whether water would accumulate in the assemblies, displayed in Figure 5.

Both wall assembly types were proven to permeate water through the exterior layers without condensation occurring in the fiberglass insulation and metal stud, which is the critical component of the wall assembly. This was determined by ensuring the fiberglass insulation never reached the dew point.

7.1 Ventilated Double Wall Facade
To maximize occupant experience and to minimizing energy impact were main drivers in the mechanical team’s facade design. Syndicate’s architectural changes created a ring of circulation surrounding the main functions of the building. The south, north, and west transient spaces have windows for natural daylight to enter the building. Because of this, the solar heat gain through the main public spaces were analyzed and it was determined that the heat could be captured in the transient spaces before it reached the occupant. To optimize performance and thermal comfort, Syndicate analyzed the benefits of utilizing a ventilated double wall facade in the north lobby, west corridor, and the south lobby, detailed in Figure 6.

The ventilated double wall façade allows daylight to enter while serving as an additional method to heat and cool the space. The exhaust from the ventilated double wall facade will connect to the air handling units with dampers so that in the summer the air can be directly exhausted, but in the winter the solar heat gain can be recovered by the air handling units to preheat the outside air. See Mechanical SD-D for further details.

The ventilated facade on the north lobby and south lobby were deemed inappropriate because of a 30-year and 15-year payback period respectively. This is due to the cost and maintenance of a double height dynamic facade. In the west corridor, the return air can recover up to 8.4MMBTU/hr in the winter and prevent 75.5MMBTU/hr from entering the corridor. This provides up to $6,600 and 14% in annual utility savings which results in an 8-year payback period; therefore, Syndicate chose to implement the ventilated double wall façade in the west corridor in the summer.

7.2 Roof
Syndicate aimed to comply with the requirement set by ASHRAE 90.1 to provide an adequate thermal barrier to mitigate unwanted heat transfer. Coordination between disciplines provided a sustainable roof solution.

Factors that were analyzed included the weight and cost of the roof. One option considered a green roof design, but further analysis showed that it added around 13 lbs/SF in weight, which increased the depth of beams in a typical bay by 19%. The current built up roof membrane costs $5.36/SF, but with the addition of a green roof assembly the cost per square foot would
When considering all these factors, Syndicate determined not to pursue a green roof.

A cross laminated timber (CLT) based roof provides more thermal mass than a typical roofing system. This mass slowly releases or absorbs heat, preventing sudden fluxes in heat flow through the roof. The roof incorporates a snow melt system in order to capture the precipitation to use as grey water throughout the year. For more details see Mechanical Section 10.2. The total makeup of the roof provides an R-Value of 36 that exceeds the ASHRAE 90.1 standard by 20% (Figure 7).

To allow daylight to enter more faculty studios and practice rooms on the third floor, skylights were designed into the roof. With the addition of solar gain, the skylights added 2,226 kWh/year to the overall cooling energy. However, with the addition of natural light, the electrical energy usage is reduced by 4,955 kWh/year, resulting in a net reduction of 2,647 kWh/year by adding skylights. In regard to the mechanical design in the faculty studios and practice rooms with skylights, the return air grille will be placed adjacent to the skylight opening. The placement will allow for hot air to be directly exhausted from the skylight opening rather than allow it to enter the space.

7.3 Occupiable Roof
As requested by the building program Syndicate has provided the option of adding an occupiable roof space that can be used year-round. In order to be utilized in the varying weather of Holland, Michigan, the space was designed with sliding glass doors incorporated into the facade, shown in Figure 8, that can be kept open in the summer months to provide natural ventilation for cooling and closed during the winter months to block north-west wind. Natural ventilation is viable in this space because there is no constraint on the temperature and humidity control that other spaces have due to instrument storage.

In accordance with ASHRAE Comfort Standard 55, overhead fans will be utilized to encourage air movement over the occupants, keeping them comfortable in the outdoor space. During the winter months, the glass doors will be closed, and a heating ventilation unit will be used to heat and provide fresh air in order to maintain a comfortable condition for performance receptions. The heating ventilation unit will be set back to 45°F during unoccupied times and be raised to 65°F two hours before a scheduled event.

The occupiable roof also acts as an additional thermal barrier above the north lobby. The space adds an equivalent R-value of 20 to the north lobby roof, saving 90MMBTU/hr in energy usage.

8.0 SYSTEM DESIGN
The overall HVAC system design is an integrative solution that complies with code and creates an environment where students, faculty, and the community of Hope College alike can enjoy. The design provides energy savings as well as acoustical considerations that reduce the sound transmitted by the mechanical equipment, which helps create an environment for superb performances. There was careful planning with other disciplines for seamless integration into the building.
8.1 Central Plant Options
When considering the mechanical system, Syndicate wanted to look at multiple heating/cooling system options to provide the optimum design for Hope College.

Option 1 - A standard mechanical central plant with thermal storage. This would include a typical decentralized plant with connection to campus steam and individual chillers that utilized an ice storage system to offset a portion of the peak electric load.

Option 2 – A centralized campus plant that includes a combined heat and power plant as well as a chilled water plant. This would take advantage of the ability to produce electricity and chilled water in addition to generating steam.

Option 3 - A geothermal based central plant. This option offers the use of the ground as a heat sink with the use of geothermal heat pumps.

See Mechanical Section 8.1.4 for central plan recommendations and Mechanical SD-A for decision matrix.

8.1.1 Decentralized Mechanical Central Plant
Currently, Hope College has a small steam plant on campus. Limited by the competition rules, an assumption is made that it serves the resident halls, office buildings and bigger buildings around campus, including The Miller Center. It is inferred that steam-to-hot water heat exchangers will convert steam to heat in the building’s hot water loops.

On the cooling side, Syndicate decided to analyze thermal storage approaches to offset the peak mechanical load due to the high electric demand charges in Holland. An internal freeze/ internal melt system was finally selected due to its ability to accommodate smaller scale projects, such as The Miller Center, see Mechanical Drawing M-6.0. “Internal freeze/internal melt” systems use a secondary coolant, such as glycol, as the charging and discharging heat transfer fluid, which is circulated through coils that are submerged in water tanks. To make the ice, a chiller cools the glycol to 24F so ice can form on the outside of the coils. Ice is released from the coil in the discharging cycle when warm glycol flows through the coils and melts the ice from the inside out. The released ice chunks, in turn, reduces the primary coolant temperature. (Figure 9).

![Figure 9: Internal Freeze/Internal Melt Diagram](image)

The final design thermal storage capacity is 400 ton-hrs, allowing for the reduction in total chiller capacity from 200 tons to 160 tons. Two 80-ton air cooled scroll chillers were chosen to meet the required load and fully charge the thermal storage overnight (Figure 10). Air cooled chillers were selected because of the low wet bulb depression due to high humidity levels throughout the year in Holland. Normally, a cooling tower would be more effective than an air-cooled chiller when the wet bulb is much lower than the dry bulb, but in this specific climate this advantage is not as prominent. Furthermore, air cooled chillers operate at higher efficiencies at night because of the diurnal outside temperatures, which is ideal for ice making. A closed loop system with glycol was chosen to mitigate any freeze/thaw concerns in the primary building distribution loop. The chilled glycol goes directly to the air handling unit cooling coils, and then is sent through a flat-plate heat exchanger for the radiant panel chilled water supply, see Mechanical Drawing M-5.0.

![Figure 10: Thermal Storage Load Profile](image)
By having two chillers and thermal storage, there are several control scenarios in the instance of mechanical failure. In the case of thermal storage failure on the worst design day with everything running simultaneously, the building cooling load is met with a 65% full concert hall. The building operator can have the choice of completely cooling a full concert hall or balance cooling of the entire building. Similarly, in the case of a chiller failure on the worst design day, the thermal storage and one chiller can cover the entire building plus 50% of the full concert hall load. If Hope College wishes to guarantee 100% operation on the worst design day in the case of a storage system failure, an additional air cooled 40-ton chiller can be added at a cost of $39,500.

With thermal storage levels equaling the load during on-peak hours for design days, this strategy eliminates the need for day time chiller use on most non-performance days. The on-peak demand charge for Holland, Michigan is $14.50/kW, so by reducing the chiller capacity during the on peak hours, the annual utility bill is decreased by $16,200/year. Due to the reduction of 40 tons in needed chiller capacity and significantly lower monthly utility cost, the economic analysis proved thermal storage to have a payback period of 1.4 years.

8.1.2 Central Heating/Cooling Plant
Examining the existing Hope College steam plant, it can be assumed that the plant is at full capacity. Option 2 introduces a combined heat and power (CHP) plant as a staged replacement of the steam plant as well as a proposed central chilled water plant. The addition of CHP would increase the capacity of steam that is produced to not only cover the existing buildings but allow for campus expansion. In addition to the steam produced, there will be electricity produced to introduce into the campus grid. The current capacity of the steam plant is estimated to be 11,500 lbs/hr of steam and the estimated campus electricity demand is 3 MW. Based on these requirements, the smallest efficient package unit for size was specified to provide optimal operational efficiency. The enclosure access and maintenance space can be seen in Figure 11.

There is an adjacent plot of land to the east of The Miller Center that can be utilized for the new central plant building (Figure 12). The total estimated cost of this additional building is $500,000, and the total area of the space is 6,500 SF. The building will include space for the gas turbine, the chillers for the central chilled water system, and the offices for maintenance and operation monitoring.

There is ample space in the new plant for additional CHP units. By only adding one more unit, the campus will have the ability to almost double in building square footage, or close to 900,000 SF expansion. The upfront cost of the CHP equipment is around $2 million while the standard boiler system equipment was estimated to be around $400,000, but the savings of fuel use each year is where CHP surpasses the standard system. Fuel cost for the standard system includes both natural gas and electrical costs which are estimated to around $1.5 million per year while the CHP fuel cost is estimated at half of this. The CHP system provides a simple payback period of around 4 years for the equipment.
On the other hand, the campus steam plant currently does not have a central chilled water system. Option 2 will introduce a campus chilled water loop. This addition will be modularized as well and added as needed for future expansion of the college for a more economical approach. Included in the plant are absorption chillers that use the steam in order to run the CHP units at close to full load in the summer to prevent any inefficient operation.

In order to phase Option 2 into the campus, there will be a switch over period that includes the existing steam plant still operating while the CHP system gradually becomes available. The central chilled water system would be phased into any new buildings and is not intended for retrofitting any existing buildings to use this technology. Option 2 takes advantage of a central plant for both cooling and heating that detaches energy generation from individual buildings. This reduces the mechanical noise generated in buildings by having the major equipment in a central plant. See Mechanical SD-E for further details.

8.1.3 Geothermal Heat Pumps
Geothermal heat pumps were considered as an innovative central plant system for Hope College. Syndicate wanted to mitigate disruptions to additional areas on campus, so geothermal bores were only considered on the given site and neighboring Physical Plant Department site. A full geothermal heat pump system and hybrid geothermal heat pump system were considered, but both produced a negative simple payback of greater than 50 years. Also considering the accessibility of campus steam for heating, geothermal heat pumps are not recommended for The Miller Center.

8.1.4 Central Plant Recommendation
Considering all options, Syndicate recommends Option 1, the standard mechanical central plant with thermal storage. Option 1 best fits within the given budget constraints when compared to the other options. On the other hand, Option 2 is forward thinking and invests in the future potential of Hope College. Syndicate recommends pursuing Option 2 because of the potential campus wide energy savings and the added flexibility for campus expansion despite the increased initial investment.

8.2 Distribution Systems
The distribution system was zoned by space design criteria and space usage as seen below:

<table>
<thead>
<tr>
<th>Space Type</th>
<th>Distribution Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Public Spaces</td>
<td>Displacement Ventilation</td>
</tr>
<tr>
<td>Faculty Studios and Practice Rooms</td>
<td>Radiant Panels and DOAS</td>
</tr>
<tr>
<td>Stage and Storage</td>
<td>Typical VAV Ceiling Supplied</td>
</tr>
</tbody>
</table>

8.2.1 Displacement Ventilation
To minimize energy impact and improve the occupants experience, the mechanical team pursued the use of displacement ventilation in large volume spaces. The supply diffusers are located to ensure every occupant receives outside air and maintains optimal indoor air quality and thermal comfort. Supply air between 63-68°F is sent through ductwork at 900 fpm into a plenum that reduces the air speed further to 50 fpm before reaching supply diffusers. In the auditorium the diffusers are located in front of the seats. This is done to prevent occupant belongings from covering the outlet while also providing each occupant with fresh supply air, detailed in Figure 13. Gradual transitions are used at duct take offs to reduce turbulence that generates airborne noise.
the cost of the distribution system and lowers the fan energy used. A CFD analysis was done to ensure there were no negative impacts on the space (Figure 14).

Displacement ventilation will serve the concert hall, recital hall, south lobby, north lobby, orchestra rehearsal and choral rehearsal spaces. All of these rooms are high volume areas that will benefit from supplying air from the floor and returning it at the ceiling. See Mechanical Drawing M-3.0 for a detailed underground duct plan view. In the concert hall, the balcony will also be served by displacement ventilation to avoid higher temperature stratified air at the occupant level. A small air handling unit will be placed adjacent to the concert hall to directly supply the balcony. The lobbies are supplied around the perimeter as those spaces are envelope load dominant, and this will take care of that load before it reaches the interior space. Perimeter placement also reduces the maintenance of the floor diffusers due to lower foot traffic.

The Blue Duct system was chosen for the below ground section of ductwork, insuring structural integrity and corrosion protection of runs. This is a prefabricated, pre-insulated duct system that can be kept clean during construction and operation, Figure 15.

Three main ducts are routed from the mechanical spaces under the first-floor hallway to have minimal impact on structural foundations and duct installation. A fourth duct travels through the second-floor ceiling and drops down through three predefined shafts that then serve the recital and two rehearsal spaces via displacement ventilation. The ductwork will be coordinated with contractors and kept clean and capped during the construction process, see Construction Section 7.1 for constructability of underground ducts. The penetrations through the precast panels will be coordinated as seen on Mechanical Drawing M-3.0.

8.2.2 Radiant Panels

For the smaller rooms, such as faculty studios and practice rooms, a dedicated outdoor air system is

Figure 14: Concert Hall CFD Analysis

Figure 15: AQC Blue Duct System provided by AQC
provided to meet ventilation requirements as set by ASHRAE 62.1. The fresh air supplied to the spaces will meet 100% of the latent load and part of the sensible load. A typical supply air temperature 55°F and 95% RH and return temperature 75°F and 50% RH was used. With these setpoints, it is assumed that a room has a room sensible heat ratio (RSHR) around 0.90. However, most rooms are interior and latent load dominant with a RSHR between 0.50 and 0.75. To account for this, the return air temperature was adjusted to 75°F 45% RH and the supply air temperature adjusted to 60°F 55% RH. This allows for a better control of humidity in the room as well as a higher change in humidity ratio, which means more latent load is taken care of per cfm. See Mechanical Section 8.2.3 for DOAS details.

Since the DOAS system does not take care of the full sensible load, a supplemental system will need to be implemented. Syndicate analyzed multiple supplemental systems to provide additional cooling and heating for the smaller rooms. It was determined that radiant panels were the most appropriate in order to best aligned with the project goals, see Mechanical SD-A.

A four-pipe radiant panel system is implemented in order to provide each zone with the flexibility of heating or cooling on demand throughout the year based on thermostat controls. Typical 2’x2’ prefabricated radiant panel modules were used for ease of constructability. The modules were coordinated with acoustical lighting fixtures in faculty studios and practice rooms in order to provide an aesthetically pleasing and functional space, see Figure 16 and Lighting Drawing L-4.0 for mounting details.

For the small practice rooms, the fresh air supplied by the DOAS is sufficient to cover the cooling load. However, supplemental heating is still needed so radiant panels will still be installed these rooms as well. Additionally, the classroom areas on the first floor do not require radiant panels as ventilation air covers the cooling and heating load required throughout the year. This is due to the solar load being taken care of by the ventilated double wall facade as explained in Mechanical Section 7.1.

### 8.2.3 Ventilation System

For the air distribution within the building, 4 main types will be used: displacement ventilation, perimeter VAV floor supplied, DOAS ceiling supplied and typical VAV ceiling supplied. Seven air handling units are installed in the building using these distribution strategies as seen in Table 4 and Mechanical Drawing M-1.0.

<table>
<thead>
<tr>
<th>AHU - #</th>
<th>Zone</th>
<th>Distribution</th>
<th>SA Set Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHU - 1</td>
<td>First Floor Concert Hall</td>
<td>Displacement Ventilation</td>
<td>65F, 45%RH</td>
</tr>
<tr>
<td>AHU - 2</td>
<td>Stage, BOH</td>
<td>Typical VAV Ceiling Supplied</td>
<td>55F,95%RH</td>
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<tr>
<td>AHU - 3</td>
<td>North Lobby</td>
<td>Perimeter VAV Floor Supplied</td>
<td>55F, 95%RH</td>
</tr>
<tr>
<td>AHU - 4</td>
<td>Orchestra, Choir Rehearsal, Recital Hall</td>
<td>Displacement Ventilation</td>
<td>65F, 45%RH</td>
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<tr>
<td>AHU - 5</td>
<td>Faculty Studios, Practice Rooms</td>
<td>DOAS, Ceiling Supplied</td>
<td>60F, 55%RH</td>
</tr>
<tr>
<td>AHU - 6</td>
<td>South Lobby</td>
<td>Perimeter VAV Floor Supplied</td>
<td>55F, 95%RH</td>
</tr>
<tr>
<td>AHU - 7</td>
<td>Balcony of Concert Hall</td>
<td>Displacement Ventilation</td>
<td>65F, 45%RH</td>
</tr>
</tbody>
</table>

Due to critical humidity levels in spaces where instruments are stored, the design of the air handling units were crucial to ensure each space maintains the correct design temperatures. The supply air setpoint for the floor supplied and DOAS systems posed a problem for the air handling unit design because of the elevated supply temperatures. The 80-ton air cooled chillers are already designed to produce lower than normal temperatures for thermal storage, so the air handling unit cooling coils will be designed to cool the mixed outside/return air to 44°F. Instead of wasting energy to reheat the air, a flat plate heat exchanger will be placed before the supply air discharges from the unit to be heated by the entering return air. See Mechanical Drawing M-2.0 for detailed analysis.
The earlier shown climate analysis showed that a simple economizer cycle would not be appropriate to use because of the high humidity levels in Holland, Michigan. An enthalpy sensor will be placed in the air handling unit to ensure the outside air meets the humidity and temperature constraints before entering the space.

Digital VAV diffusers will be implemented in each of the spaces supplied by AHU-5. In each room, a thermostat will be installed to control the diffusers to allow for individual control. One VAV box will be placed on each floor to control the distribution of air flow among these rooms. A pressure differential sensor will detect when the VAV diffusers are mostly closed and will reduce the amount of airflow entering the zones (Figure 17). Reference Lighting Drawing L-5.0 for further control details.

In the mechanical rooms, the spaces will be directly ventilated during the short cooling season and conditioned by 2 pipe fan coil units during the heating season. In other equipment room spaces, 2 pipe fan coil units with minimum ventilation are used to counter the load from electrical and AV equipment.

9.0 ACOUSTICS

Acoustics was an important driver in the mechanical team’s design in order to provide premier performances with little interrupting background noise. The mechanical equipment produces noise and vibrations that had to be analyzed with respect to different factors, such as distance from noise sensitive spaces. Both the airborne and structural borne noise was considered in the analysis. The airborne noise was first addressed by analyzing the sound transmission class (STC) of the walls between the mechanical room and noise sensitive spaces such as the concert hall. There was also a combination of round and rectangular ducts and sound attenuators used to mitigate noise traveling through the ductwork. The structure borne noise travels through the structure, so structural isolation of the mechanical room and equipment isolation reduced this travel.

