ARCH 5226 and the Role of the Architectural Engineer

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Abstract

The primary purpose of this paper is to serve as description of my senior design project culminating my degree in architectural engineering at Oklahoma State University. This studio utilizes the skills gained in this degree program and prepare exiting students for the challenges and complexities of accomplishing a real built project. Individual students have control over their own designs, starting at schematic design and reaching into construction documentation. In schematic design, it is important to view all aspects of a building, beginning with a concept selection that drives the architecture, and gives the structural and mechanical systems a direction for coordination. At the conclusion of this stage, work is compiled into a presentation before a panel of professors and working professionals, who critique and give guidance for the next stage.

With this advice, each student makes adjustments and begins design development. For the engineers, this means focusing on structural design, and continuing with the mechanical systems. Additionally, we will develop the architecture and constructability by creating a wall section, looking at the assembly and its thermal properties. This is longest portion of the semester, and detailing to this level is not something we have as much experience with in school. Developing our proposals to this level is the most complicated part of taking a concept to the point that it can be constructed. Following this stage, students will take their designs into the beginning of construction documentation, and then finish the semester with a final presentation jury.

As this project is the conclusion of the degree program, it also serves to be the launching point for the next step beyond undergraduate education. As such, this project represents an important step at the beginning of one's career. The work presented at the end of the semester is the skills, knowledge, and abilities of the architectural engineer. This course is meant to be the last step in the training given by the professors before students begin their careers.

Concept

To simulate a real project as much as possible, this studio is typically connected to actual clients who have the desire for a new building of their own. Our professors connected us to OtherOptions, a food pantry in Oklahoma City with a very specific mission. They work to supply the needs of people who have been diagnosed with HIV/AIDS. Even though modern medicine has enabled much longer lifespans and standard of living than for these patients than in the past few decades, the expensive prescriptions and dietary restrictions do make life more challenging. OtherOptions is made mostly of volunteers, some who are positive themselves, who work to run their current facility with the goal to improve the lives of these patients. To introduce the project, we visited their current facility, a renovated dentist's office, and spent one morning volunteering to distribute food. This was a great opportunity for the class to see the deficiencies in their current space. In addition to a brand new food pantry facility, the clients also wanted to create a community center space for at risk youth. Included in this program would be a lounge, classroom, and a gym, with a variety of support and office spaces. Creating a new facility that could house both of these functions effectively in Midtown Oklahoma City would be our challenge for the next three months.

One of the initial challenges faced by myself and the other architectural engineers, was even though we had experience working on buildings in our previous studios, this was a much more complicated program than we had encountered before and the expectations were significantly higher. Our expertise is in structural design, so creating a quality environment while still considering the importance of our past knowledge and experience. Fortunately, our critique professors were excited to help us rise to the occasion, and gave us guidance on how to solve these problems. Arranging the spaces on site caused issues, due to zoning restrictions and a need to parking and delivery access on the back of the site. My process began with many iterations of how these could be set up effectively, and what benefits they would have as a connection to the surrounding neighborhood.

One of the key challenges I began to realize about this program through my designs and discussion with the clients was the need to create privacy while also establishing a presence within Midtown. The newest neighborhood in Oklahoma City, Midtown has a young, artistic character north of downtown, and is the location of several new contemporary buildings. An architect in this area has the opportunity to create a distinctive new piece of this development. Even though there was a strong opportunity to create a facility that will draw lots of attention to the surrounding community, the privacy of the internal users was a key component of the program. I began to sketch a variety of structures that could cover most of the site. As I brainstormed, I began to move towards the creation of a large arch, something that could draw views from across the area and provide a private connection. It was also the chance to use my skills as an engineer to create architecture that would been impossible without an understanding of the science behind structural design.

Design

As the project evolved, the arches took the shape of a catenary curve. They became taller, and the profile slimmed to only cover a portion of the site. Through my research, I found that this would be a more efficient method of spanning the gym space, most of the internal force would be in compression. As this evolved, the design split into two levels, with the pantry and teen lounge on the ground level, and the gym and support spaces above. Since the facility has two different purposes the program is divided, a north entry for the LGBT Teen Center, and a south entry with parking for the clients to the pantry. The arches span the basketball court and public spaces for viewing. The structure continues into the ground floor spaces, with the arches serving as a divider between public and private spaces. To continue the concept of protecting user privacy, a paneled façade system balances transparent glass and metal elements. The bold red metal, matching the OtherOptions logo, is used to highlight the importance of this project in the community, but still serves as a defense for the interior spaces, and transitions into an exterior fence to surrounding the parking area.

The centerpiece of the second-floor is the gym, surrounded by flexible social spaces, including a terrace overlooking 11th Street, bleachers for viewing games, and seating for a gathering space. To the south, a block of support spaces including locker rooms and laundry care. All of this area is flexible, so that this space becomes like a home for these youth, returning a sense of control and freedom. In my research, I have found that in similar facilities that serve this demographic, these young people don't have much control over their circumstances, so flexibility can return this to these teens.

Before the conclusion of schematic design, I needed to make a decision on the primary structural material of the project. Initially, I considered using steel, as this would save on the weight of the structure and could be easily fabricated into the correct curve of the arch. Steel can allow more flexibility in column grids, but in certain situations vibrations can become a concern. Since the basketball court is on the second floor, impact and movement can cause shaking in the spaces below. Concrete is the ideal material for this building use, since the concrete will absorb any shaking. One of the benefits of using this type of construction is that it will be easy to taper the form through the height of the arch. Tapering the arch will save the clients some expense, and create a more efficient structure at the top where the loads are smaller.

One of the challenges with designing a non-traditional building form is determining the correct shape and creating a digital model. One of the benefits of creating architecture in a digital world is the design tools available. As someone who has experience in mechanical drafting, visual communication is key to construction, and every project must be able to become project documents by the end of the design process. In my research, I found that catenary curves, being an efficient compressive structure, can be defined by a hyperbolic function: $y = a\cosh\left(\frac{x}{a}\right)$ "Y" defines the vertical distance, "x" defines the horizontal, and "a" is a constant that controls the steepness, or width of the curve. By setting this up in a spreadsheet, I could adjust the shape of the curve and control the form of the building. Taking these coordinates from this spreadsheet, I set up a script a using Dynamo to model this form. Dynamo and Grasshopper are two parametric software programs that are the cutting edge of architecture modeling. The coordinates from the spreadsheet can be taken directly in the software, which creates a conceptual mass that can be imported into my architectural model. If I want to change the constant "a", the model is immediately updated in 3D. Utilizing parametric tools helped me to design a form faster and more accurately than possible even a few years ago.

As the project progressed into design development stages, the arch structure would become the biggest challenge, but also an opportunity to apply what I have learned the past few years to a new form. Typically, for design, we use RISA to create a structural analysis model that verifies what we are able to do with hand calculations, but this type of structure is beyond what we have been taught in our courses. I decided that the arches could be modeled as a separate RISA file, but I wanted some method to check the way that the forces transfer through the concrete. Knowing that the RISA is performing correctly for such a bizarre form is very important, and I wanted to create an analysis method that would be as adaptable as the parametric model that I used for my form. To accomplish this, I wanted to combine my knowledge of stiffness matrices, with their broad range of applications, with advanced computer tools to make this effective.

In order to create a global stiffness matrix, I needed to set up a list of coordinates. My model would represent the arch as a series of straight members, and these points would be the location of the transverse members, which connect dead and wind loads to the primary structure. Each length between two points is treated as a separate member, and so I created a visual basic program that could instantly take a list of point and create adjacent segments of a larger form. Alongside this list of points are vertical and horizontal loads, compiled into a matrix. Using matrix algebra, this visual basic program will output the deformation at every location and the reactions at the base. By having this as a program, if the form of the arch or the value of the point loads changed, a new solution could be found.

Once the shape of the arch was set, I set the program to resist gravity loads and wind from the north, and verified these with the RISA model. The resulting set of deflections became a very helpful design aid, as I learned that the majority of drift was horizontal, very little vertically. The original size of the members chosen using rules of thumb in the schematic design phase was 18" x 36", but the deflections from the first round of testing were just tenths of an inch, so this seemed larger than necessary for these loads. I reduced the size of some of the links, as a way to reduce the self-weight and taper the form. This was an excellent application of the visual basic program, because changes can be rapidly evaluated. This allowed me to refine the form quickly. One of the strongest advantages of this design process is that if there are form changes in form, analysis and sizing can be completed rapidly. These digital tools, if used correctly, can allow engineers to be more helpful in assisting the process of architects. Like parametric modeling, using programming is a new skill architectural engineers can start to apply to more complex projects.