9.1 Mechanical Room

After considering various sound and vibration isolation methods, Syndicate decided upon an isolated structural system that will separate the mechanical room structure from the rest of the building. This means the mechanical room structure is completely independent from the rest of the building which helps by eliminating the travel route for the structure borne noise. See Structural Drawing S-8.0 for further details on the isolated structure. Pumps generate high levels of vibration during operation, so they have been strategically placed in the first-floor mechanical room to direct more of the vibrations through the slab and into the ground. Each pump is installed on a concrete inertia base that is spring mounted, see Figure 18.
The inertia base reduces the vibratory motion that the pumps produce while also acting as a rigid machine base. The pipe connections to each pump will have molded rubber flex connectors to mitigate any vibrations travelling from the pump through the pipes in the building.

In order to reduce vibrations that may travel through the structure, each second floor AHU will be spring mounted on molded acoustical neoprene isolation pads. The scroll chillers will also be spring mounted on a neoprene pad, but the mount will limit the vertical movement to prevent any safety concerns with high wind speeds outdoors. The chiller pipe connections will also have a molded rubber flexible joint to mitigate vibrations travelling through pipes.

9.2 Acoustical Isolation within Spaces

Syndicate wanted to ensure the mechanical design had minimal impact on the acoustics of each space. The air handling units emit large amounts of sound that travel through the ducts at all frequencies. The program AIM by Pottorff was used to determine the NC ratings for each space. In order to achieve these ratings, duct silencers, duct lining, long duct runs, and mitered elbows were all utilized where needed. The silencers and liners are more effective at higher frequency sounds while the long duct runs, and mitered elbows help with the lower frequency sounds. Rectangular and round ducts were used in specific areas respectively due to their differing abilities. The square ducts work well with allowing breakout noise and were utilized in the mechanical spaces and the hallways. The round ducts were used closer to and around the acoustically critical spaces because they prevent breakout noise from entering a space. See Mechanical Drawing M-4.0 for more details on acoustics.

10.0 PLUMBING

Syndicate pursues minimizing environmental impact and enhancing Hope College throughout all the system designs for The Miller Center.

10.1 Fixture Improvements

In the average year, The Miller Center plumbing fixtures are predicted to consume 7,600 gallons of water. With the installation of low flow fixtures, the plumbing water consumption can be reduced by 30%. This will save roughly $3,800 a year in terms of water and sewage cost creating a payback period of less than 1 year, see Mechanical Drawing M-7.0 for breakdown.

10.2 Rainwater Collection and Reuse

Responsible rainwater management was one of the key components of our design. The annual rainfall in Holland, Michigan accounts for 1.25 million gallons in potential water collection for The Miller Center. In addition, the collection of annual snowfall would add an additional 200,000 gallons in potential greywater collection.

The daily estimated greywater demand is 5,200 gallons. The average daily collection potential including snow and rainfall ranges from 2,500 gallons to 5,000 gallons. By selecting a 5,000 gallon underground storage tank for the rainwater collection system, the maximum amount of daily precipitation will be able to be collected and stored for greywater use the next day.

The snowmelt system will be served by a glycol-water mix loop that gains energy from the returning condensate from the central steam plant. After the campus steam is sent through the hot water and radiant panel heat exchanger, the condensate is sent through a secondary flat plate heat exchanger that will heat up a glycol water mixture to 80°F. The snow melt water loop is then sent to the roof to melt any snow accumulating in the winter months. In addition to collecting more greywater, melting the snow and ice means Syndicate prevents any snow from drifting or falling from the roof during heavy snowfall. The City of Holland currently has a snowmelt system for the roads and sidewalks within the city, so The Miller Center’s plazas will be included in plans to be a part of the city’s snowmelt expansion. See Mechanical Drawing M-5.0 for more details.

When precipitation falls on the roof or plazas, it is then captured by drains. The drains either send the water to rainwater collection tanks located underground adjacent to the mechanical room or sent directly to the filtration system. After being filtered, the greywater will be sent to the toilets and urinals throughout the building based on demand. By reusing the site’s rainwater, the collection system will save $9,100/year based on the current water and sewer utility rate and
has a payback period of 7 years, see Mechanical Drawing M-7.0 for additional snowmelt details.

11.0 FIRE PROTECTION
When adjusting the architectural design and floor plans of the building, fire protection and life safety was a main concern. With the addition of the occupiable roof and third floor, Class I standpipes needed to be added since the highest occupied floor was greater than 30’ above fire truck access. A Class III standpipe also needed to be placed by the stage since there is a higher risk of fire in this area. Throughout the building, sprinklers will be implemented to manage flames at the source, see Mechanical Drawing M-8.0 for sprinkler layout. According to NFPA 13, automatic sprinklers with extended coverage can be placed at most 15 ft apart for light hazard use. In every faculty studio two side wall sprinklers will be placed on the walls, and in every practice room one side wall sprinkler will be placed. The north and south lobbies do not need a designated smoke exhaust system since the open second levels are designated as mezzanines and not an atrium.

12.0 ENERGY STANDARDS
*Syndicate* has decided to help Hope College create a sustainability plan that helps them become a leader in sustainability. The four main pillars of the sustainability plan are waste reduction, energy conservation, indoor environment, and materials/resources. The mechanical design team was able to use this sustainability plan to help promote a culture of forward thinking at Hope College, see Mechanical Drawing M-9.0 for further details.

13.0 LESSONS LEARNED
The design process of The Miller Center was a series of lessons learned for all disciplines involved. The mechanical team learned quickly that one design change can have a domino effect with other discipline designs. Meeting as a team to discuss these design changes and evaluate the best solution was quickly adopted in order to mitigate this domino effect. By collaborating and communicating together, the mechanical design team was able to create an effective mechanical system that fulfilled all the goals of the team.

14.0 CONCLUSION
*Syndicate* has given Hope College the option to enhance its future by designing a central heating and cooling plant that will allow for an additional 900,000 SF of building space for future expansion throughout the campus. This option combined with the personalized sustainability plan sets Hope College on a path to be a leader in sustainability and clean energy.

By utilizing displacement ventilation in high volume spaces, fresh air is directly supplied to the occupants, which increases the quality of air in the occupant’s zone. Furthermore, the ventilated double wall façade and reorienting the building prevents direct glare and uncomfortable solar heat gain from deterring from the occupant’s experience within the spaces.

All spaces were analyzed to ensure the background noise level and vibrations from the mechanical equipment did not impede on acoustically critical spaces. In addition, the mechanical rooms are completely separate from the structure of the rest of building to mitigate structure borne noise from travelling to acoustically critical rooms.

Performance and sustainability were an integral part of Syndicate’s design. Making advantageous architectural changes and system selections, the building was optimized to have minimal impact on the environment. The system saves 44% in mechanical energy demand in reference to the ASHRAE 90.1 baseline design.
### Supporting Document A | Project Summary

#### SYNDICATE - Mechanical Supporting Documentation

<table>
<thead>
<tr>
<th>Team Goals</th>
<th>Construction Schedule</th>
<th>Cost</th>
<th>Sustainability</th>
<th>Necessity</th>
<th>Quality</th>
<th>Safety</th>
<th>Schedule</th>
<th>Flexibility</th>
<th>Commissioning</th>
<th>Life Cycle</th>
<th>Efficiency</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

Additional Comments: The campus central plant and a standard in-house mechanical plant tied in the decision matrix, Syndicate decided to propose two options for Hope College to consider. Option 3 is a standard mechanical plant with 2HRS and a steam station, while Option 2 is proposing a brand new campus central plant that has gas turbines for VRV and flirters for a chilled water plant.

#### SYNDICATE - Distribution System for Student And Faculty Areas

<table>
<thead>
<tr>
<th>Team Goals</th>
<th>School</th>
<th>Energy</th>
<th>Sustainability</th>
<th>Necessity</th>
<th>Quality</th>
<th>Safety</th>
<th>Schedule</th>
<th>Flexibility</th>
<th>Commissioning</th>
<th>Life Cycle</th>
<th>Efficiency</th>
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</tbody>
</table>

Additional Comments: Radiant Panels were selected by Syndicate as the main cooling and heating distribution system in the faculty offices and practice rooms. This system will allow for seamless integration with lighting, plumbing and fire protection to the ceiling of these rooms.

#### SYNDICATE - Distribution System for Large Volume Spaces

<table>
<thead>
<tr>
<th>Team Goals</th>
<th>School</th>
<th>Energy</th>
<th>Sustainability</th>
<th>Necessity</th>
<th>Quality</th>
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Additional Comments: Displacement Ventilation was selected as the way to provide heating and cooling in large volume spaces. By providing air directly to the occupants, Syndicate saw energy and increase the indoor air quality for the occupants.

### Rating—Weighting

<table>
<thead>
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### Scoring

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<td>Worst</td>
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</tbody>
</table>
Throughout the year, humidity poses an issue in Holland, Michigan. As can be seen in the tear drop graphs, every month has concentrations of high wet bulb temperatures that will be an issue for the humidity constraints in The Miller Center due to instrument storage.

### Environmental Conditions

<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
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<tbody>
<tr>
<td>Cooling</td>
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<td>Dry Bulb</td>
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<tr>
<td>Wet Bulb</td>
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<tr>
<td>Heating</td>
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<tr>
<td>Dry Bulb</td>
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</tbody>
</table>

### Monthly Temperature Tear Drop Graph

### Site Analysis

Hope College Site Map with Assumed Steam Plant Connections

Utility Connections

- Sewer Utilities
- Water Utilities
- Steam Utilities
- Electric Utilities

### ASHRAE Handbook 2017 Design Conditions

**West Michigan Regional**

**Climate Analysis**

**ASHRAE Climate Zone Map**

**Wind Analysis**

**IES Virtual Environment**

**Holland, Michigan Weather Analysis**

**Environmental Conditions**

<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
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<td>Cooling</td>
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<td>Heating</td>
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### Energy Analysis

#### Peak Cooling Load

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<td>Overall %</td>
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#### Internal Loads

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<th>Optimized Design</th>
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<tbody>
<tr>
<td>Lights</td>
<td>694,957</td>
<td>226,719</td>
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<tr>
<td>People</td>
<td>842,293</td>
<td>840,356</td>
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<tr>
<td>Misc</td>
<td>203,882</td>
<td>144,794</td>
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<tr>
<td>Overall %</td>
<td>63.77%</td>
<td>73.73%</td>
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#### Mechanical Loads

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<tr>
<td>Supply Fan Heat</td>
<td>-7,005</td>
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<td>Exhaust Heat</td>
<td>-40,127</td>
<td>-51,571</td>
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<tr>
<td>Total</td>
<td>283,5118</td>
<td>196,4447</td>
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<tr>
<td>Savings</td>
<td>1,151,045</td>
<td>36.95%</td>
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#### Peak Heating Load

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<tr>
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</thead>
<tbody>
<tr>
<td>Roof Cond</td>
<td>-76,698</td>
<td>-40,130</td>
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<tr>
<td>Glass Conduction</td>
<td>-211,481</td>
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<tr>
<td>Wall Conduction</td>
<td>-92,189</td>
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<tr>
<td>Overall %</td>
<td>35.56%</td>
<td>37.71%</td>
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</table>

#### Monthly Heating Load Comparison

- **Envelope Conduction**
- **Solar Gain**
- **Lighting Load**
- **People Load**
- **Misc Load**
- **Mechanical Load**

### Monthly Cooling Load Comparison

- **Envelope Conduction**
- **Solar Gain**
- **Lighting Load**
- **People Load**
- **Misc Load**
- **Mechanical Load**

### Baseline Envelope Comparison

<table>
<thead>
<tr>
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<th>ASHRAE 90.1 2016 Baseline</th>
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<td>Climate 5A</td>
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### Total Building Profile Loads

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<tr>
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<th>Cooling Load (MMBH)</th>
<th>Heating Load (MMBH)</th>
<th>Total (MMBH)</th>
<th>% Savings</th>
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<tr>
<td>ASHRAE 90.1 Baseline</td>
<td>17,616,712</td>
<td>1,177</td>
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<td>Optimized Design</td>
<td>9,890,512</td>
<td>696</td>
<td>15,586</td>
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### Baseline Envelope Comparison

<table>
<thead>
<tr>
<th></th>
<th>U-Value</th>
<th>U-Value</th>
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<th>U-Value</th>
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<tbody>
<tr>
<td>ASHRAE 90.1 2016 Baseline</td>
<td>0.051</td>
<td>0.38</td>
<td>0.38</td>
<td>0.52</td>
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<td>Optimized Design</td>
<td>0.033</td>
<td>0.27</td>
<td>0.33</td>
<td>0.51</td>
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</table>

By reorienting the building and going beyond the 90.1 baseline envelope standards, Syndicate was able to significantly reduce the building load. The inclusion of an enthalpy wheel and the ventilated double wall façade allowed for significant reduction in cooling and heating load on the air handling unit coils as demonstrated in the pie charts.
The ventilated double wall façade is implemented on the west hallway glass façade. The glass panels are designed in modular panels that allow for easy constructability. The 2 exterior glass panes are 1/4” panes with low-e coating that are separated by a 1/2” airgap. The middle glass pane has an extra tinted film on the exterior side to capture the solar heat gain traveling through the window. A tertiary 1/4” glass pane with a grille at the top and bottom of the assembly is added to create a 4” airgap for airflow. The tertiary glass pane is hinged at the mullions to open up and allow for maintenance access. Through the bottom grille, 1000 cfm enters a 4” air, which then is heated up by the solar heat gain and exhausted through a grille at the top of the assembly connected to a forward curved fan. The hot air is then either exhausted during the cooling season, or sent back to the air handling unit through the enthalpy wheel to preheat the outside air during the heating season.

Thermal and Moisture Analysis done in Wufi for the typical wall assembly. Moisture does not condense in the fiberglass insulation, which is the critical component of the assembly.
Option 1 is the connection to the existing steam plant that would provide the heat for both the radiant panel and air handling unit hot water loops. Option 2 is an option that lends itself to future expansion as well as generating electricity instead of buying it all from the grid. The new central plant would include a 3 MW gas turbine that would be placed in an open lot adjacent to the Physical Plant Department building next door. This new space would have room for an additional turbine for expansion as well as the new chillers for the proposed central chilled water system as seen below. This new central plant building will account for additional office and storage space that would be needed to manage a central campus plant. This option centralizes the hot and chilled water generation in one building and reduces noisy mechanical equipment and maintenance from each individual building.
AHU ZONING

1. FIRST FLOOR AHU ZONING
   - **AHU-1**: FIRST FLOOR CONCERT HALL
     - Distribution: Displacement Ventilation
     - SA Set Point: 65F, 45%RH
   - **AHU-2**: STAGE, BOH
     - Distribution: Ceiling Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-3**: NORTH LOBBY
     - Distribution: Perimeter VAV, Floor Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-4**: ORCHESTRA, CHOIR REHEARSAL, RECITAL HALL
     - Distribution: Displacement Ventilation
     - SA Set Point: 65F, 45%RH
   - **AHU-5**: FACULTY STUDIOS, PRACTICE ROOMS
     - Distribution: DOAS, Ceiling Supplied
     - SA Set Point: 60F, 55%RH
   - **AHU-6**: SOUTH LOBBY
     - Distribution: Perimeter VAV, Floor Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-7**: BALCONY OF CONCERT HALL
     - Distribution: Displacement Ventilation
     - SA Set Point: 65F, 45%RH

2. SECOND FLOOR AHU ZONING
   - **AHU-2**: STAGE, BOH
     - Distribution: Ceiling Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-3**: NORTH LOBBY
     - Distribution: Perimeter VAV, Floor Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-4**: ORCHESTRA, CHOIR REHEARSAL, RECITAL HALL
     - Distribution: Displacement Ventilation
     - SA Set Point: 65F, 45%RH
   - **AHU-5**: FACULTY STUDIOS, PRACTICE ROOMS
     - Distribution: DOAS, Ceiling Supplied
     - SA Set Point: 60F, 55%RH
   - **AHU-6**: SOUTH LOBBY
     - Distribution: Perimeter VAV, Floor Supplied
     - SA Set Point: 55F, 95%RH

3. THIRD FLOOR AHU ZONING
   - **AHU-1**: FIRST FLOOR CONCERT HALL
     - Distribution: Displacement Ventilation
     - SA Set Point: 65F, 45%RH
   - **AHU-2**: STAGE, BOH
     - Distribution: Ceiling Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-3**: NORTH LOBBY
     - Distribution: Perimeter VAV, Floor Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-4**: ORCHESTRA, CHOIR REHEARSAL, RECITAL HALL
     - Distribution: Displacement Ventilation
     - SA Set Point: 65F, 45%RH
   - **AHU-5**: FACULTY STUDIOS, PRACTICE ROOMS
     - Distribution: DOAS, Ceiling Supplied
     - SA Set Point: 60F, 55%RH
   - **AHU-6**: SOUTH LOBBY
     - Distribution: Perimeter VAV, Floor Supplied
     - SA Set Point: 55F, 95%RH
   - **AHU-7**: BALCONY OF CONCERT HALL
     - Distribution: Displacement Ventilation
     - SA Set Point: 65F, 45%RH
Six out of seven air handling units are located in the second level mechanical room. Each unit is equipped with spring isolators mounted on an acoustical neoprene pad. The outside air is first mixed with return air and sent through a MERV 14 filter and cooling/heating coils. During the heating season, a humidifier will introduce steam into the airflow to ensure the humidity requirements for the spaces are met. Finally, the supply air exchanges heat with return air through a flat plate heat exchanger as the last stage of reheat before entering the designated spaces. In the case that the flat plate heat exchanger does not meet the desired reheat setpoint, a supplemental reheat coil will be placed in the supply ducts. By utilizing the flat plate heat exchanger, Syndicate is able to reduce the chiller load by 50 tons since the return air is cooled by the supply air at each unit before mixing with the outside air.

The exhaust air is routed to discharge below the air cooled scroll chillers. Since the air was cooled from the flat plate heat exchanger, it is rejected at a design point of 58°F. The air cooled scroll chillers become more efficient with cooler outside air, so by exhausting the cool air above the chillers, Syndicate is able to slightly increase the operating efficiency of the chillers during the cooling season.
**BLUE DUCT SYSTEM**

The Blue Duct System is provided by AQC Industries as a solution to running ducts underground. The duct system is made up of high density polyethylene and can be directly buried underneath the slabs. The Blue Duct is guaranteed and warranted not to rust, mold or crush, and can easily be capped during construction to prevent dust and debris from entering the duct. The system does not require concrete housing, and only needs backfill soil when installing. The blue duct system is long lasting and durable. With built in R-10 insulation and resistance to mildew and corrosion, the cleanable blue duct system will provide clean fresh air to the occupants.

**DISTRIBUTION TO SPACES**

To best supply the large volume spaces throughout The Miller Center, Syndicate ensured the concrete footers were 6' below top of slab where needed to allow the blue duct system to maneuver to the designated spaces. This allowed for uniform excavation depth of footers and easier coordination between mechanical and structural elements during the construction process. When ducts penetrate into spaces, the precast panels will be coordinated to have openings to allow the ducts to pass through into the space. To minimize excavation, three main duct runs were used to limit the duct sizes to 48"ø, 40"ø, and 28"ø. To minimize underground duct cost, the recital and rehearsal zone duct run was routed through the mechanical storage space on the second floor before penetrating the precast panels underground. The main duct runs were ensured to allow air to travel at 1200 fpm and then reduce to 500fpm in the duct branches. Directly beneath each diffuser is an acoustically lined plenum to reduce the velocity to 40fpm when entering the space. The concert hall balcony is served by an adjacent located air handling unit to minimize friction loses. The displacement ventilation ductwork in the balcony was coordinated to run between the structural beams to adequately supply the occupants with the appropriate amount of fresh air.
The concert hall and the recital hall fall under the category that specifies an NC value of 20. This is a very stringent requirement and is due to the sensitivity of these spaces. The orchestra and choir rehearsal halls do not have live performances in them, so they are slightly less sensitive at an NC rating of 25. Practice rooms and faculty studios have a more lenient rating of NC-30. The long rectangular duct runs worked to allow for much of the sound to be mitigated before reaching the diffusers. When the long duct runs were not sufficient, there was a combination of duct silencers and 1" duct liners added a short distance after the air handling units. The addition of these design features was only needed right after the AHU and not through the entire duct run due to the effective sound mitigation at the different frequencies just a short distance into the duct.