Once a form was chosen, wind loads could be applied from all directions for analysis. Along the arches, lateral loads will go directly down into columns to the foundation. Transverse to these, steel tension rods will transverse the east and west wind forces. The steel x-braces could run inside the decking, and will reduce the weight of the structure. After all of this analysis, the reaction loads can be applied the first floor structure of the building. I created a second model for the remainder of the project, which would transfer these loads from the arch. Additionally, dead and live loads for the structure are applied to the gym floor level, and move to the foundation. For a single story building, the gravity loads were very small, and the span were short, a maximum of 27' on the beams, and 22' on the girders. In contrast, the form catches a lot of wind pressures, so many of the base members were sized based on the lateral loads. In the lower structure, moment frames were used to transfer loads from the gym floor slab.

Synopsis

This project was really interesting because we had the opportunity to develop one design much further than in any other project. This is an excellent learning experience, and it was also a chance to evaluate my own decisions and how they affected the later stages of a project. Tackling this form requires a lot of understanding of what consequences each decision will have in the early stages of the project. My familiarity with structures and architecture made me comfortable with the problems I will have to solve later in the project, but I did have challenges with some of the façade detailing and mechanical systems. To match the curve, I wanted an enclosure system that could easily adapt to the form as it changed. An aluminum panel system on a curtain wall grid would work well, but this can be difficult to model in Revit. This studio has given me an appreciation of all the specialties that are required in completing a complicated building.

One of the other challenges in design was with the mechanical design. Heating, cooling, and lighting for such an environment is a chief concern for the client, because this can be expensive and uncomfortable if done improperly. Inputting this form into E-Quest was difficult with the geometry, but the model was able to give me data about this system to use in duct sizing.

The Role of the Architectural Engineer

As I have discovered, even a small project can quickly become complex, and to create these buildings everyone in the project will need to be an expert in their discipline and familiar with methods. In the same way that the architect must understand the work of every discipline in order to successfully coordinate work, consultants need to understand the priorities of the designer to better assist them in their work. If I took the project and broke down what I did into the different specialties, it will illustrate this point. For the architect, sensitivities to the users' needs and understanding the midtown context led to the decision on the metal façade and the arched form, respectively. As the structural engineer, I was able to bring my expertise to this effort, knowing the structural potential and making assumptions on size and materials. With the aid of Dr. Mansy, I, the mechanical engineer, saw the potential for passive ventilation and lighting strategies in the large gym volume. The project manager was able to oversee all of this, coordinate the design, and find the best way to present these ideas to the clients.

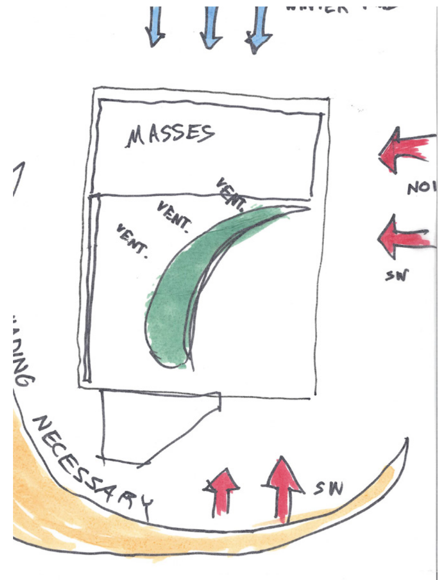
In the future, I will never have this same control over all aspects of a design. I will work exclusively on the structure system, but that does not reduce the value of my role on this project. In fact, having the experience of filling other roles will aid me in understanding what other entities are focused on, and how structural decisions will affect the rest of the project. An architect may have approached this program with a similar idea as myself, but I only created the arched form believing that I was capable of this design, and that it would be appropriate for the space. Understanding my abilities with this project and material allowed me to understand what I could create and if it would work for this project. As a member of a collaborative team, I can offer my advice and translate my abilities into something that the architect can use to further the concept.

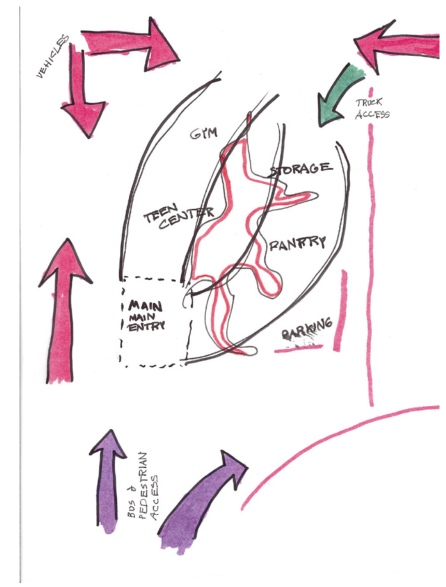
Even though my textbook knowledge of structural design is my greatest asset, my ability to understand what the architect needs and how I can aid this process is something I can bring to an office. The ability of engineers to collaborate, to bring something that can effectively connect with the other disciplines, will be pivotal in the future. There is growing demand for integrative design processes, and as architects and clients demand more responsive buildings, engineers need to become closer involved in the design process with their skills.