Diffusers were selected to ensure the NC requirement was met in each space. In the area with displacement ventilation 10" floor diffusers from Price Industries were selected with a design flow rate of 50CFM, which has a NC Rating below 15. In the office and practice rooms, a ceiling mounted VAV diffuser from Titus was selected with an NC rating of 17. Both of these selection meet the NC requirements for the spaces, ensuring the functions of the building will not be disturbed by mechanical background noise.

Syndicate was able to stack the first and second floor mechanical rooms and completely isolate the structure shown below. Through this design, the vibrations from the mechanical equipment are greatly mitigated.
Ice is formed and stored on the tube heat exchanger surface while the glycol flows through the tube side. A 25% glycol mixture was used to allow system water to be cooled below the freezing point of water. The chiller is upstream and in series with the thermal storage. This allows the chiller to operate more efficiently when discharging since it will precool the water to 48°F instead of 40°F. Thermal storage are easy to maintain and operate, making the system ideal to significantly lower the utility cost at little extra cost. See M-6.0 for specific thermal storage cycles.

The precipitation collection system collects water and melted snow from all the roofs and the plazas on the ground level. The water is either sent directly into the filtration system to be used for grey water, sent into the storage tank, or sent into the gravel surrounding the tank during overflow conditions. See M-7.0 for roof drain layout.
THERMAL STORAGE CHARGING CYCLE

1. CHILLER AND THERMAL STORAGE DISCHARGING CYCLE

THERMAL STORAGE BYPASS CYCLE

2. THERMAL STORAGE ONLY DISCHARGING CYCLE

THERMAL STORAGE COST ANALYSIS

<table>
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<tr>
<th></th>
<th>First Cost</th>
<th>Yearly Maintenance Cost</th>
<th>Yearly Utility Savings</th>
<th>Simple Payback</th>
</tr>
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<tbody>
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<td>$8,100</td>
<td>$16,200</td>
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<tr>
<td>No Thermal Storage</td>
<td>$100,000</td>
<td>$7,900</td>
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</table>

MONTHLY UTILITY COST WITH AND WITHOUT THERMAL STORAGE

CHARGING/DISCHARGING SCHEDULE FOR WORST LOAD CONDITION
**Snowmelt loops located on all horizontal roof surfaces**

Active loop ends, main headers and control valves mounted centrally at a utility room.
Concealed pendant sprinklers were used throughout the building to maintain a clean aesthetic but still providing adequate protection against fire. For example, in performance spaces, sprinklers will be installed and concealed in acoustical ceiling panels/ribbons. In the faculty studios and practice rooms, two side wall sprinklers were placed based on the requirements for area coverage from NFPA 13. By adding an occupiable roof and third floor, standpipes are now required to be placed in stairwells. In addition, the stage will require a Class III standpipe due to the area of the platform being greater than 1000SF. The fire suppression system utilizes an automatic sprinkler system in accordance with NFPA 14. The system is also equipped with smoke detectors in every room.
THE HOPE COLLEGE SUSTAINABILITY PLAN

Syndicate, after considering aspects of the LEED and WELL plans and the efforts that Hope College is already making, has created a customized sustainability plan for Hope College. This plan allows Hope to pursue environmentally-minded goals without sacrificing their academic objectives. There are four main canons that encompass large sustainability aspects, and those four are broken down into several implementation categories (shown below). The objectives that were considered during the mechanical design of The Miller Center are highlighted below.

JACK H. MILLER PILOT PROGRAM

Syndicate has implemented this Sustainability Plan on The Miller Center project. Below are the specific aspects of the plan that are highlighted during the mechanical design, color-coded by the main sustainability categories.

- **Alternate Systems**
  - The concert hall is currently scheduled for 15 events a year, so to condition the space at the same rate as the rest of the building would be a waste of energy. Therefore, Syndicate put the concert hall and stage on three separate air handling units that will only run closer to full capacity when there are performances. The design also allows for the three independent operations of the platform, auditorium, balcony for different occupancy uses.

- **Sensors**
  - Occupancy sensors will be placed in all rooms and interact with lighting controls as well as air handling unit controls. When the occupancy sensors detect 60% of the faculty studios and practice rooms are unoccupied for more than 2hrs, the air handling unit will adjust the setpoint to avoid cooling/heating unoccupied spaces.

- **Daylighting**
  - By incorporating the ventilated double wall façade on the west corridor, ample amount of daylight was incorporated in interior spaces will saving heating/cooling energy. In an average year, the ventilated double wall façade will save 83.9MMBTU/hr in heating and cooling loads.

- **Air Quality**
  - Displacement ventilation through buried ducts was implemented on the Miller Center project. This provides the fresh air to the building occupants because the air is being supplied at floor level. The air will reach the occupants first, ensuring their load is met before the air is exhausted from the ceiling above. The upper zone in large volume spaces is unoccupied, so the level of air quality above the occupants is not a concern. This is implemented and extremely effective in the large volume spaces; the atriums, concert hall, and recital and rehearsal spaces.

- **Environmental Impacts**
  - Syndicate chose to reorient the Miller Center so the main atrium faces north in order to decrease the amount of uncomfortable sunlight that it would have originally received when oriented West. Additionally, the curtain glass used in the West façade is ventilated double wall façade to stabilize thermal levels and repurpose the solar energy. Finally, implementing displacement ventilation in the concert hall will maximize thermal comfort during performances by providing slow, cool air directly to the occupants.

- **Life-Cycle Impacts**
  - The central plant option will provide Hope Campus with a long lasting CHP and chilled water plant that will allow Hope College to expand and grow in the future. A central plant provides higher efficiency and centralized operation and maintenance.

- **Water Efficiency**
  - A snow melt system was installed on the roof of the Miller Center. This system uses waste heat from the condensed water before it is returned to the central steam plant. The water is sent through a heat exchanger that warms a glycol/water solution, which is then sent to the roof on days that ice or snow occur. Year round, precipitation from the roof and plazas are collected, stored, and filtered to use as greywater for toilets throughout the building. This prevents over 1.53 million gallons of water every year from being wasted and sent to the sewer. The 1.53 million gallons of water will also be reused throughout the building as greywater, doubling the cost savings based on sewer and water utility rates.

- **Cycle Impacts**
  - By reorienting the building ninety degrees, going beyond the envelope requirements set by ASHRAE 90.1, and by making many other energy conscious decisions during the design phases, Syndicate was able to reduce the overall building load by 41% based on the given architecture and ASHRAE 90.1 standards. This reduction in energy demand allows for smaller mechanical equipment and significant reduction in fuel consumption.
Supply and return fans operate only to maintain temperature and set points deviation >5°.

1. Occupied Cycle
   - Warm-up cycle – energize system 1 to 3 hours in advance of event
   - Open OA, RA, and relief dampers to minimum OA positions
   - Energetic supply and return fans
   - Set points: supply air at 65°F and room temperature at 75°F.

2. Enthalpy Cycle
   - When the wall thermostats detect deviation from the setpoint, the supply fan will adjust airflow.
   - If the room temperature remains between the occupied heating and cooling setpoints, the controller will index the supply fan to provide conditioned minimum air ventilation to the room.

   - The return air humidity setpoint will be between 45-60%
   - The humidifier will turn on if the RH goes below 45%
   - When the room RH goes above 60%, the reheat coil will modulate.

3. Unoccupied Cycle
   - Supply and return fans operate only to maintain temperature and humidity
   - Outside air and relief dampers closed
   - Return air damper open
   - Maintain room temperature at 3 degrees above or below room set point.

4. Fire Alarm
   - When unit duct smoke detector detect smoke, unit to go into smoke exhaust mode
   - Supply and Return fan at 100%
   - Outside air and relief air damper open
   - Return air damper closed

5. Trouble Alarms
   - Freeze Protection – When supply air is below 38°F
   - Fan to deenergize
   - Chilled water valve open to 50%
   - Hot water valve open

Abnormal conditions:
   - Set points deviation >5°
   - Fan failure
   - Fan VFD fault
0.0 LIGHTING/ELECTRICAL EXECUTIVE SUMMARY

LIGHTING DESIGN
- The lighting design creates a welcoming building environment, highlights important architectural features and memorabilia, and provides a safe and enjoyable experience through innovative technology.
  - All lighting fixtures are LED with dimming capabilities and are properly coordinated with the appropriate drivers to mitigate humming.

DAYLIGHTING
- Syndicate collaborated to provide several daylighting features within the building:
  - The north lobby
  - The south lobby
  - The west corridor
  - Additional third floor with skylight rooms
  - These designs allow daylight into 96% of the commonly occupied spaces while mitigating direct sunlight exposure, providing a healthier environment for occupants, and reducing the electric lighting energy consumption by 48%.

CONTROLS SYSTEM
- Implementing a Lutron Vive Wireless Controls System introduces the opportunity for daylight harvesting, occupancy sensing, vacancy sensing and time scheduling.
- A controls system connects to the building systems to reduce total building energy by 32% when compared to ASHRAE 90.1-2013 standards.

MAIN ELECTRICAL SYSTEM
- The building utilizes Hope College’s existing campus utility with an exterior 1000 KVA transformer to step down the voltage to a 480Y/277V.
- Syndicate developed two options for power generation:
  - On-site 200-kW fuel cell generator to produce clean energy when needed
  - Introduction of a campus central plant with combined heat and power (CHP) to reduce energy waste and provide power campus-wide

SPECIALTY ELECTRICAL SYSTEMS
- A reduction of the building’s carbon footprint was made by providing alternative electric systems that allow for clean energy production through the use of:
  - A photovoltaic array that can generate 93,000 kWh/yr, located on the concert hall roof
  - Vibration Energy Harvesting (VEH) to produce a max of 27.5 mW for powering of all low-voltage systems

ENERGY CERTIFICATION
- A dashboard display is located in both lobbies for occupant observation to showcase the energy conscious design and continuous cost savings.
- Information is gathered through Lutron’s Quantum energy management system, which speaks directly to the Lutron Vive and Senseware systems for lighting, electrical and mechanical load information.
## 1.0 PROJECT OVERVIEW

The Jack H. Miller Center for Musical Arts (The Miller Center) is a proposed building for Hope College located in Holland, Michigan. **Syndicate** is an integrated design-build team that produced a high-quality design and construction plan for this project. The project site is situated in the northeast corner of campus across from downtown Holland, near Lake Michigan. The Miller Center acts as an investment for the future of Hope College and as a showcase pilot for a new sustainability plan on campus. The addition of an occupiable roof and south lobby allows this building to act as a gateway space for connecting Hope College campus to downtown Holland. The Miller Center can be seen in **Figure 1**.

Syndicate’s final design is a three-story building designed for serving the educational and performance requirements of Hope College. Totaling 70,000 square feet (SF), The Miller Center includes an 800-seat symphonic concert hall, a smaller recital hall for intimate chamber performances, and two large rehearsal spaces for choirs and orchestras. The building also includes classrooms, faculty studios, and student practice rooms distributed throughout the three stories.

### 2.0 VISION STATEMENT

Through a multidisciplinary team strategy, Syndicate produced a high-quality center for musical arts that met the goals and mission of Hope College. As a team, Syndicate chose to pursue this project with a vision statement that would contain individualized team and discipline goals. The vision statement is **HOPE** and the goals are to:

- Enhance Hope College Campus
- Maximize Occupant Experience
- Create Premier Performance Spaces
- Minimize Energy Impact

Refer to **Integration SD-A** for details about the vision statement.

### 3.0 PROJECT GOALS

To achieve **HOPE**, **Syndicate** created specific integration goals for these four vision statements. Below are the objectives for the lighting/electrical team to meet the integrated team goals.

#### 3.1 Enhance Hope College Campus

Through an interdisciplinary design approach, Syndicate wanted to create an addition to the Hope College campus that would have lasting positive impacts. The team collectively understands the budgetary and timeline concerns of the owner, and as a result, set out to:

- Create both lighting and electrical systems that are economical, efficient and accommodating of other building systems
- Provide a building controls system that sets the new standard for sustainability on campus.
Develop electric lighting schemes that draw occupants towards the building.

### 3.2 Maximize Occupant Experience

*Syndicate’s* goal is to provide a world-class facility that enhances both the education and entertainment value of the musical arts through the built environment. In addition to enhancing the architecture, the team sought to accomplish this goal by:

- Providing safe, sufficient lighting levels in each space.
- Allowing for a higher degree of occupant control.
- Providing daylight into at least 90% of all commonly occupied spaces.
- Mitigating solar heat gain and reducing uncomfortable glare that may be caused by direct sunlight exposure.

### 3.3 Create Premier Performance Spaces

The primary purpose of The Miller Center is to provide superior performance spaces, which *Syndicate* held as a priority driving all design decisions. For each performance space, the team aims to provide:

- A unique and visually stunning lighting design.
- Properly coordinated LED fixtures with the appropriate drivers to mitigate potential noise from equipment or flickering from lighting.
- The ability to adapt to any intended experience of the performance type.
- A higher degree of controls flexibility for all present and future performances.
- The appropriate controls to command both the lighting and mechanical systems.

### 3.4 Minimize Energy Impact

*Syndicate* recognizes the substantial energy impacts of the built environment and strives to create a building for Hope College that reflects this challenge by:

- Exceeding the ASHRAE 90.1-2013 standard by at least 20%.
- Providing various forms of clean energy generation.
- Coordinating all electric lighting with the proper photocells, occupancy/vacancy sensing, timeclock scheduling, high end trimming, and demand response control where appropriate.
- Integrating mechanical and receptacle loads into the controls system.
- Reducing the need for electric lighting within the building by at least 30%.

### 4.0 DAYLIGHTING DESIGN

#### 4.1 Solar Considerations

*Syndicate* ran a daylight analysis on the given building layout to identify potential areas of improvement using Licaso, an AGi32 plugin, as the main software. This helped to visually analyze daylight and sunlight penetration into spaces as well as gather daylighting metrics such as daylight autonomy (DA) and annual sunlight exposure (ASE). Analyses were run using 300 lux as the baseline. Initial modeling demonstrated an uneven distribution of daylight throughout the building, while the given west-facing lobby experienced a large amount of direct sunlight penetration. This resulted in an ASE of 87% for this orientation, which creates an uncomfortable space due to both solar heat gain and direct glare (*Figure 2*). When moving forward with design decisions, *Syndicate* set a goal to increase daylighting and DA values in spaces currently receiving none while decreasing ASE, solar heat gain, and glare in spaces receiving direct exposure. Refer to Mechanical SD-B for a detailed climate analysis.

*Figure 2: Annual Sunlight Exposure (ASE) for given west-facing lobby*
4.2 Daylighting Performance Benefits

In the conversation of minimizing energy impact with a focus on maximizing occupant experiences, daylighting strategies are an important feature in all building types. Since this building encompasses musicians, students, and faculty, the benefit of natural light can have a significant positive impact on focus and performance. Therefore, it is important for occupants spending more than 4 hours in these spaces to receive ample amounts of daylight for their benefit. Coordination between all disciplines of Syndicate began early in conceptual design to ensure that the architectural layout would aid in the delivery of natural light to regularly occupied spaces. The final solution included the following features that improved upon the given design:

- A northern oriented lobby
- An additional southern lobby
- A western corridor
- An additional third floor with skylight rooms

4.3 Daylighting Redesign

4.3.1 North Lobby

As mentioned in Lighting/Electrical Report Section 4.1, the given west-facing lobby was experiencing an ASE of 87% under this orientation. Through this analysis, Syndicate was able to conclude that rotating the building 90 degrees clockwise allowed for maximized comfort by decreasing the ASE to 1.8%, as shown in the comparison in Figure 3. Under this new orientation, the north lobby is still achieving 99% DA, meaning it is receiving ample amounts of natural daylight without the negative effects of direct sunlight.

4.3.2 South Lobby

To further improve the new orientation of The Miller Center, Syndicate created an additional southern lobby to encourage flow from campus into the building. By adding this lobby, another opportunity to consider the effects of daylighting arose. Horizontal louvers were placed along the exterior façade windows to mitigate the effects of direct sunlight penetration while providing a view to the exterior. Refer to Lighting/Electrical Report Section 4.4.2 within this report for further details on sunlight mitigation. This allows for a DA of 91% with an ASE of 48% for the south lobby.

4.3.3 West Corridor and Classrooms

On the first floor, a west corridor joins the two lobbies together and provides a direct connection between Hope College and downtown Holland, which encourages flow through the building. This corridor was relocated to the exterior façade to provide the classrooms with access to daylight. Syndicate developed a glass ventilated double wall façade on the exterior and placed large windows adjacent to the classrooms, resulting in an increase in the daylighting in commonly occupied spaces by 10% (Figure 4). Refer to Lighting/Electrical Report Section 4.4.1 for further information on the ventilated double wall façade integration. Under this design, the classrooms are reaching a DA of 82% with an ASE of 23%.

![Figure 3: Annual Sunlight Exposure for west facing lobby (top) vs. north facing lobby (bottom)](image)

![Figure 4: 3D section of west corridor and classroom connection detailing daylight penetration into these spaces](image)
4.3.4 Faculty Studios and Practice Skylight Rooms

The team chose to reconfigure the architectural layout of the building to maximize daylight throughout the facility. In order to do this, Syndicate created an additional third floor on the western façade. This houses the faculty offices and practice rooms previously not receiving daylight on lower floors, as well as the occupiable roof space.

![Figure 5: Section detail of third-floor and skylights rooms (right)](image)

For rooms unable to reach the exterior facade, skylights were implemented to admit natural daylight, further increasing the daylighting in commonly occupied spaces by 11% (Figure 5). These skylights are providing the faculty offices with a DA of 29% and are providing the practice rooms with a DA of 14%. Both spaces are experiencing an ASE of 0%. A drawback to the design of the skylight was that it added 2,226 kWh/yr to the overall cooling energy. However, Syndicate further analyzed this issue and found that the addition of the natural light into the 9 spaces reduced the need for electrical energy usage by 4,955 kWh/yr. This then allowed the skylight to benefit the design through a net reduction in energy of 2,647 kWh/yr.

With these redesigns, Syndicate was able to reduce the number of spaces without daylight from 23 (18 practice rooms, 3 classrooms, and 2 faculty studios) to the 12 practice rooms on the second floor. This brings the baseline design of 75% commonly occupied spaces receiving natural daylight to Syndicate’s design of 96%, exceeding the goal of providing daylighting in at least 90% of commonly occupied spaces. In addition, Syndicate was able to mitigate the annual sunlight exposure, solar heat gain, and glare from direct sunlight to provide occupants with a healthier, comfortable environment. Refer to Lighting Drawing L-6.0 for all daylighting calculations.

4.4 Integrated Curtain Wall Facades

Investigation into architectural daylighting strategies produced multiple iterations for the curtain wall facade designs. Input from all disciplines shaped these designs, focusing on daylighting benefits, thermal performance, structural stability, and overall cost. Specific glazing and shading devices were selected to improve the overall performance of the curtain wall types. With these designs, the building was able to increase the total amount of glazing on the building’s facade, furthering Syndicate’s goal to maximize occupant experience through added daylight.

4.4.1 Ventilated Double Wall Facade

By adding a glass façade to the west corridor, Syndicate worked to ensure solar heat gain will not bring discomfort to the occupants when sunlight is entering the space. The ventilated double wall facade constructed on the exterior of this corridor mitigates this solar heat gain prior to reaching the occupant while still allowing natural daylight to enter this space and the classrooms. This return air travels upwards through the glass between the double wall and is then redirected back to the mechanical room (Figure 6). In addition to ensuring comfort, implementing this design also provides occupants in the corridor and classrooms with a view to the exterior. Refer to Mechanical Report Section 7.1 for a further explanation on this façade design.

![Figure 6: Ventilated double wall façade detail](image)
4.4.2 Glazing Selections

Material selection played an integral part in the north and south lobby curtain wall designs. Since 50% of all glazing would be affected by direct sunlight penetration, Syndicate sought to maintain a visual transmittance (VT) of 50% for all glazing selections to mitigate this penetration while still providing a view to the exterior.

Through collaboration with all disciplines, the glazing selected for the north lobby was Viracon VUE1-40 Insulating Monolithic Glass (Figure 7). This selection allows for a relative VT of 50% and improves the thermal performance with a winter U-value of 0.25, a summer U-value of 0.21, and a solar heat gain coefficient of 0.21. The south lobby also incorporates the Viracon VUE1-40 glazing with an additional 70% tint that is added to further block any direct sunlight penetration.

In the classrooms, a different approach was taken to conserve the view through the large windows. An electronic glazing made by Smart Tint that can range from 3% to 97% transparent was chosen. This self-adhesive electronic film is powered by its own external power unit and can be controlled through switching to dim the transparency. This system provides the occupant with a wider range of flexibility over the tinting of the glass and can maintain a view to the exterior when preferred. Refer to Lighting/Electrical SD-E for additional information on the glazing selections.

4.4.3 Shading Selections

To counteract the comfort issue from the large amount of additional glazing on the southern facade, properly aimed louvers were implemented to omit any direct sunlight as well reduce solar heat gain into the space. These louvers are spaced between 4’ and 8’ vertically, with 10 “fins” per system at a tilt of 114° from the horizontal (Figure 9).

Coupled with the glazing on this façade, Syndicate was able to further reduce amounts of direct sunlight and solar heat gain while still allowing for natural daylight to enter (Figure 10).

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Various spaces require interior shading to properly serve the occupant’s needs by adding flexibility. These shades are controlled via the Lutron Pico Wireless Controller, which is provided near a main switch in these spaces. All faculty studios located along the west façade on the second floor are

![Figure 7: Viracon VUE1-40 Insulating Monolithic Glass](image)

![Figure 8: Rendered image of a classroom with no Smart Tint Self-Adhesive Film (left) compared to a classroom with the film at 30% transparency (right)](image)

![Figure 9: Dimensioned detail of louvers on the south lobby](image)

![Figure 10: Section detail of the south lobby louvers operating during the summer and winter months](image)
equipped with Lutron’s T Screen with KOOLBLACK-THEIA in charcoal/grey. These shades have a 2.6% openness factor with a VT of 8.1%. With this combination, faculty members can reduce the amount of direct sunlight penetration, solar heat gain, and uncomfortable glare while maintaining a partial view to the exterior. Blackout shades from Lutron’s Serena Shades are provided for the classrooms, the choral rehearsal space, and the orchestral rehearsal space for situations when the projector is in use. Refer to Lighting/Electrical SD-E for further shading performance and specifications.

5.0 LIGHTING DESIGN

_Syndicate_ developed lighting design criteria and methods to produce a welcoming building environment, to highlight important architectural features and memorabilia, and to provide a safe and enjoyable experience through innovative technology. All of Syndicate’s lighting designs incorporate LED fixtures and incorporate energy efficient building strategies, such as control methods and dimming capabilities. All fixtures are to be properly coordinated with the appropriate drivers to mitigate potential humming. Refer to Lighting/Electrical SD-E for lighting fixture specifications.

5.1 North Lobby

![Figure 11: Rendered image of the North Lobby](image)

When arriving in downtown Holland and Hope College, one will first notice The Miller Center as a beacon for the university. By highlighting various structural features and memorabilia within the north lobby space, a captivating aura is created that can be seen through the glass atrium. This draws occupants to the building by:

- Complimenting the CLT structure through a grazing technique, creating a warm glow on the ceiling
- Providing surface mounted track fixtures to satisfy ambient lighting conditions
- Using sconce lighting to enhance the verticality of the wooden columns and provide markers to the concert hall entrance on the first and second floors
- Highlighting important memorabilia located along the wooden feature walls
- Encouraging flow to the second floor and the occupiable roof space using LED tape lighting underneath stair and balcony railings
- Backlighting the box office signage to guide occupants to the ticket purchasing location upon entering the building
- Backlighting two feature clocks to highlight the presence of Jack H. Miller, a clock-maker and collector, and his contributions to the construction of this building

Refer to Lighting Drawing L-3.0 for mounting details and directional output of the north lobby fixtures.

5.2 Concert Hall

![Figure 12: Rendered image of the Concert Hall](image)

The concert hall encompasses dynamic lighting that can adapt to the intended experience of the musical
performance while also providing future flexibility with the implementation of DMX controls. This lighting provides a relaxing performance venue by:

- Creating a “starry night” effect with an LED fiber optic array controlled by DMX to provide irregular shimmers of light to mimic a realistic nighttime sky. Refer to Lighting Drawing L-3.0 for details on the construction of the fiber optic array and mounting details.
- Enhancing the presence of the acoustical ribbon features using wall grazers
- Providing snooted, cylindrical pendant fixtures aligned with the fiber optic array to satisfy ambient lighting conditions and minimize glare visible to the occupants
- Providing recessed downlights along the perimeter walkways to satisfy ambient lighting conditions while entering and exiting the concert hall
- Defining the aisle ways and row markers using LED tape lighting

5.3 Recital Hall

The Recital Hall is a dynamic, small-scale performance space with a flexible lighting system to complement the range of configurations and concerts. The entire space is treated as a performance area with customizable architectural features, such as a moveable floor in the center of the space and unfixed seating. The flexible space is supported through the lighting design by:

- Providing flexible track lighting to accommodate to the intended performance experience while satisfying ambient lighting conditions
- Complimenting both the upper and lower wooden acoustical panels by recessing grazers in the channels that wrap around the north and south walls
- Highlighting the wooden feature wall to provide a warm glow when first entering the space by recessing wall grazers in the channel located above

5.4 South Lobby

The south lobby is an additional entrance that provides a direct connection to Hope College Campus. This space is to be used primarily by students and faculty but will also be used by the general public during musical performances. Therefore, two lighting schemes are utilized to satisfy the needs of the occupants. One scheme encourages students to sit and study by creating a comfortable lounge space. The other scheme encourages occupants to move through the west corridor to the north lobby and concert hall entrance. These schemes are achieved by:

- Creating a comfortable lounge space by staggering three large ring pendants of various diameters in a clock-like design to lower the visual plane of the space and translate feelings of intimacy
- Providing general ambience in all transient spaces

Figure 13: Rendered image of the Recital Hall

Figure 14: Rendered image of the South Lobby
through sconce lighting and surface mounted track fixtures to encourage flow to the next space

- Encouraging student flow to the second floor and practice rooms using LED tape lighting underneath stair and balcony railings

5.5 Classrooms

The intent behind the classroom lighting design is to create a comfortable learning environment that encourages productivity. Glare is reduced on work surfaces for comfort and the use of electronic devices. This lighting encourages productivity by:

- Reducing the amount of glare on the work plane while satisfying ambient lighting conditions using direct/indirect pendant fixtures
- Highlighting any content that may be displayed on the whiteboard for visual clarity purposes using wall washing fixtures recessed into the channel above

5.6 Faculty Studios

The intent behind the faculty studio lighting design is similar to design of the classroom. Each faculty office houses an instrument, which requires ample lighting for visual clarity of sheet music and for collaboration between students and faculty. Acoustically integrated pendant fixtures are used for diffuse lighting that satisfies both ambient lighting and acceptable sound criteria when instruments are played. These fixtures are pendant at higher levels than the radiant panels to ensure the radiant panels have a direct line of sight to the occupant. Refer to Lighting Drawing L-4.0 for mounting details and directional output of the acoustical pendant fixtures in the faculty studios.

5.7 Occupiable Roof Space

The occupiable roof space is an additional feature provided by Syndicate at the request of Hope College as a venue space for various events. The lighting design in this space is to provide a private, comfortable aesthetic for occupants and encourage them to spend time here while providing sufficient lighting levels in the event of a performance occurring in this space. This is achieved by:

- Creating 6’ x 16.5’ drop-ceilings, pendant 1’ from the CLT, in three separate bays for drop-ceiling locations with LED tape lighting along the top perimeter to cast a warm glow on the CLT above.
- Recessing linear strip fixtures into the bottom of the drop-ceiling panels to satisfy ambient lighting criteria
- Mimicking the south lobby and creating private lounge areas with circular pendant lighting to lower the visual plane in these areas and translate feelings of intimacy.
• Highlighting the texture of the brick features along the wall of the concert hall by placing grazing fixtures behind a 5’ partition wall to eliminate any direct glare in occupant eyes. Refer to Lighting Drawing L-4.0 for mounting details and directional output of the occupiable roof fixtures.

6.0 POWER CONSIDERATIONS

Syndicate analyzed various options for the electrical design to generate the best solution for the building and the team’s intended goals. Over the course of the design phase, the following alternative energy generation system options were analyzed and researched:

- Photovoltaic Power
  - Rooftop Array
  - Glass Enclosure
- Vibrational Energy Harvesting
- Fuel Cell Generator
- Combined Heat and Power

Syndicate looked at the advantages, disadvantages and associated efficiencies against building operating loads and costs for each system. Refer to Lighting/Electrical Drawings SD-C and SD-D for more information on the electrical equipment analysis.

6.1 Photovoltaic Power

6.1.1 Rooftop Array

Early in the schematic design phase, Syndicate considered using photovoltaics to generate electricity. The project’s location of Holland, Michigan lends itself to an average of 175 sunny or partly sunny days. The concert hall’s height provides an ideal mounting location for a rooftop photovoltaic array with a relatively flat surface and no surrounding shadows to interfere with daylight exposure. Upon running system calculations through both Helioscope and System Advisory Model (SAM), a rooftop array with a 57.9-kWdc nameplate can generate approximately 93,000-kWh/yr. With Holland’s energy and demand charges factored into the potential savings of the system and with an initial cost of $123,000, Syndicate has determined the system has an 11-year payback period. This payback is only one year above the recommended 10-year ideal. With the average lifespan of a PV system being 35 years, there will be a net gain of 24 years before a new system is required. Over the entire 35-year period, 3.26 GWh of energy will be generated, resulting in a total net savings of $243,000. Therefore, Syndicate recommends a rooftop PV system be implemented for this building.

The proposed layout of the rooftop PV array is shown in Figure 18 with the photovoltaic array highlighted in yellow. Refer to Lighting/Electrical SD-D and Integration I-9.0 for further details on the rooftop array.

6.1.2 Glass Enclosure

Syndicate also investigated the use of a new photovoltaic system technology referred to as transparent photovoltaic panels (PV glass) on the south lobby (Refer to Figure 19, windows highlighted in yellow for placement of glass). Calculations for the PV glass were completed in SAM similar to the rooftop PV array. After running these analyses, Syndicate determined that the annual generation is 2,850 kWh/yr, resulting in a net savings of $298 each.
year. This provides a 57-year payback period for the glass system. This payback period is about 6-times the recommended period of 10 years. Therefore, the system will fall short of being 100% paid off by its end of life (35 years). As a result, the PV glass is not recommended by Syndicate for implementation on this building. Refer to Lighting/Electrical SD-D for further details on the integrated PV glass system.

6.2 Vibration Energy Harvesting

Part of the alternative energy analysis was an evaluation of the vibration energy harvesters (VEH). The purpose of a VEH system is to power low-voltage equipment sensors that can remain self-powered through the conversion of vibrations into energy. Syndicate’s design approach was to expand the VEH load from low-voltage sensors to a variety of low-voltage equipment, thereby reducing the need for external grid power sources. In coordination with the structural design team, it became apparent that the structure has natural vibrations caused by factors such as wind or occupants walking around. While completely unnoticeable by occupants, the VEH equipment is sensitive enough to pick up the vibrations. At the compact size of a D battery, a VEH can produce a max 27.5 mW to discretely power the sensors from behind the scenes. This will remove the need for lithium batteries, reducing the carbon footprint of the building. Syndicate decided to implement these energy harvesters to power all low-voltage sensors in The Miller Center, which includes all 128 wireless lighting control sensors and all 70 automatic lavatory sensors. Refer to Lighting/Electrical SD-D for further details on the VEH system.

6.3 Emergency Power Generation

6.3.1 Fuel Cell Generators

Syndicate implemented an alternative source to emergency power for life safety loads in the event of normal power failure. One of the acceptable options is the utilization of a solid oxide fuel cell system. Through the conversion of chemical energy from natural gases like hydrogen, electricity can be generated with far less emissions than a standard diesel generator or the electric grid. With this knowledge, Syndicate proposes the use of the BloomEnergy Solid Oxide Fuel Cell to produce energy during a power outage, as well as reduce energy demands during peak times. This will reduce the carbon footprint of the building further by generating cleaner energy than that of Holland’s electrical grid. The proposed system will be a 200-kW fuel cell that can service the emergency loads of The Miller Center and off-set grid reliance during normal operations. The fuel cell is located above ground outside the main electrical room and will connect to the natural gas lines running through Holland, Michigan. This option is recommended if Hope College desires to only focus on The Miller Center. The next section covers Syndicate’s solution to a campus-wide focus. Refer to Lighting/Electrical SD-C for further details on the solid oxide fuel cell system.

6.3.2 Combined Heat and Power

Syndicate analyzed the existing Hope College steam plant and has concluded that it is near capacity. Therefore, a central campus plant including cogeneration and chilled water production is being introduced as a viable replacement for the central steam plant. Should Hope College choose this option as proposed by Syndicate, it would be provided with an alternative to an on-site generator for production of back-up power, as described in Mechanical Report Section 8.1.2. The plant can provide an estimate 3-MW of electricity and can sync to the switchboard to provide a voltage with phasing identical to the grid. Similar to a fuel cell, the central plant can reduce The Miller Center’s dependency on the grid during peak demand periods and the building’s carbon emissions.
Refer to Lighting/Electrical SD-C for further information on combined heat and power carbon emissions. Fuel costs for a standard system require the purchase of both natural gas and electric, costing roughly $1.5 million per year. However, the proposed system only requires the cost of the natural gas to power the gas turbine. Therefore, the centralized plant would further contribute to cost savings with a lower up-front cost and by providing independency from Holland’s electrical grid.

**7.0 BUILDING ELECTRICAL SYSTEMS**

**7.1 Normal Power**

The Miller Center will pull its main source of electricity from the campus utility. At the utility entrance, an exterior 1000 KVA transformer will step down the voltage to a 480Y/277V. This voltage is the main distribution voltage for the building because a higher voltage allows for smaller conductor sizes due to a lower current, resulting in lower material costs. A utility line connects into a 1200 A switchboard that will act as the main fault protection device for the system (Figure 21). Downstream of the switchboard are four lighting panels, three mechanical panels, three normal power panels, two emergency power panels, and one standby power panel. In compliance with ASHRAE 90.1-2013, all panels are metered.

A central distribution system was chosen to provide consolidated control over the power for this project. This was chosen in place of a distributed system because distributed works best in larger multi-story buildings that have large quantities of varying space types. Therefore, an electrical closet containing both a lighting panel and a normal power panel can be found near the north end of the building on each floor (Figure 22). The closets are stacked to provide short runs between the panels, reducing the impact of voltage drop. The second-floor lighting panel acts as a distribution panel feeding both the first and third-floor lighting panels. Each lighting panel will feed their respective floor’s normal power panel, connecting through a 45 KVA transformer to step the voltage down to 208Y/120V. A fourth lighting panel is in the second floor dimming room to provide dedicated protection to all lighting and controls within the concert hall. Refer to Electrical Drawings E-1.0, E-2.0 and E-3.0 for a full power plan layout on each floor.

**7.2 Emergency Power**

An emergency lighting panel that is fed from the switchboard is located in the emergency electrical room that is adjacent to the main electrical room, per the National Electric Code (Figure 23). The emergency power panel will serve all emergency egress lights required to provide the occupants with sufficient light levels to safely evacuate the building. This includes aisle lighting in the concert hall, egress lighting in all large spaces and corridors, and stair corridor lighting. A distribution panel will also be located in the emergency electrical room and will serve both the emergency lighting panel and one mechanical panel on stand-by power. All emergency loads will either be serviced by a 200-kW fuel cell located on-site or from the new proposed campus central plant. Refer to Lighting/Electrical Report.
Section 6.3 for more information on the emergency power generation options.

**8.0 SUSTAINABLE STRATEGIES**

Syndicate made it a priority to reduce energy consumption through the utilization of a number of electrical and lighting systems. This was done to provide Hope College with a new standard of building design to meet their desired green energy mindset. These systems include daylight harvesting, dynamic lighting controls, and sustainable energy generation through photovoltaics and VEH (Figure 24).

**8.1 Daylight Harvesting**

Syndicate placed great value in ensuring that daylight was incorporated in the architectural design based on the many benefits that natural light has for productivity and occupant satisfaction. Refer to Lighting/Electrical Report Section 4.0 for further information on the daylight design. With this integration, Syndicate recognized the opportunity to incorporate daylight harvesting to reduce electric lighting loads throughout the building. Spaces that are receiving an ample amount of daylight are equipped with photocells that will automatically dim or shut off the lights when sufficient daylight levels are present. Closed loop sensors are used in faculty studios and practice rooms to capture both electric light and daylight values. Open loop sensors are used in both lobbies to account for the high levels of daylight in these spaces. With these controls implemented, Syndicate was able to reduce electric lighting loads by 48%. Refer to Lighting Drawing L-5.0 for further analyses on daylight harvesting and energy savings.

**8.2 Lighting Controls**

Energy reduction and occupant comfort were the driving factors for Syndicate when it came to the implementation of lighting controls. Aside from photocells, ASHRAE 90.1-2013 requires occupancy/vacancy sensing, plug load control and bi-level control. To exceed these standards, Syndicate is providing additional controls such as timeclock scheduling, high-end trimming, demand response control, and HVAC integration to further reduce energy loads. Refer to Lighting Drawing L-5.0 for a detailed explanation on all control implementations for the building. The Lutron Vive system was chosen for centralized command over these controls because of its wireless flexibility and simple interface (Figure 25). One major feature of the Vive system is the BACnet protocol and its ability to communicate with Lutron’s Quantum energy management system. This provides the capability to monitor and record energy usage, contributing to the new sustainability plan that has been designed for Hope College. Lutron’s Radio Powr Savr Sensors are used for occupancy, vacancy and photocell sensing because of their wireless interface, which reduces wiring costs. These sensors can speak to the dimmers, switches, and Vive system using Clear Connect RF Technology. The Vive wireless hub is installed in four centralized locations per floor.

*Figure 24: Energy Savings baseline vs. Syndicate’s design*

*Figure 25: Integration of Building Controls*
(Refer to Lighting Drawing L-5.0 for these locations) and are powered through PowPak Modules. Each hub can speak to all local controls through the same Clear Connect technology at a maximum radius of 71’. This system operates through an uncongested radio frequency band, providing reliable communication among all controls. With these controls implemented, Syndicate was able to reduce total building energy by 32% compared to ASHRAE 90.1-2013. Refer to Lighting Drawing L-5.0 for further analyses on the controls system and energy savings.

A DMX lighting control system will be used in the concert hall to control both house lighting and performance lighting. With the current lighting design of the concert hall, a DMX system can provide nearly unlimited control over the lights through its 512-channel universe, such as the “starry night” effect through the fiber optics. With the DMX system being implemented early on, an infrastructure is now available should more theatrical performances become common in the future.

9. ENERGY CERTIFICATION

To further Hope College’s notion to become a more sustainable campus, Syndicate went above and beyond to implement a sustainability plan for the future of the university. Refer to Construction Report Section 8.0 for a further explanation The Miller Center’s sustainability plan.

To bring the certification to an everyday occupant level, Syndicate designed a dashboard system to display the various ways the building is improving energy savings daily. The energy display will be present in both lobbies for occupant observation. Behind the scenes, Senseware is gathering mechanical load, water consumption, solar payback, structural sustainability and cost information while speaking to the Vive to gather lighting load, additional HVAC load, and electrical load information. This system creates a digital display for Hope College to proudly present the ways in which they are embracing a more sustainable community (Figure 26).

10. SPECIALTY SYSTEMS

10.1 Fire Alarm System

![Figure 27: Gamewell’s Fire Control Instruments from left to right: Fire Alarm Control Panel, Photoelectric Smoke Sensor, Manual Pull Station, and Multi-Criteria Detector for heat detection](image)

The Miller Center is classified as building type A-2, therefore in accordance with NFPA 72, a manual fire alarm system will be installed. Gamewell’s Fire Control Instruments by Honeywell products are used throughout the building (Figure 27).

All smoke detectors shall utilize photoelectric obscuration smoke detection. With these detectors being line-type, all large areas will be secure with a detector having a greater coverage area. As an additional precaution, fire alarms and visual type horns with strobes were also placed throughout the building so that all occupants are aware of an emergency. A fire alarm control panel is in both the north and south lobbies for convenient access in the event of an emergency. Several manual pull stations will be located at the vestibules in both lobbies, corridors, and equipment rooms. Heat detectors will also be installed for the elevator and any activation of this detector will result in a trip of the circuit breaker serving the elevator. Flow switches and tamper switches are also installed for the required sprinkler system to react in the event of a fire.

10.2 Security System

The Miller Center is a hub for faculty, students and expensive musical instruments. Therefore, Syndicate
 implements several security strategies to ensure safety for all visitors.

Honeywell’s OMNIPROX card readers are installed at every exterior entrance. These readers are to operate during non-core hours, or between the hours of 7PM and 7AM. During this time, students and faculty are permitted to swipe their university ID card to enter through the two lobbies. All other entrances are accessed by facility managers only. In addition, the concert hall, recital hall, practice rooms, faculty studios, and rehearsal spaces always require OMNIPROX swipe access to prevent instrument theft and ensure privacy. Students, faculty, and facility managers always have access to these spaces with their university ID card.

10.3 Telecommunications System

Telephone and data ports are to be installed within all faculty offices, practice rooms, and classrooms for proper connection to internet sources. Cat6 horizontal cabling is used to provide a wider bandwidth at 250 MHz, compared to Cat5’s 100 MHz bandwidth. All horizontal cabling imposes a 296-foot length restriction before cabling must be terminated.

11.0 LESSONS LEARNED

The design process of The Miller Center was a series of lessons learned for all disciplines involved. The lighting/electrical team quickly learned that one design can have major impacts on other discipline designs. Therefore, meeting as a team and discussing all design changes helped to mitigate any negative impacts that could occur from improper coordination. By collaborating and communicating together, Syndicate was able to create an effective design that fulfilled all goals as a team.

12.0 CONCLUSION

Syndicate was able to enhance Hope College’s campus by creating both lighting and electrical systems that are economical, efficient and accommodating of other building systems, as well as develop a controls system that sets a new standard for sustainability on campus.

Syndicate worked together to maximize the occupant experience by enhancing the architecture through the lighting design, providing safe, sufficient light levels in each space, and by implementing a higher degree of occupant control in all faculty studios, classrooms and practice rooms. In addition, the team collaborated closely to incorporate more natural light into the building with the end result of increasing daylight by 96% in all commonly occupied spaces.

The lighting/electrical team provides a unique and visually stunning lighting design in all performance spaces. Controls in these spaces allow for flexibility and the ability to adapt to any intended experience of the performance while automatically commanding the lighting and mechanical systems.

Syndicate strived to minimize energy impacts resulting from the built environment by properly coordinating all electric lighting, receptacle loads, and mechanical loads to the Lutron Vive System and by displaying the energy savings resulting from Syndicate’s design on a dashboard system in the north and south lobbies. In addition, a PV array and VEH system were implemented to provide clean alternatives to energy sources, reducing the building’s carbon footprint.
DECISION MATRICES

Syndicate’s four project goals drove the ultimate decisions for all final designs. A weight value of 1-3 was assigned to each of the goals for each category to help us select which option was in the team and project’s best interest. All end results are checked marked by an X and are thoroughly explained throughout the entirety of the Lighting/Electrical report and throughout the supporting and drawing documents. Further explanation of how the decision matrix operates is explained within Integration SD-A.

### SOFTWARE USAGE

The software usage flowchart above lays out the various applications used in the process of designing The Miller Center. Syndicate’s lighting/electrical team utilized primarily the programs listed in the yellow section, while the orange section represents the integrative software used by all disciplines. Revit stands at the top of the hierarchy to represent where all information culminated for the finalized design. Syndicate used 3D exports from Revit to bring into AGi32 to run accurate illuminance calculations. Daylighting analyses were performed in Licaso, a plug-in for AGi32, to obtain daylight autonomy and annual sunlight exposure metrics. Comcheck was implemented to cross check the lighting power densities within the building against those of ASHRAE 90.1-2013. Floor plans were also exported from Revit to create lighting and power layouts within AutoCAD, as well as to create an overall site model in Sketchup. SAM, Helioscope, and Excel were used for all photovoltaic calculations. Photoshop and Excel allowed Syndicate to create informational graphics to help the reader along the way.
Syndicate, after considering aspects of the LEED and WELL plans and the efforts that Hope College is already making, has created a customized sustainability plan for Hope College. This plan allows Hope to pursue environmentally-minded goals without sacrificing their academic objectives. There are four main canons that encompass large sustainability aspects, and those four are broken down into several implementation categories (shown below). The objectives that were considered during the lighting/electrical design of The Miller Center are highlighted below.

**THE HOPE COLLEGE SUSTAINABILITY PLAN**

- **Energy Conservation**
- **Waste Reduction**
- **Indoor Environment**
- **Materials & Resources**

**DASHBOARD DISPLAY**

The above figure displays a representation of what the occupants of The Miller Center will see when walking into either the north or south lobby. This display will be interactive for all visitors to observe the real-time energy and cost savings achieved through lighting and electrical design strategies. The user will have the option to explore daily, monthly, and annual energy data to become well acquainted with the positive impact The Miller Center has on the environment. This interaction with the public will help to promote a sustainable way of thinking across the campus and provide a positive influence for Hope College’s future.

**JACK H MILLER PILOT PROGRAM**

### Daylighting

The final design of The Miller Center allowed daylighting into 96% of all commonly occupied spaces. Reference Lighting Drawing L-6.0.

### Interior Lighting

Light levels were designed to meet IES recommended values. Reference Lighting/Electrical Report Section 5.

### Life-Cycle Impacts

High end trimming was enabled for all controlled spaces to extend the life of all LEDs. Reference Lighting Drawing L-5.0.

### Environmental Impacts

A natural gas fuel cell and vibration energy harvesters are implemented to emit lower emissions into the environment. Reference Lighting/Electrical SD-C and Lighting/Electrical SD-D.

### Sensors

Occupancy, vacancy, and daylight sensors were implemented in all commonly occupied spaces to reduce lighting, HVAC, and plug loads. Reference Lighting Drawing L-5.0.

### Alternate Systems

The photovoltaic rooftop array was designed to generate around 93,000 kWh/yr, reducing energy dependency on the electric grid. Reference Lighting/Electrical SD-D.
SOLID OXIDE FUEL CELL

The BloomEnergy Solid Oxide Fuel Cell runs on a variation of natural gas mixed with oxygen to produce electricity. This fuel cell will connect to the natural gas lines running through Holland, Michigan and requires a fraction of the fuel quantity that other back-up energy generation options do. Through the utilization of an anode and cathode, the fuel cell is able to cause a chemical reaction between a mixture of steam and natural gas with oxygen ions from the cathode. This process results in a reformed fuel, which is able to produce electricity. The fuel cell is capable of generating 200 kW, limiting the amount of unneeded energy being produced during an emergency.

Clean Energy
No combustion is required in the production of energy, therefore emissions to the environment are miniscule.

Smaller Foot Print
With a dedicated natural gas line, the fuel cell does not require on site storage of fuel.

COMBINED HEAT AND POWER

Unlike a conventional power plant, combined heat and power is able to generate electricity without wasting energy during the process. A standard power plant will waste as much as 60-70% of the energy generated, while a central plant will only waste around 10%. Using the natural gas pipelines running through Hope College, the central plant will not only produce electricity at a cleaner rate than a standard generator, but will also supply steam and hot water. The proposed plant is able to provide 3 MW of electricity providing general and emergency power to multiple buildings located on campus.

Improved Efficiency
CHP ensures that energy typically lost in a standard powerplant is conserved, limiting waste drastically.

High Redundancy
The incorporation of CHP allows for many campus buildings to no longer rely on the temperamental electric grid.
Supporting Document D | Specialty Electrical Systems

PHOTOVOLTAIC ROOF ARRAY ANALYSIS

 Syndicate used HelioScope to design the proposed PV-system and get a detailed analysis of the system’s performance. The above graph is a monthly breakdown of the energy potential that the system can generate in kWh. HelioScope was also able to analyze potential system losses, shown in the left diagram. Shading is the largest contributor to system loss due to the inclusion of snow fall.

 Syndicate understands that sun position and self-shadowing are major factors that must be accounted for when designing a photovoltaic system. The lighting/electrical team researched Michigan's public weather data and found that in the spring and fall seasons the most common solar angle is 47° from the vertical. This meant that Syndicate’s PV system needed to be angled at 43° from the horizon. The design team chose to recommend Solar Canada’s Hanwha photovoltaic panels as their robust design, efficient power generation, and manufacturing proximity to Holland made it the optimal choice. With a length and depth of 5-feet and 3-feet respectively the panel is able to withstand snow loads up to 5,400 Pa. These dimensions, along with the design angle, lead to a preferred spacing of 5-feet to avoid any self-shadowing. This spacing was calculated using the sun’s position on December 21, at 12:00 PM.

PHOTOVOLTAIC GLASS ANALYSIS

 Syndicate was aware that this technology is newer when compared to other PV-systems. With this knowledge, an effort was made to find a PV glass product that balanced cost, energy output, and transparency. The design team ultimately noticed a negative correlation between efficiency and transparency of the glass. Syndicate decided to analyze OnyxSolar PV-glass as it provided a wide range of system specification options. To analyze a realistic glass transparency, the least efficient of Onyx’s products had to be chosen. This transparency was 30% with an energy output of 28 W/m². The end results of the analysis showed that the PV glass system had an annual energy production-to-system cost ratio of 0.16, almost 5-times smaller than the rooftop array’s ratio of 0.76. While an exciting technology, Syndicate decided that the system was still too new to fit into the design goal set forward for The Miller Center.

 Syndicate used System Advisory Model (SAM) to accurately analyze how the PV glass would perform. Comparatively, the annual energy output of the window system is 0.03% of the total output of the rooftop array. Similar to HelioScope, SAM was able to produce potential system losses. While not as severe, shadowing is still the largest contributor to shade due to the system spanning from a west to south orientation.

 VIBRATION ENERGY HARVESTER ANALYSIS

 The replacement of disposable single-use batteries with a renewable and sustainable energy source is a long term opportunity to reduce Hope College’s carbon footprint. Syndicate found that if every sensor utilized in The Miller Center design used an average of 2 AA batteries with a lifespan of 1.5 years, roughly 400 batteries would be disposed every 1.5 years. This immediate number may not sound large, but over the course of 15-years a total of 4,000 batteries will have been used. The average lifetime carbon footprint for a AA battery is 175kg of CO₂, meaning over a time period of 15-years, 700,000kg of CO₂ emissions could be avoided with the use of VEH technology. This is equivalent to removing 168 passenger vehicles off the road for one year.

 ReVibe Energy’s Model-D VEH technology induces electromagnetic induction by placing a copper wire in the center of a magnetic field. The magnets are set between two springs to allow for movement from vibrations. As the magnets move up and down, a voltage is generated and fed through the copper coil out to the sensor it is wired to, eliminating the sensors need for an external power source.
### Lighting Criteria

<table>
<thead>
<tr>
<th>SPACE</th>
<th>ASHRAE 90.1 2013 LPD (W/FT²)</th>
<th>ACTUAL LPD (W/FT²)</th>
<th>TARGET AVERAGE (FC)</th>
<th>ACTUAL AVERAGE (FC)</th>
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<td>Faculty Studios</td>
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<td>31</td>
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<td>Practice Rooms</td>
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</table>

### Glazing Selections

**South Lobby Glazing & Louvers**

- **VLT = 44%**
- **SHGC = .58**
- **U-Value = .48**

**North Lobby Glazing**

- **VLT = 44%**
- **SHGC = .70**
- **U-Value = .48**

### Shading Specifications

<table>
<thead>
<tr>
<th>SHADE TYPE</th>
<th>OPENNESS</th>
<th>VISIBLE TRANSMITTANCE</th>
<th>COLOR</th>
<th>LOCATION</th>
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<td>8.1% (+/- 7.9%)</td>
<td>WRITE/CHARCOAL</td>
<td>FACULTY STUDIOS</td>
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<tr>
<td>SERENA</td>
<td>~0%</td>
<td>~0%</td>
<td>BLACKOUT</td>
<td>CLASSROOMS</td>
</tr>
</tbody>
</table>

Rendering of the T-SCREEN with KoolBlack-Theia shading device shown in a Faculty Studio with a punch window.

Provided by Lutron

Rendering of the Smart Tint film shown in a Classroom

- **VLT = 4-98%**
- **SHGC = .71**
- **U-Value = n/a**
Schematic detail of the fiber optic lights anchored to the wire mesh, which is flush with the snooted pendant lights.

Schematic detail of the North Lobby lighting design to show mounting and directional output of the fixtures.
Schematic detail of a typical Faculty Studio with a punch window and of a typical skylight room to show the directional output of the acoustic fixtures, the mounting relationship between the fixtures and the radiant panels, and the sunlight penetration into each space.

Schematic detail of the Occupiable Roof lighting design to show mounting and directional output of the fixtures and the customized drop-panel.
Lighting Controls Summary - Lutron Vive Wireless System Integration

**Lighting Controls**

- **Daylight Harvesting**
  - Dimming of electric lighting when sufficient daylight levels are present, resulting in potential savings of 25-60% in electric lighting costs.
- **Occupancy/Vacancy Sensing**
  - Sensing occupancy within a space and turning off electric lighting after a period of vacancy, resulting in potential savings of 20-60% in electric lighting costs.
- **Timeclock Scheduling**
  - Providing programmed changes in the electric lighting levels based on the time of day, resulting in potential savings of 10-20% in electric lighting costs.
- **High End Trimming**
  - Setting maximum allowed light levels based on each space to reduce the production of excess light, resulting in potential savings of 10-30% in electric lighting costs.
- **Demand Response**
  - Automatically reducing electric light levels during peak periods, resulting in potential savings of 30-50% in peak period costs.
- **Plug Load Control**
  - Automatically turning off loads after a period of vacancy, resulting in potential savings of 15-20% in controlled electric load.
- **HVAC Integration**
  - Controlling the heating, cooling, and ventilation systems through BACnet protocol, resulting in potential savings of 5-15% in HVAC costs.

**Dashboard System**

Identifying important lighting, electrical, and HVAC consumption and coordinating with Lutron's Quantum energy management system to display the energy conscious design.
Prior to designing any of the systems of the building, Syndicate analyzed the pros and cons of orienting The Miller Center to face north instead of the given west facing façade. Immediately, the team was aware that the west facing atrium would let in ample amounts of direct sunlight, thus causing discomfort and glare for the occupants inside. The analysis was run at 300 lux, following the typical higher educational building criteria for illuminance. Syndicate’s orientation provides an annual sunlight exposure (ASE) of 1.8% in comparison to the original 87% ASE when faced west. However, a key design to point out is that while Syndicate was able to reduce the direct sunlight into the lobby, we were still able to achieve ample amounts of daylight at 99% daylight autonomy (DA), not breaching far from the 100% DA in the given orientation.

In order to successfully implement daylight into most of the spaces, faculty offices (right grid) and practice rooms (left grid) were organized to encompass the second and third floor western facades. In order to generate a better understanding on the affect of the surrounding buildings on The Miller Center, Syndicate analyzed the sun’s path on both equinoxes, the summer solstice, and the winter solstice (shown above). The Miller Center stands tallest at 64’ to the top of the central concert hall, with surrounding buildings like the Martha Miller Center at 35’. Concluding that shadowing would not be an issue for our building, Syndicate furthered the approach to incorporate as much daylight as possible. However, given the original orientation of The Miller Center it was obvious that more direct sunlight was penetrating through our major curtain wall façade, creating discomfort for the occupants. There was also a lack of daylight spaces throughout the entirety of The Miller Center, which Syndicate took upon themselves to amend.

The re-orientation of the building provided Syndicate with another opportunity to bring daylight into The Miller Center. A second lobby was added to the southwestern side of the building to welcome all students and faculty in a more intimate manner than when entering the building. Taking inspiration from The Martha Miller Center across the street, a glass and brick rotunda was created. However, with a large amount of glazing facing the southwest direction, comes direct solar glare and discomfort. To combat this, Syndicate analyzed many iterations (two of which are shown) including combinations of tinted windows and different louver lengths and counts. With four rows of louvers per column of curtain wall and 30% transparent windows, we were able to reduce the ASE to 48% from the original 100% while keeping DA at 91%.

In the given design, the three classrooms within this facility were left dark with no daylight. Quickly, that was able to change when Syndicate was given the opportunity to incorporate an accent curtain wall façade corridor that connects the south lobby to the north lobby. Setting the classrooms back into the corridor against the concert hall and implementing large glazing on the entrance wall to the classrooms allowed for daylight to penetrate into the classrooms while minimizing solar heat gain and direct sunlight within the space. While the ASE is only at 23%, Syndicate still implemented a Smart 30 Tint self-adhesive film on the classrooms to add an extra layer of comfort for the occupant’s in times when glare is present.

In order to successfully implement daylight into most of the spaces, faculty offices (right grid) and practice rooms (left grid) were organized to encompass the second and third floor western facades. For spaces without access to the exterior walls, tilted skylights were incorporated to admit natural daylight. The larger faculty offices allow for more daylight due to the larger span of glass above in comparison to the half-size practice room. Direct sunlight is not an issue because the 64’ tall concert hall walls are able to block any direct sunlight until the late afternoon hours.
The location of the BloomEnergy Solid Oxide Fuel Cell power generator is shown to be adjacent to the main electrical room on the exterior side of The Miller Center. This fuel cell will connect to the natural gas lines running through Holland, Michigan.
SINGLE LINE DIAGRAM

MECHANICAL/ELECTRICAL COORDINATION SCHEDULES

AIR HANDLING UNIT SCHEDULE

<table>
<thead>
<tr>
<th>Tag</th>
<th>Voltage/Phase/Hz</th>
<th>Supply Fan [hp]</th>
<th>Equivalent Load per Pole [VA]</th>
<th>Return Fan [hp]</th>
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<tr>
<td>AHU-1</td>
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<td>AHU-7</td>
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<td>5.0</td>
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</table>

VARIABLE AIR VOLUME SCHEDULE

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<thead>
<tr>
<th>Tag</th>
<th>Volt / Phase</th>
<th>Horse power [hp]</th>
<th>Equivalent Load [VA]</th>
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</thead>
<tbody>
<tr>
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<td>1</td>
<td>745</td>
</tr>
<tr>
<td>VAV-2</td>
<td>120 V / 1</td>
<td>1</td>
<td>745</td>
</tr>
<tr>
<td>VAV-3</td>
<td>120 V / 1</td>
<td>1</td>
<td>745</td>
</tr>
</tbody>
</table>

PUMP SCHEDULE

<table>
<thead>
<tr>
<th>Tag</th>
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<td>GW-1</td>
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</table>
To achieve the most efficient power production possible, Syndicate designed the photovoltaic rooftop array to have a mounting angle of 43-degrees. With the project's geographic location, the electrical design team found a due south orientation allowed for the maximum number of panels to be mounted with the highest power generation. One major challenge in the design of a photovoltaic system is the loss in efficiency due to shadows. For the design of the Miller Center's PV-array, the design team did not need to consider shadows from nearby obstructions as the panels are mounted on the rooftop of the 60' concert hall. Self-shadowing was a major concern, however, and the design team performed calculations to find a balance between the required spacing to avoid large losses and still have an ample number of panels on the roof. Syndicate found that a 5' spacing would accomplish this goal allowing for 13 rows of panels to be installed onto the roof. The final design utilizes a total of 140 photovoltaic panels with a minor 5.9% shadow loss factor.
# 0.0 Construction Executive Summary

## Constructability
- Coordinated underground duct system with structural foundations
- Created BIM plan to enhance total building systems and constructability

## Delivery Method
- Integrated design-build facilitated a multidisciplinary approach
- Minimized amount of contracts for owner
- Full team involved from project conception
- Allowed for faster construction, safer design, and higher quality

## Sustainability
- Created a new sustainability plan for Hope College
- Encourages environmentally focused design and construction practices
- Incorporates current university efforts

## Quality
- Developed a robust quality plan for construction of heavy timber and concrete precast panels
- Implemented QR code tracking technology and regular acoustically focused meetings with subcontractors

## Cost
- Total budget: $23,926,850.00
- Delivered the project $1,073,150.00 under the $25 million budget
- Breakdown:
  - Services: 32%
  - Shell: 23%
  - Interiors: 16%
  - Fee: 12%
  - Equip/Furnishings: 8%
  - GCs: 7%
  - Substructure: 2%

## Schedule
- Total construction schedule is 16 months
- Expedited traditional schedule by 3 months through fast-tracking
- Phased to allow for a higher level of control and organization
- Implemented parade of trades to mitigate conflict
1.0 PROJECT OVERVIEW

The Jack H. Miller Center for Musical Arts (The Miller Center) is a proposed building project for Hope College located in Holland, Michigan. Syndicate is an integrated design-build team that produced a high-quality design and construction plan for this project. The project site is situated in the northeast corner of campus across from downtown Holland, near Lake Michigan. The Miller Center acts as an investment for the future of Hope College and as a showcase pilot for a new sustainability plan on campus. The addition of an occupiable roof and south lobby allows this building to act as a gateway space for connecting Hope College campus to downtown Holland. Syndicate’s final design is a three-story building designed for serving the educational and performance requirements of Hope College. Totaling 70,000 square feet (SF), The Miller Center includes an 800-seat symphonic concert hall, a smaller recital hall for intimate chamber performances, and two large rehearsal spaces for choirs and orchestras. The building also includes classrooms, faculty studios, and student practice rooms distributed throughout the three stories.

2.0 VISION STATEMENT

Through a multidisciplinary team strategy, Syndicate produced a high-quality center for musical arts that met the goals and mission of Hope College. As a team, Syndicate chose to pursue this project with a vision statement that would contain individualized team and discipline goals. The vision statement is HOPE and the goals are to:

- Enhance Hope College Campus
- Maximize Occupant Experience
- Create Premier Performance Spaces
- Minimize Energy Impact

Refer to Integration SD-A for details about the vision statement.

3.0 PROJECT GOALS

To achieve HOPE, Syndicate created specific integration goals for these four vision statements. Below are the objectives for the construction team to meet the integrated team goals.

3.1 Enhance Hope College Campus

In order to meet Syndicate’s goal of enhancing Hope College campus, the construction team developed a schedule and site logistics plan that minimizes campus disturbance and mitigates possible exposure to safety hazards.

3.2 Maximize Occupant Experience

To maximize the occupant experience, Syndicate’s construction team facilitated open discussions and constant coordination between the design entities to ensure all options were thoroughly considered. Syndicate also implemented a parade of trades sequence in the construction schedule to ensure a high focus on finishes and minimize conflicts.
3.3 Create Premier Performance Spaces

Syndicate’s construction team has created a rigorous Quality Assurance / Quality Control (QA/QC) system to ensure that all performance spaces are constructed with the utmost attention to acoustic excellence. Various isolation techniques were considered in order to minimize the possibility of sound and vibration mitigation from room to room.

3.4 Minimize Energy Impact

To further the university’s sustainability efforts, a new sustainability plan for Hope College was created by Syndicate to be implemented campus-wide. This owner-based plan allows the team to minimize the energy impact of their design. It will first be applied to The Miller Center as a pilot to ensure the Hope College Sustainability Plan meets all of the university’s environmentally conscious needs before it is applied to any future projects.

4.0 INTEGRATED DESIGN AND DELIVERY

Syndicate offers its services under an integrated design-build delivery method. This delivery method allows streamlined communication between the owner and the project team. Syndicate wanted to ensure that Hope College is an integral part of the design and construction process when providing this premier space for its user groups. Through this delivery method, Hope College will only have one contract and one point of contact for the designers and construction professionals. This method ensures that the team is providing the best quality while budgeting reasonably. The designers and construction professionals will be delivering on a fast-tracked timeline because they are under one roof and collaborate from project conception. Refer to Figure 1 for The Miller Center’s organizational chart.

4.1 Stakeholder Analysis

Syndicate has performed a stakeholder analysis (refer to Figure 2) to determine how and when each stakeholder should be incorporated into the project and at what stage. The Hope College Administration has the highest level of influence over this project because they control the funds and programming but will not experience the day-to-day performance of the building like the faculty and students. Therefore, Syndicate will include administration heavily at the beginning of the project and keep them informed at a high level, expecting that they provide the project team with a budget and expected schedule. The faculty and students will be involved at a more detailed level, such as classroom layout and storage spaces. They will participate in design reviews with Syndicate at various times throughout the design process to ensure the spaces are meeting their needs using both renderings and virtual reality. Another stakeholder that Syndicate
wants to keep in mind is the maintenance staff and Physical Plant Department. Although they do not have much influence or interest in the project details, they are still affected by the project and play a large role once the project is complete. Therefore, Syndicate wants to encourage an open dialogue with these parties to ensure that their needs are being met. Finally, Syndicate acknowledges that the residents of Holland will be affected by this project both positively, through the performances provided, and negatively, through any unavoidable inconveniences caused by construction. Syndicate will provide a social media page in which all inconveniences caused by construction will be announced with plenty of time for residents to adjust. This page will also provide a public forum in which the residents can express any requests or grievances so that Syndicate is aware and can work to accommodate.

4.2 Design/Collaboration Work Space

Syndicate worked in a highly integrated collaborative design space. This space houses individual work stations, a conference area to meet with consultants or advisers, a team meeting space, a virtual reality immersive area, and white boards for visual collaboration. An interactive monitor was utilized in the team meeting space, where the team holds meetings twice a week to discuss the progress in every discipline and make major design/engineering decisions. The layout was chosen by Syndicate, fully equipped with updated technology, and outfitted with modular furniture that can adapt should the team decide to change the layout for a special meeting or consulting session. Refer to Construction SD-B for more detail.

4.3 Collaboration Hours

Syndicate had six designated hours throughout the work week in which all ten members were required to be in the collaboration space. This time was used for weekly meetings, consultations, or general work. The team found it useful to keep these hours consistent throughout the project for general collaboration without going out of their way to plan specific meetings. Working in the same room at the same time allowed team members to ask questions real-time and involve everyone in the discussion and decision-making process.

4.4 Multidisciplinary Teams

In addition to the four disciplines and integration, Syndicate created three multidisciplinary teams to address certain design/engineering challenges; an architecture team, an acoustics team, and an enclosure team (Figure 3). These teams were made up of members from every discipline who worked together to not only improve the overall building performance, but also to improve the total team interdisciplinary collaboration.

4.5 Decision Matrix

One aspect that assisted in team integration and design/construction enhancement was the implementation of objective decision matrices. This tool is used to help make unbiased decisions across all disciplines and is weighted to ensure the final outcome benefits the project as a whole, not one specific discipline. Figure 4 on the next page showcases the important integration decision of which sustainability plan to use on this project and will be discussed further in Construction Report Section 8.0.
4.6 Pull Planning

Pull planning is a collaborative scheduling approach that involves all responsible parties listing the items they need from other parties in order to complete their tasks. This was an important aspect of Syndicate’s integration on the project. The team used an online organizational tool called Trello to keep track of interdisciplinary deadlines and to encourage transparency between the work each discipline was accomplishing. Refer to Figure 5. Trello typically consisted of eight sections (four disciplines, integration, and three multidisciplinary teams), in which to-do lists, upcoming deadlines, and completed work were listed. Disciplines would put lists of needed items in the responsible discipline’s section. Refer to Construction SD-B for more detail.

Syndicate also instituted pull planning in their weekly meetings. In the coordinated weekly meetings, the team listed upcoming deadlines and what was needed from each option to meet them. A white board was utilized to list needed items, sketch possible design solutions, or list meeting topics.

Pull planning will be implemented during project construction for the inter-trade coordination. The office trailer will have a full-wall white board and sticky-notes color-coordinated for each trade. The trades will be required to update the pull-plan weekly in the foremen meetings.

5.0 SITE ANALYSIS

Taking into consideration the site location and its influence on the surrounding area was a crucial first step in the planning and design process.

5.1 Existing Conditions

The project site is situated along the northern edge of Hope College’s campus at 221 Columbia Avenue. It is surrounded by three streets, with 10th Street to the south, 9th Street to the north, and Columbia Avenue to the west. 9th Street acts as the divider between Hope College campus and the downtown Holland
community, so The Miller Center is located near on- and off-campus residential and educational buildings. The Miller Center also shares a plot of land with Hope College’s Physical Plant Department to the east, which is mostly utilized for storage of snow removal equipment. Additionally, the site is that it is within close proximity of the Pere Marquette Amtrak transit route, less than 300 feet from the center at its closest point to the east. Refer to Figure 6 for more information.

5.2 Zoning

Given that The Miller Center is located on Hope College’s Campus (shown in blue on Figure 7), zoning ordinances are compliant with zoning class ED (Education) for the City of Holland. As mentioned, the center lies on the northern boundary between the Hope College campus and the downtown Holland community, with zoning class C-3 (Central Business, shown in red) being the compliance requirements for that portion of downtown. The permit fee for this zone is $125,000 and the plan review fee is $31,000. The project site is outlined in orange on Figure 7.

5.3 Site Logistics

With minimal site area and pedestrian safety to keep in mind, site planning and logistics have been carefully considered for the construction of The Miller Center. Throughout the different phases of the project, the site will have to be modified to account for the materials arriving and the means by which they will be installed. Refer to Construction Drawings C-8.0. Due to their direct adjacency to narrow campus streets, the southern and western perimeters of the site present challenges with very limited space for material storage and equipment maneuvering. There is, however, ample space on the east side of the site for laydown, an office trailer for all trades, and other amenities.

Shown in Figure 8 is the site logistics plan that Syndicate will be implementing. 9th Street will be reduced to one lane to allow for deliveries and waste removal to occur in a safe and efficient manner along the north site perimeter when a crane is present on site. The total cost of the road closure, to include permitting and renewal fees, is roughly $500. There is a parking lot south of the site along 10th Street that will be utilized for worker parking.
The access points to the site will consist of two gates located on or directly off of 9th Street (depending on whether or not the lane is closed), one for entry and one for exit. A third smaller gate strictly used for foot access at the southeast corner of the site, across from the worker parking lot.

5.4 Phasing

The Miller Center will be constructed in five primary phases: Substructure, Superstructure-1 (lateral systems), Superstructure-2 (non-lateral systems), Enclosure, and MEP / Finishes / Commissioning. Refer to Construction Drawing C-8.0. The Miller Center requires only light excavation as there is no below grade space and relies on a shallow foundation system placed six feet below the top of the slab at its deepest points.

The acoustical criteria for the concert hall, recital hall, choir rehearsal room, and orchestra rehearsal room require these spaces to be isolated from any potential noise disturbance. Syndicate has chosen to construct these areas as separate, shelled structures by utilizing concrete precast panels. Superstructure-1 phase includes the erection of these four room shells, as well as the stair towers, elevator shaft, and organ room. These precast walls will make up the lateral system for the building. Work will move left to right to minimize congestion on the eastern side of the site, so the organ room will be completed first, followed by the stair towers and elevator shaft. The concert hall three rehearsal/recital spaces will follow. Refer to Figure 9 for the phasing plan of Superstructure-1.

Superstructure-2 phase will involve erecting the remaining structural components and placing the concrete cast-in-place floors, following a counterclockwise sequence (refer to Construction Report 10.2).

For the final phase, detailed coordination efforts will be utilized for spaces such as the concert hall that have complicated finish items, and extra precautions have been considered to ensure acoustical performance isn’t sacrificed when interior walls and flooring are installed. Refer to Construction Drawing C-2.0 for further details regarding the extra precautions, and Construction Drawing C-8.0 for more phasing information.

5.4.1 Crane Logistics

Syndicate will be using two different cranes during the construction of The Miller Center. The first will be a Manitowoc 2250-Series 3 300-ton crawler crane, used for phase two (Superstructure-1) of the project, a total of 20 weeks. The critical pick for this crane is a 528 SF precast panel weighing 37.8 tons. The second crane is a Manitowoc 8000-1 80-ton crawler crane, used for phases two, three and four (Superstructure-1, Superstructure-2, and Enclosure) of the project, a total of 30 weeks. The critical pick for this crane is a 208 SF cross-laminated timber (CLT) panel weighing 2.9 tons. Refer to Construction SD-E for more details.

5.5 Site Safety

Syndicate is committed to the safety of all workers onsite as well as surrounding communities (faculty/staff/students/public) and will keep a safety professional onsite throughout the duration of the project. University campuses often face the challenge of protecting construction sites from possible student trespassing, and Syndicate is prepared to assist in ensuring that all potential hazards are inaccessible at all times. All adjacent sidewalks will be blocked from pedestrian access, with signage expressing the safety risk and alternate routes. Perimeter fencing is fundamental in separating the project activities from its surroundings, and some modifications that exceed
the Occupational Safety and Health Administration (OSHA) requirements will be implemented with perimeter fencing as an extra precaution. For example, rather than using the standard eight-foot fence, a ten-foot fence will be installed to reduce the chance of trespassing. Full coverage netting will also be installed on the fence to prevent debris from entering or leaving the project site. As referred to in Construction Report Section 4.1, Syndicate will create a Miller Center Construction Facebook page and Twitter account to keep students and local residents up-to-date on safety concerns and any pedestrian or vehicular travel restrictions. There will also be video cameras running on site at all times, indicated by signage around the fence, to increase security and discourage potential trespassing.

All entering employees must be equipped with the appropriate Personal Protection Equipment (PPE). Any employee new to the job will be required to complete Syndicate’s safety orientation prior to participating in any work on the site. There will be hold daily stretch exercises before the work day begins and organize weekly meetings to discuss potential safety hazards associated with upcoming activities. Failure to comply with these strict safety standards will result in re-training for staff at the cost of the negligent company and/or disciplinary action if the issue persists. Safety of the project employees and the surrounding stakeholders is Syndicate’s top priority.

5.5.1 Prevention Through Design

The Prevention through Design (PtD) concept, also commonly referred to as Design for Construction Safety or Safety by Design, is an initiative lead by the National Institute for Occupational Safety and Health (NIOSH). It aims to anticipate and design out safety hazards, both during construction and operation of the facility in the early design phases of a project. This initiative requires a highly collaborative approach with an integrated construction team from the project’s conception to ensure success. The Miller Center is a good candidate for PtD because it is being delivered through design-build. Although safety was considered a priority throughout the design of this project, Syndicate specifically focuses on confined spaces, signage on site, and access/ergonomics for maintenance during operation. Checklists have been created to ensure these safety aspects will also be implemented into the Quick Response (QR) code system. Refer to Construction Report Section 6.2 and Construction SD-C for more information.

5.5.2 Safety During Heavy Timber Construction

Laborers and contractors are expected to understand and abide by OSHA standards and keep an eye out for their fellow workers. This is particularly important as heavy timber is a relatively uncommon system and therefore extra precautions to keep subcontractors safe is needed. Safety-minutes during this part of the project will focus on heavy timber.

5.5.3 Worker Tracking

One of Syndicate’s safety standards requires all workers onsite to wear a wristband radio frequency identification (RFID) tag. This wristband, paired with software, shows the location of each worker on the project site. Syndicate uses this as a medical emergency measure and to track if workers enter an “off-limits” zone while there are safety hazards present. Workers will pick them up from the office trailer at the beginning of each day and leave it on site when they leave to mitigate any concern of privacy interference.

6.0 QUALITY ASSURANCE/QUALITY CONTROL

The Miller Center will be Hope College’s first dedicated musical arts building; therefore, Syndicate has put a heavy focus on creating premier performance spaces through acoustical excellence. Constructing an acoustically-sensitive area can be extremely difficult. Inconsistencies in construction or any lack of attention to detail can lead to leaks and cause problems for the performances that will take place in those spaces. Therefore, it is important that the laborers and contractors on the project are very knowledgeable about not only the importance of their work quality, but also how to perform the level of work necessary to ensure the best acoustics possible. Syndicate has developed several quality
assurance and quality control measures to guarantee accurate results throughout the entire building, with a heavy focus on the acoustically critical spaces. The construction team will include acoustic reminders during the weekly foremen meetings with information specific to the areas they are working on at that time. QR code quality checklists (refer to Construction Report Section 6.2) will have information about the large spaces, and the workers will need to be sensitive about even the most minute detail. Refer to Construction Drawings C-2.0 for more information.

6.1 Structural Systems

The structural materials being used have also been included in Syndicate’s quality control research. Given that many laborers and contractors are not familiar with glued-laminated timber (glulam) and CLT, the quality control plan emphasizes the importance of construction methods. It also emphasizes expected results related to the structure, as well as potentially harmful factors that could affect quality. Damages to the wood structure would be detrimental to the project budget and schedule, so proper training and quality measures are extremely important to successful installation.

Syndicate’s structural system also includes concrete precast walls that make up the lateral system for the building. These concrete walls act as a natural sound isolator and are a large aspect of Syndicate’s goal of Creating Premier Performance Spaces in The Miller Center. These panels will be pre-installed with embed plates to allow for the heavy timber structural members to be connected to the concrete shells. Syndicate has carefully analyzed the sizes and shapes of the panels, optimizing the layout to ensure there are as many duplicate panels as possible to reduce customization costs. There are a total of 168 panels in The Miller Center. Any openings or variations in the panels have been specifically and accurately called out for the manufacturer to form them correctly. Ultimately, it is the manufacturer’s responsibility to ensure the panels are created to meet Syndicate’s stringent quality requirements, but it is Syndicate’s responsibility to ensure thorough and effective coordination, and that the manufacturer receives accurate shop drawings. Any error or defects in these panels would prove extremely costly in terms of budget and project schedule. Refer to Figure 10 for the precast panel plan.

6.2 QR Code Tracking

In order to ensure that quality control measures are precisely followed, a QR code tracking system will be implemented in select spaces throughout the project. QR codes will be placed in the door frames of the selected spaces using phones or iPads. The QR codes will contain quality checklists, safety reminders, and punchlist items. They will track who scanned them and when.

For the quality aspect of this system, QR codes will be placed in the door frames of acoustically sensitive spaces. These include the concert hall, the recital hall, the choir rehearsal room, the orchestra rehearsal room, the faculty studios, and the individual practice rooms. Once scanned, the worker(s) will be able to access the specific quality control checklist for that space. This checklist will enable them to leave comments about certain aspects, upload pictures of any concerns, and contains contact information for the quality control representative on site.

Another advantage of utilizing a QR code tracking system is that Syndicate will be able to monitor which
subcontractors are entering and working on a space and at what time. This will pinpoint the source of any errors that are encountered through the work progression.

Syndicate will perform their punchlist in the online database called Procore. This allows them to continue to use the QR code system in a similar capacity to the quality checklists. For this aspect, QR codes will be placed in all door frames and will be scanned using the Procore app to access the specific punchlist items for that space.

An example quality control checklist for the Choir Rehearsal Room can be found on Construction Drawing C-2.0, or you can scan the QR code in Figure 11 (or visit http://l.ead.me/Syndicate).

6.3 Virtual Reality

Syndicate will use virtual reality (VR) throughout the project. The stakeholders will be invited during the design phase of the project to experience VR of their future space to make decisions or suggestions. VR will also be available in the job trailer in the form of virtual mock-ups for all job-site workers to use. This allows workers to consult the model (in the form of virtual mock-ups) if there are any questions about how something should be constructed or what it should look like. Refer to Figure 12 for an example of VR for the north lobby.

7.0 CONSTRUCTABILITY

Syndicate’s construction team aimed to increase constructability in order to maximize the efficiency of the schedule and minimize construction waste. The mechanical system’s constructability was a focal point due to the level of coordination and collaboration required. The construction team also implemented Building Information Modeling (BIM) to further improve the overall constructability of the project.

7.1 Underground Ducts

Displacement ventilation requires a significant amount of ducts in overhead spaces to properly move air in a building. To reduce the number of ducts in the ceiling space, Syndicate utilized AQC Industries Blue Duct underground preinsulated duct system. Refer to Figure 13 above for the underground duct plan, and to Mechanical Drawing M-3.0 for more information about these ducts. The ducts will run under the hallways and penetrate the large spaces up through
the slab on grade (SOG). The ducts that supply the concert hall and recital/rehearsal spaces must pass through the concrete precast panels at the subgrade level first before they penetrate the SOG. Refer to Figure 14 for that detail. There was a considerable amount of interdisciplinary collaboration, facilitated by the construction team, that was necessary to ensure that the footings and underground ducts did not clash.

![Image](Image1.png)

**Figure 14: Underground Duct Penetrating Strip Footer**

These ducts will be placed and tested immediately before the SOG is poured. Extensive commissioning and inspections will be necessary to avoid any demolition and rework after the concrete slabs are placed and cured. The counterclockwise pattern of the project (refer to Construction Report Section 10.2) allows the SOG to start at a different part of the project while the ducts are being placed. By the time the testing is finished, the SOG sequence will reach that area. It is important that the slab gets poured as soon as testing is done because the longer the ducts are exposed, the higher risk they incur of being damaged.

When the decision was made to go with the underground duct system, there was some concern about keeping the ducts clean during construction, considering the amount of dust, dirt, and debris that usually occurs on project sites. Syndicate reached out to several construction managers working in the local area that were also installing underground ducts, and they assured the team that as long as the standard cap is placed on the duct opening, they had never experienced any issues with keeping them clean.

7.1.1 Underground Duct Coordination

The installation of the underground ducts and the erection of the precast panels is a detail that required a significant amount of coordination between the construction, structural, and mechanical teams, especially for the concert hall. The three main problems that caused a schedule clash are:

1. The precast panels require bracing until their roof system is installed.
2. The balcony in the concert hall requires a crane to build.
3. The underground ducts cannot be installed until the slab is ready to be placed.

After deliberation, the three teams came to the decision that 25 feet of concrete precast panels would be left out of the south end of the concert hall until the balcony is built and the slab is placed. Refer to Construction Drawing C-1.0 for more information and refer to Figure 15 for an exploded view of some of the key factors for this space.

![Image](Image2.png)

**Figure 15: Exploded View of Concert Hall**

7.2 Building Information Modeling

Building Information Modeling (BIM) is a “digital representation of physical and functional characteristics of a facility that serve as a shared knowledge resource” according to the National BIM Standard. It can be implemented to improve the
design, construction, and/or operations of a project. *Syndicate*, an integrated design-build team, has the capability to implement several different types of software on projects without the concern of turning models over to other designers/construction professionals because everyone is in-house. This saves time and effort, which can be spent on implementing more software that further improves projects. *Syndicate* used these constructability challenges, along with the construction team’s project goals, as an opportunity to utilize several BIM uses. The BIM implementation plan was split into seven major areas: schedule/site logistics, budget, safety, QA/QC, coordination/waste minimization, prefabrication, and sustainability. Potential BIM uses for each of those areas were listed at the beginning of the project, and those uses were reevaluated to show the ones that were implemented and feasible. Refer to Construction Drawing C-9.0 for the full implementation plan.

8.0 SUSTAINABILITY PLAN

*Syndicate* believes that sustainability should be an integral part of design, rather than an add-on to be pursued once design is complete. That is why, in lieu of pursuing LEED or Building WELL, *Syndicate* decided to assist Hope College in their goal to be a more sustainable campus by developing a custom plan that focuses on general sustainable aspects that they find the most valuable. These include indoor environment, materials and resources, energy conservation, and waste reduction (refer to Figure 16). By doing this, *Syndicate* is building with a focus on the long-term impacts this project has on its occupants and environment, rather than simply aiming to finish a checklist. Once this pilot project proves the value of this new sustainability plan, *Syndicate* encourages Hope College to adopt this policy as their official campus sustainability plan and apply it to any future building projects.

8.1 Dashboard

A proud integration feature of *Syndicate’s* green initiative for this project is a digital dashboard, using *Lutron Quantum* and *Senseware* software, that will be located in the north and south lobbies of The Miller Center, where there is the highest amount of foot traffic. This dashboard will talk to a *Senseware* system, that tracks the real-time savings with regard to HVAC and plumbing, and *Lutron Quantum*, that tracks real-time lighting, and electrical controls. It will also display static contributions such as structural system sustainability, lifecycle impacts, air quality efforts, and construction waste reduction. Refer to Integration Drawing I-10.0 for the full Hope College Sustainability Plan and Construction Drawing C-10.0 for the construction team’s specific sustainable contributions to this effort.

Figure 16: Hope College Sustainability Plan

9.0 COST MANAGEMENT

*Syndicate* was challenged with completing The Miller Center within a building cost budget of $25 million, which equates to a baseline of approximately $360 per SF. During the early design phase, *Syndicate’s* estimating team calculated an initial building cost of $26,092,102.00. The design entities then collaborated with both the construction team and the owner to discuss where costs could be reduced. After those discussions, *Syndicate* has achieved an estimated cost of $23,926,850.00. Details as to how the budget is distributed amongst the project can be found in Construction Drawing C-7.0.
9.1 Budget Tracking

Once the initial $25 million budget was provided, Syndicate utilized RSMeans Square Footage Cost Data 2018 to determine approximately how much funding was available for each of the main building systems according to Uniformat II Classification, an elemental classification for building specifications, cost estimating, and cost analysis. Given that the scope of The Miller Center is a combination of “auditorium” and “college classroom building” according to RSMeans, the concert hall was priced as an auditorium whereas the remainder of the building was priced as an educational building. Syndicate’s Optimized Design is estimated at $23,926,850.00, $1,073,150.00 below the given budget (a 4.3% savings). The following chart in Figure 17 displays the progress of Syndicate’s budget and the relative cost of each building system and general conditions.

![Figure 17: Budget Tracking](image)

9.2 Cost Breakdown Structure

As previously mentioned, Uniformat II Classification was used to deconstruct the overall budget for The Miller Center. The categories used can be seen in Figure 18, with the associated cost for Syndicate’s Optimized Design. The construction team achieved level two detailed estimates in the initial design, as well as level three estimates for the final design. Some detailed comparison costs between Syndicate’s iterations can be seen in Construction Drawing C-7.0.

9.3 Life-Cycle Analysis

Syndicate has designed innovative systems that require life-cycle analyses to be considered.

The mechanical cooling system utilizes thermal storage buried outside in a 400 ton-hour tank. The simple payback period is roughly a year. The stormwater management system, a 5000 gallon storage tank that will be used for greywater, has a payback period of roughly seven years.

Syndicate has also chosen to utilize a 52 kilowatt-hour photovoltaic system upon the concert hall roof in order to generate solar energy, and the payback period of 11 years can be seen further explained in Lighting/Electrical SD-D.

An alternative mechanical design that Syndicate considered included the use of cogeneration through the installation of a combined heat and power (CHP) plant on campus. This, of course, would require the coordination of the entire Hope College campus in order to connect said CHP Plant to all new construction. The CHP plant would be housed in a structure on The Miller Center site (between The Miller Center and the Physical Plant Department). It would cost about $500,000 not including the equipment. Syndicate has decided that if Hope College proceeds with this option, the team would only be financially responsible for the percentage of energy output expected from The Miller Center. Syndicate would design, plan, and construct the plant with proper additional funding.

<table>
<thead>
<tr>
<th>Uniformat II Breakdown</th>
<th>Syndicate’s Optimized Design</th>
<th>Syndicate’s Optimized Design</th>
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<td>A Substructure</td>
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<tr>
<td>B10 Superstructure</td>
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<tr>
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<td>F Special Construction</td>
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<tr>
<td>TOTAL</td>
<td>$23,926,850.00</td>
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![Figure 18: Estimate](image)
10.0 SCHEDULE

Syndicate, while also holding student and local resident safety paramount, recognizes the importance of a timely project delivery. To address both aspects of the project, Syndicate’s construction team developed a 24-month total project schedule, sixteen of those months being construction, that will minimize student exposure to the project. Design and planning will begin in August of 2019 and the Notice to Proceed will be in April of 2020, which will allow site demolition to start as soon as the spring semester ends. Substantial Completion will be in June of 2021 and Full Occupancy in August of 2021, which will not only allow the performing arts faculty plenty of time to move in and adjust to their new space before the fall 2021 semester begins, but will also facilitate any sort of “Open House” for The Miller Center that Hope College wants to host. A total of seven of the sixteen total construction months will happen during the summer semester when student residency is at a minimum.

10.1 Fast-Tracking

Delivering The Miller Center through design-build grants Syndicate the flexibility to fast-track the construction process, because the designer and construction teams are integrated in their work and both have a full understanding of the project. While the design team finishes the building design, the construction team will begin on the site demolition, excavation, and foundations. This expedites the full project schedule by three months.

10.2 Parade of Trades

A parade of trades sequence is one in which activities are stacked to follow one another in order to decrease the amount of time necessary and to minimize conflicts between those trades. This acts as a quality assurance measure and schedule buffer. The more the trades repeat the same work, the faster and higher quality their work becomes. Each activity is matched with a weekend to allow time for a trade to work overtime to recover from any problems, should they arise. Syndicate will not tolerate delays in the overall schedule once the parade of trades has been reached. The construction schedule reflects a specific amount of time for each activity, but the team recognizes that the first few times performing the activity may be slower. Trades are expected to reach their stride by the time they hit the second floor (area E). The time reflected on the schedule is expected to be the average amount of time needed.

Syndicate is using a counterclockwise sequencing pattern to keep the site as organized as possible. In phase three (Superstructure-2) and phase five (MEP / Finishes / Commissioning), trades follow this pattern. They start in the north lobby (area A) and proceed clockwise through the 3 floors. The four main lateral spaces (the concert hall and recital/rehearsal spaces, shaded in grey in the figure) will come after the four lettered spaces, working from darkest to lightest (shown in Figure 19). Refer to Construction Drawings C-6.0 for more information.

![Figure 19: First Floor Parade of Trades](image)

10.3 Transition Plan

As previously stated, the building turnover is intended to offer the faculty the summer to get accustomed to their space before the students arrive for the fall 2021 semester. The transition plan is 6 weeks in total. The occupancy date is June 28, 2021, meaning the faculty can move in at that time as the
finishing touches are put onto the building. Full occupancy is on August 12, 2021, also allowing the students to get accustomed to their new space and allow for any events that Hope College wants to host.

11.0 OCCUPIABLE ROOF FUNDRAISING

*Syndicate* has included the occupiable roof in their Optimized Design but would like to offer Hope College an alternate way to cover the cost. The construction team suggests that the college pursues a fundraising strategy for this feature. By doing so, the college could save approximately $700,000.00 from The Miller Center budget. Some options for this could include program advertising for local business sponsorship, a “Patron Levels” program with incentives for donors, a performance gala for school of music students, or naming opportunities for the rooftop space. As the design-build team, *Syndicate’s* role would be to donate the following for potential donors:

- a free design of the roof
- models
- renderings
- virtual reality walkthroughs for the potential donors

By working with the design disciplines to increase daylighting and improve thermal comfort, along with organizing the schedule with a focus on high quality finishes, *Syndicate’s* construction team has ensured a space with maximum occupant experience.

12.0 LESSONS LEARNED

Throughout this process, the construction team learned that because construction is the last step, it is important that the construction professionals are part of the process at every step prior. While the design is being developed, it can be easy to take a step back and wait for the design to be finished. However, being involved in every phase to facilitate discussions between disciplines and develop iterations of the schedule and budget is an extremely valuable way to help the team be prepared when the time comes to work solely on construction.

13.0 CONCLUSION

The construction schedule and site logistics plan developed for The Miller Center minimize campus disturbances and safety risks to ensure the students and faculty of Hope College are the top priority by:

- Maximizing the amount of construction happening over the summer when student attendance is low
- Turning over the building in enough time for faculty and students to adjust to their new space before the fall 2021 semester begins
- Installing a ten-foot fence and video-cameras on the site
- Closing a lane on 9th Street during craned phases

*Syndicate* has developed a custom sustainability plan for Hope College to encourage and supplement their environmentally-conscious efforts and to minimize the energy impact of this project.
**DECISION MATRIX**

*Syndicate* implemented a decision matrix to ease the burden of making multidisciplinary decisions, where it is often difficult to compare criterion. The overarching decision-making themes are the team project goals, and are broken up into smaller components that are given a weight for each decision. For construction, the most important decisions made that required a matrix were the sustainability plan, the mechanical equipment isolation system, and the lateral system. These three decisions are perfect examples of the amount of integration that this project required, because although these three were not specific to construction, the construction team had a lot to offer in terms of cost benefits, schedule impacts, and overall benefit to the project.

### DECISION MATRIX: CONSTRUCTION

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**SUSTAINABILITY PLAN**

|          | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 49 | 3 | 1 |
| WELL      | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 2 | 3 | 4 | 5 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 49 | 3 | 1 |
| LEED      | 0 | 0 | 0 | 2 | 1 | 3 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Hope College | 0 | 0 | 0 | 0 | 2 | 1 | 3 | 0 | 2 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

**ADDITIONAL COMMENTS:**

*Syndicate* has created a sustainability plan specific to Hope College and their priorities by taking into account aspects of other sustainability plans and major sustainability themes. This sustainability plan is intended to be introduced in the early phases of projects so they are designed for sustainability rather than trying to react after the construction is nearly complete.

**MECHANICAL EQUIPMENT ISOLATION**

|          | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Basement Addition | 1 | 2 | 1 | 2 | 1 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Detached Structure | 1 | 2 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Isolated Structure within Building | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

**ADDITIONAL COMMENTS:**

The location of the mechanical equipment was considered for not only how the mechanical equipment itself impacts the building, but also how the space acts as a buffer zone from the sound transmitted from the train. Syndicate’s design incorporated as isolated structure within the building.

**INTEROPERABLE SOFTWARE**

*Syndicate* utilized interoperable software to facilitate interdisciplinary communication. All disciplines used *Revit*, *Sketchup*, *Autocad*, *Photoshop*, and *Excel* at various stages of the project. Specifically, the construction team also utilized *Primavera* for scheduling, *Navisworks* for clash detection, *RS Means* for estimating, *Synchro* for 4D modeling, *Illustrator* for site layouts, and *Odeon* for acoustic analysis.
TEAM DYNAMIC, COLLABORATION, AND PLANNING

The members of Syndicate took a personality test before the project started called “The Personality Matrix” which categorized each member into four dominant personalities: a lion (“the doer”), a peacock (“the communicator”), a koala (“the listener”), and an owl (“the thinker”). The team had members in three of the four categories, and for the most part, there were no repeat categories in any option. The team used this information to mitigate conflicts before they arose by learning the communication techniques for the other dominant personalities. Refer to Integration SD-D for more information.

Collaboration Space

Syndicate worked in a highly collaborative area to encourage constant interdisciplinary interaction. The red area indicates the individual workspaces, each equipped with 2 monitors, organized by discipline. The purple area indicates a large interactive monitor that the team could project their work onto simultaneously. The yellow area indicates two white boards that were used to work out design discrepancies and create to-do lists. The blue area indicates a conference space that the team used to meet and discuss group decisions. The green area shows the designated rest space for the team.

Team Meetings and Task Organization

Syndicate held full-team meetings twice a week. Prior to the meeting, each discipline was required to enter the talking points into a shared document that the construction team used as the meeting agenda. One member of the construction team would take notes in the meetings and organize them into meeting minutes that were made available to everyone. These minutes proved useful when the team needed to reference decisions made weeks later.

Syndicate used an online organizational tool called Trello to organize items for which each discipline was responsible. This tool became the team’s form of pull planning throughout the project. Each discipline was assigned a color, and whenever a task was created, the responsible discipline’s color was added. Whenever one discipline needed an item from another, they would create a task with the corresponding color. The tasks could be assigned a deadline, and the online tool also has a corresponding app for added convenience to the team.

PROJECT DELIVERY

Syndicate will be utilizing an integrated design-build delivery method throughout The Miller Center project. The method lends itself to a high level of integration between the owner, design team, and construction team. This method also decreases the number of contracts from a traditional project delivery method.

Integrated Design-Build Organizational Structure

Syndicate as a Design-Build Firm

Syndicate offers a unique opportunity to owners by housing their designers and construction team together. This allows collaboration from the early design stages, ensuring maximum constructability review through the entire project. Syndicate also established three multidisciplinary teams to address issues or main areas of focus as the owner defines them. In the case of The Miller Center, Syndicate created an architectural team to address changes to the original architecture, and acoustics team to focus on the acoustic challenge of the project and ensure every option was acoustically focused, and an enclosure team to ensure The Miller Center enclosure offers innovative solutions to the team’s project goals.
PREVENTION THROUGH DESIGN (PTD)

PTD is a concept in which safety during the construction and operation phases is considered during the design phase. Although PPE is rightfully required on all jobs sites, in terms of hazard elimination, it is the least effective tactic in the industry. In the hierarchy of controls, elimination (PTD) is the most effective in keeping workers safe onsite. It is often considered difficult to do because it requires including the construction team early in the design process. Syndicate’s construction team is apart of the project from its conception, allowing them to implement this initiative.

Below is an example of a checklist used when designing for safe construction.

<table>
<thead>
<tr>
<th>Design Consideration</th>
<th>Requirements</th>
<th>Meets?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confined Space</td>
<td>Avoid designing in confined spaces</td>
<td>Yes</td>
<td>There are no accessible confined spaces per Syndicate’s design</td>
</tr>
<tr>
<td></td>
<td>Confined space egress/access unobstructed</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proper signage is in place for the confined space</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Access/Ergonomics</td>
<td>Is there suitable access to equipment?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Will there be enough room to maneuver equipment?</td>
<td>Yes</td>
<td>Any areas in the building that require large maneuvering (pianos) has been sized appropriately</td>
</tr>
<tr>
<td></td>
<td>Will the traveling surface be suitable?</td>
<td>Yes</td>
<td>The safety officer onsite will ensure that all paths are safe and accessible</td>
</tr>
<tr>
<td></td>
<td>Has ergonomics been considered for the workers and end-users?</td>
<td>Yes</td>
<td>The maintenance staff will be involved in design to ensure all areas meet their needs</td>
</tr>
<tr>
<td>Signage</td>
<td>PPE</td>
<td>Yes</td>
<td>Provided in the trailer and around site</td>
</tr>
<tr>
<td></td>
<td>Gate Signage includes project name and contact information</td>
<td>Yes</td>
<td>Safety officer, project manager, and superintendent will be listed</td>
</tr>
<tr>
<td></td>
<td>Restricted access/security signage</td>
<td>Yes</td>
<td>Video camera signage on fence, restricted access listed in trailer for workers</td>
</tr>
</tbody>
</table>

WORKER TRACKING (RFID)

Radio Frequency Identification (RFID) uses electromagnetic fields to automatically identify specific pieces of technology called “tags”. RFID tags and tracking is used in many industries to improve efficiency or accuracy. In construction, they are often used for safety and time-tracking.

Worker tracking with RFID tags is a Syndicate standard for safety on the job site. All workers pick theirs up at the beginning of the work day and return it at the end. These tags allow the project team to be able to see where the workers are in the case of a medical emergency, or to track workers during special hazardous conditions onsite.

To the right is the hazard zoning for Superstructure-1 when the roofing system for the concert hall and recital/rehearsal spaces are being placed. The green shows the areas workers are allowed to access and red shows restricted areas. The blue arrow is the worker access to the project during this time. RFID allows the project team to ensure no one is in the restricted area during this activity.

SITE SAFETY

In the event of an emergency onsite, everyone is expected to meet at the Physical Plant Department building adjacent to the site (highlighted in orange).

Syndicate has implemented a zero tolerance policy onsite. This includes substance abuse, personal protective equipment (PPE), and any main hazards that require a zoning map (see above) to include precast installation and all heavy timber members. Any violations of this policy will result in re-training at the cost of the negligent company.
The construction team used *Synchro* as a 4D phasing model. Using a schedule from *Primavera*, a model was built to help the team visualize the construction schedule and sequencing between disciplines. This became particularly helpful during the underground duct and structural system coordination. Below are images from *Syndicate’s* five primary phases.

*NAVISWORKS*

The construction team used *Navisworks* to determine if there were any clashes in the project design. The *Revit* model was uploaded and a clash detection was run. This step of the construction team’s analysis was extremely important because the disciplines typically worked in discipline-specific models within *Revit*, so performing a clash detection was a way to check the design progress periodically and recover from any interferences.

The top image shows a mechanical duct running into the concrete precast panel of the organ room (shown in red on the plan).
MANITOWOC 2250—SERIES 3 SELECTION CRITERIA

To order to determine the type of crane required to completed construction of The Miller Center, Syndicate had to calculate which building component would be the critical pick. After analyzing the weight of each of the structural members, it was found that many of the concrete precast panels were significantly heavier than any of the other members, with the 48’x11’ size weighing in at 75,600 pounds (37.8 tons). The site location of those panel sizes was also observed to determine the boom radius required to safely and efficiently install them. Referring to the precast plan on Structural Drawing 5-9.0, the critical picks comprise the west stairwell at wall 36, as well as the south stairwell at walls 24 and 27. The required boom radius was measured using the planned crane path along the site, and was found to be 100 feet at a maximum. A boom length of 170 feet was assumed based on the 48 foot height of the panel, along with the height of the rigging. Utilizing these values within load charts for various crane sizes, it was found that a 300 ton crawler crane (Manitowoc 2250 - Series 3) could withstand the critical pick with a capacity of 84,000 pounds at the desired radius and length.

MANITOWOC 8000-1 SELECTION CRITERIA

Given that the remaining structural members weigh significantly less than the precast concrete, Syndicate chose to demobilize the 300-ton crane and mobilize a smaller 80-ton crane once the precast members have all been erected. By analyzing the other structural components, it was found that the next critical pick would be a group of 24.42’ x 8.5’ x 10.5” CLT panels located in the 2nd floor mechanical room. With a weight of 5,832 pounds (2.9 tons) and a boom radius of 150 feet, Syndicate decided that it was an unnecessary expenditure to keep the 300-ton crane on site and chose an 80-ton crawler crane (Manitowoc 8000-1) for the remainder of construction. The selection criteria can be shown below, where the crane capacity is 3.3 tons versus the 2.9 ton critical pick.

CRANE RENTAL AND ASSEMBLY

Both cranes will be rented from Laramie Crane in Wixom, MI, about 2.5 hours away from the Miller Center site. According to Syndicate’s schedule, the 300-ton crane will be needed for 20 weeks and the 80-ton crane will be needed for 30 weeks. Assuming a daily operator cost of $182 for the 300-ton crane and $76 for the 80-ton crane, the total rental and operating cost for both cranes will be $1,200,275.00.
Constructability of the underground ducts proved to be one of Syndicate’s major integration and coordination aspects. The foundations had already been designed and laid out when the decision was made to use the Blue Duct system for displacement ventilation. The construction team held several meetings to facilitate discussion between the structural and mechanical teams. The following are the steps Syndicate took to reach a solution:

1. Ensure that the concrete piers and the duct runs did not clash.
   - There was a clash under the mechanical room where the ducts penetrate the slab. The mechanical team was able to move the ducts and the mechanical equipment they connect to in order to avoid the clash.

2. Ensure the depths of the footers and ducts did not clash.
   - The largest underground duct is 48 inches in diameter, and originally the footers were three and a half feet deep. In order to leave six inches above and below for the underground ducts, the structural team decided to drop the footers to six feet below the top of the slab (see the figure below).

3. The last step in this collaboration was to determine how the underground ducts would penetrate the strip footers that support the lateral system.
   - The duct that supplies the concert hall is 40 inches in diameter and the ducts that supply the recital/ rehearsal spaces are 24 inches in diameter. The structural team created a detail that shows a cut out for the supplying duct to enter each space (shown in the far right figure).

Finally, the construction team worked with the two teams to determine the sequence of construction. The panels will be placed and braced, the roofing system will be installed, the bracing will be removed, the underground ducts will be installed, and the slab will be poured. Refer to Construction Drawings C-5.0 for more information.
QR CODE TRACKING

QR Codes will be used in the acoustically sensitive spaces as a quality assurance measure. When scanned, they will show any critical information needed including a checklist to ensure that worker knows exactly what is expected for that space. Every time the code is scanned, it logs which device was used, so if there are any quality issues, it is easy to determine the responsible contractor. Scan the QR code to the right to view the editable pdf quality checklist for the Choir Rehearsal Room.

VIRTUAL REALITY

Syndicate used VR throughout their project to verify their design and layout was optimal. Syndicate will use VR as a design tool to keep their stakeholders involved at every major decision point throughout the project. By providing the stakeholders with a way to put themselves in the space before it has been built, it allows them to understand how the space will feel, make decisions or suggestions before the design or construction is too far along, and keep them invested.

VR will be in the office trailer, and will also be used by the workers on site to clarify how an item is to be built or what it should look like.
Syndicate modeled the Individual Practice Rooms in ODEON and discovered that the reverberation time values were below the desired range, calling for a removal of sound absorbing materials. The given design provided 9 acoustic wall panels measuring 4’x4’2”, and removing 5 of those provided the desired RT values. With 19 rooms, this resulted in 95 panels able to be removed overall. A cost breakdown comparison can be seen in the table to the left.

Syndicate incorporated a grid consisting of 2’x2’ acoustical lighting fixtures and 2’x2’ radiant panels into the Faculty Studios. Upon analysis in ODEON it was found that there were too many sound absorbing materials in the space. This allowed Syndicate to remove the acoustic wall panels from the given design, reducing some of the additional cost brought on by the advanced equipment. A detailed cost comparison breakdown for the 17 studios can be seen in the table below.
**MILESTONE SCHEDULE**

*SYNDICATE*’s construction team has created a 24-month total design and construction schedule for The Jack H Miller Center for Musical Arts, sixteen of those months being the construction phase of the project. Shown above is the milestone schedule for the project that was created to give the owner a high-level summary of the project activities and total duration and to ensure any major conflicts with campus events are mitigated. The following are the exact dates of the project’s major milestones:

- Design Begins: August 1, 2019
- Notice to Proceed: April 2, 2020
- First Pour: June 4, 2020
- Substructure Complete: July 8, 2020
- Underground Ducts Installed: September 24, 2020
- Enclosure Begins: January 21, 2021
- Superstructure Complete: February 22, 2021
- Watertight: March 4, 2021
- Initial Occupancy: June 28, 2021
- Full Occupancy: August 12, 2021

Further schedule detail can be found on Construction Drawing C-5.0 and Construction Drawing C-6.0.
SCHEDULE DETAILS

The total construction schedule for the Miller Center is centered around ensuring it is ready for the Fall 2021 semester. Delivering through a design-build approach allows Syndicate to fast-track the beginning of the project, so the design will be finalized through the foundation installation and placement of the construction process. Construction will start immediately after the Spring 2019 Commencement, so some of the most interfering activities are happening when most students are home for the summer. The precast and heavy timber construction facilitate an expedited superstructure construction, allowing the project team to spend a significant amount of time on the interiors. This is especially important for this project, as one of Syndicate's main goals is to maximize occupant experience.

### Long Lead Times

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Item</th>
<th>Lead Time (wks)</th>
<th>Procure By</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Radiant Panels</td>
<td>10</td>
<td>March 12, 2021</td>
</tr>
<tr>
<td></td>
<td>Acoustic Panels</td>
<td>12</td>
<td>January 13, 2021</td>
</tr>
<tr>
<td></td>
<td>Concert Hall Seating</td>
<td>16</td>
<td>December 28, 2020</td>
</tr>
<tr>
<td></td>
<td>Heat Exchanger</td>
<td>16</td>
<td>August 21, 2020</td>
</tr>
<tr>
<td></td>
<td>Heavy Timber</td>
<td>16</td>
<td>March 20, 2020</td>
</tr>
<tr>
<td></td>
<td>Precast Panels</td>
<td>16</td>
<td>March 12, 2020</td>
</tr>
<tr>
<td></td>
<td>Chillers</td>
<td>20</td>
<td>July 24, 2020</td>
</tr>
</tbody>
</table>
PARADE OF TRADES SEQUENCING

Parade of trades is a highly efficient way of scheduling trades back to back in a certain space, and following a pattern through a project. This tactic is similar to Short Interval Production Scheduling (SIPS), the difference being SIPS is used for highlight repeatable tasks. When one trade follows another consistently, they become accustomed to the way in which the trade ahead of them works and shortens the total time for equipment or material installation. The Miller Center project has four very distinct areas and therefore lends itself to a sequenced schedule. Implementing this sequence will ensure efficiency and high quality of the finishes.

The parade of trades sequencing starts with the framework and includes the MEP, insulation, drywall and cable tray installation, paint and door frames, electrical wiring and ceiling grid, lighting installation, ceiling installation, flooring installation, doors, hardware, and fixtures installation, and casework aspects of the project. This sequencing begins in December of 2020 and goes through June of 2021.

The sequence moves counterclockwise, starting in the north lobby, moves to the west side, then the south lobby and the rest of the south side, and then the east side. The concert hall and recital/rehearsal spaces follow.
ESTIMATING METHODS

The Uniformat II table above details the design phases of Syndicate's cost estimate. The program-set target cost of $25 million was referenced as the baseline, with RS Means SF Estimate Data 2018 being used to divide the overall cost into Uniformat II categories. Given that the Miller Center is both a college classroom building and an auditorium, the data percentage values for both were combined based on the area ratio of the concert hall to the rest of the building. Syndicate's first design included assembly estimates along with some detailed estimates for fully-designed items, and was found to be $1,092,102 over budget. Following thorough design meetings with the entire team, various changes were made to lower Syndicate's final Optimized Design estimate of $23,926,850 and consisted of a fully detailed estimate. The final estimate resulted in a 4.3% savings in relation to the given budget of $25 million.

LIFE-CYCLE AND PAYBACK PERIOD ANALYSIS

By using integrative design approaches Syndicate achieved an overall energy savings of 44%, exceeding the team’s goal of 40%. A life-cycle analysis was performed on the various mechanical and electrical design decisions to determine how economically feasible they will be to the owner. The photovoltaic system that Syndicate installed on the concert hall roof added $123,173 to the electrical systems cost while providing a payback period of about 11 years, which Syndicate deemed an appropriate amount of time. The radiant panels and the ventilated double wall façade added $227,872 to the mechanical systems cost, with the ventilated façade providing a payback period of 8 years. For detailed energy cost and savings data, see Electrical Drawing L-5.0.

STRUCTURAL SYSTEM COMPARISON

As part of the program challenges, Syndicate was prompted to design the Miller Center with 25% engineered wood. The team exceeded this goal by implementing a structural system that was 86% engineered wood by volume. As heavy timber structures are still a developing concept, there are higher costs associated with the manufacturing and delivery of wood members. In order to compare the cost and schedule impacts associated with wood structures, Syndicate also designed the Miller Center with a steel structure. Detailed takeoffs were extracted from each design in order to provide an accurate estimate, and it was found that the wooden structure was about $700,000 more expensive than the steel structure. These costs did include, however, the manufacturing and shipping costs associated with the wood structure. The steel system designed consists of a standard concrete on metal deck floor system on top of steel beams and columns. If the owner would become interested in pursuing a more economical option, the steel structure provides a cheaper alternative up front at $1,318,233.96.

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**SITE LOGISTICS AND PHASING**

**Site Layout** - The Miller Center site will be secured with a 10' fence. One of the lanes of 9th St. will be closed during several phases of the construction process. There are delivery entry and exit gates in the northwest and northeast corners of the site, respectively. The gate in the southeast corner of the site is for pedestrian entry/exit. There are 2 standard dumpsters and 2 recycling dumpsters to mitigate construction waste.

**Substructure** - This phase consists of excavation and placing strip footings and spread footings. The footings will be placed from east to west. This phase will require an excavator and compactor, as well as a concrete truck.

**Superstructure 1** - This phase consists of erecting the precast lateral systems (shown in dark grey), the roof on those spaces, the underground ducts, and the SOG. A 300-ton crawler crane is required to place the precast panels. 25' of the precast panels for the Concert Hall lateral system will be placed at the very end, leaving a hole for the crane to enter the space to build the balcony.

**Superstructure 2** - This phase consists of placing Glulam beams and CLT, placing the CIP floors on the CLT structure, and framing. An 80-ton crawler crane is required to place these items. This phase will follow a counterclockwise sequence, starting at the north, then the west, then the south, and finally the east. The laydown area of this phase is larger to account for the timber, and will have stilts and tarp to protect the wood from weather.

**Enclosure** - This phase consists of completing the façade on all sides of the building and placing the roof on the non-lateral areas. It will be finished from west to east to mitigate issues with a crowded site on the west and south sides. This phase will also require the 80-ton crawler crane, along with a forklift.

**MEP/Finishes/Commissioning** - This phase consists of installation and start-up of all MEP equipment, all finishes, initial occupancy, and turnover. This phase will also follow a counterclockwise sequence (refer to phase 3). The material hoist will be located at the end of the southeast hallway, and the main entrances for workers will be there and the north lobby.
Syndicate decided to implement BIM on the Jack H. Miller Center for Performing Arts project to improve quality of design and to increase constructability by creating an enhanced technology plan of action.

The first step in the BIM execution was to list the aspects of the project that would benefit from increased technology implementation. The construction team decided to use their main goals throughout the project; schedule/site logistics, budget, safety, QAQC, coordination/waste minimization, prefabrication, and sustainability. Next, Syndicate assigned each of those goals a priority. It is important to note that this priority level only applies to how important it is to use BIM for that goal, not the priority of the goal in the overall project.

The next step in Syndicate’s BIM execution was to determine which BIM uses they could implement for each goal. All potential uses were listed for each goal and the entire team got together to discuss which uses were feasible and would benefit the Miller Center. The team set out to implement as many of those feasible uses as possible.

The table to the right is the graphic Syndicate used to organize the BIM goals and uses. The BIM uses bolded and italicized are the ones that were successfully implemented in the Miller Center project. The graphic above is a modified level one BIM process map that shows the order in which the BIM uses were implemented throughout the project.

Syndicate found that implementing engineering software to control quality, plan the site logistics, and enhance multidisciplinary coordination proved the most useful in its goal to improve constructability on the Miller Center project.

Above are pictures from the main software utilized by each discipline.
THE HOPE COLLEGE SUSTAINABILITY PLAN

Syndicate, after considering aspects of the LEED and WELL plans and the efforts that Hope College is already making, has created a customized sustainability plan for Hope College. This plan allows Hope to pursue environmentally-minded goals without sacrificing their academic objectives. There are four main canons that encompass large sustainability aspects, and those four are broken down into several implementation categories (shown below). The objectives that were considered during the construction design of The Miller Center are highlighted below.

Dashboards Display

In lieu of a plaque or certificate for the achieving the desired level of sustainability on a project, the Hope College Sustainability Plan, calls for the installation of a dashboard display to show off their environmentally conscious decisions and progress. This display will act as an interactive connection point in each lobby to showcase Hope College’s energy conservation efforts for the occupants of the building. The user will have the option to explore daily, monthly, and even annual energy usages to fully understand how they too can make an impact on the future of Hope College. With this display, the sustainability plan initiative will further be pursued and hopefully encourage students and faculty to carry this throughout the rest of the campus.

The main hub receives data from various system sensors and meters, interprets the input, and produces a visual display for aspects of sustainability like saved electricity, saved water, and carbon reduction. It can also display static numbers or facts that were achieved through the construction process, like air quality information, construction waste reduction, and materials that were chosen for environmental reasons.

JACK H MILLER PILOT PROGRAM

Syndicate has implemented this Sustainability Plan on the Miller Center project. Below are the specific aspects of the plan that are highlighted in the construction period of this project.

Construction Waste

There was a site wide effort on the Miller Center project to minimize waste. Prefabrication was heavily utilized to minimize the amount of formwork needed. QR code checklists were implemented to reduce rework and wasted materials. Materials that could be reused were held in a specific area on site that was available to all workers to pull from, and any materials that could be recycled were thrown in separate dumpsters.

Recycling Initiative

Syndicate admires Hope College’s recycling initiative that has already been implemented on campus and wants to ensure that it is achieving its maximum effectiveness. While recycling is not a perfect system, separating the types of recyclables decreases the possible waste that still remains from a single-stream recycling system.

Sourcing/Production

The manufacturer providing the precast concrete panels for the lateral system, Kerkstra, is located 12 miles away from site. This allowed Syndicate to ship the panels as full 64 foot pieces, reducing the need for additional materials and labor.

The manufacturer for the heavy timber, Nordic Structures, ensures all the trees used for their material are immediately replanted to keep the forest integrity in tact.

Life-Cycle Impacts

Systems were chosen for the Miller Center project that will last a long time, decreased the cost and production requirements of replacing the systems, and will improve the longevity of the building itself. The five main systems implemented in The Miller Center are photovoltaic, thermal storage, ventilated double wall façade, snowmelt, and CHIP.

Environmental Impacts

By building with heavy timber, the project acts as a carbon sink, absorbing carbon that is released into the atmosphere by other products.

Acoustic Performance

By implementing the QR code tracking system and checklists, the construction team was able to ensure that the workers onsite are keeping quality at the forefront of their focus, especially during the finishes phase of the project.