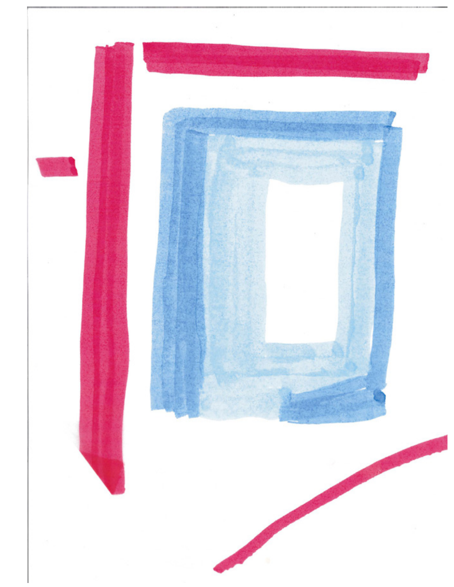
Even though my comprehensive design project only spanned about three months, my understanding of my own skills, how I can use them, and ways that I can be most helpful in a project. The purpose of this degree program has been to create engineers that are capable of bringing new potential to an architectural design team. Part of doing this is looking to new potential in structures. When I started this project, I did not know how I would solve this, but I knew this is something I would be capable of designing. Working on these projects at this school has been a source of inspiration, and in this way, I hope to use this on my work in the future.

THESIS PORTFOLIO AND DOCUMENTATION
ARCH 5226
OTHEROPTIONS FOOD PANTRY AND LGBT TEEN CENTER
ROBINSON & 11TH, OKLAHOMA CITY, OK
BEN SCHWARZ

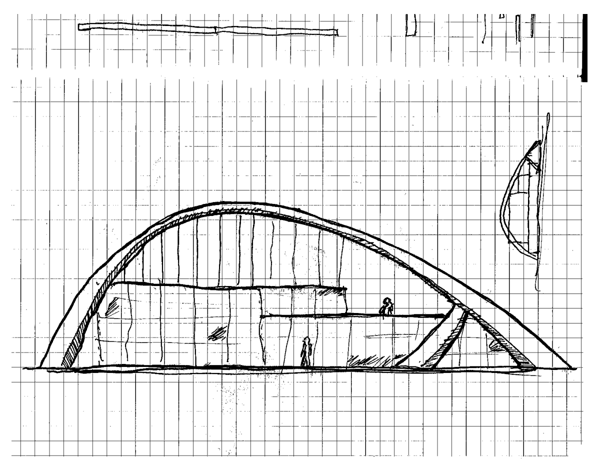
Early Conceptual Diagrams
Sketches of how the site interacted with the context. My site analysis included environmental, accessibility, and exposure. These diagrams helped to define many of my original floor plan layouts, and generated the idea of one building with two main entries, on the North and the South.

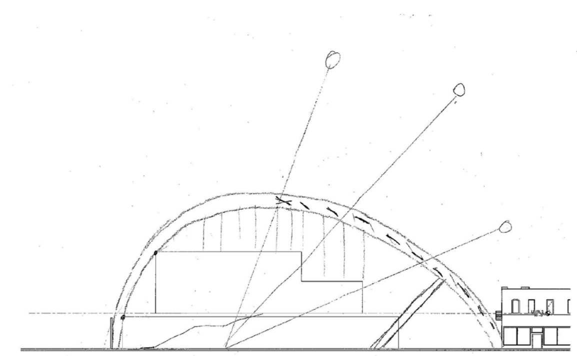


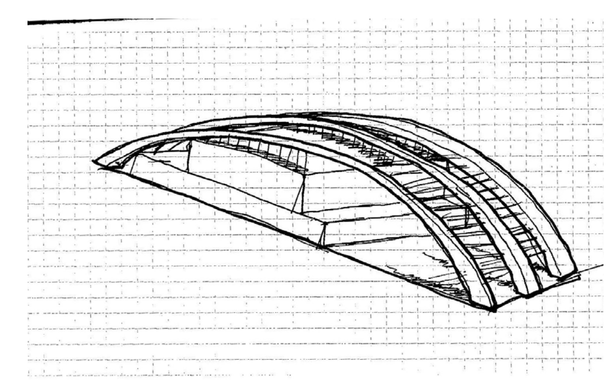




Structural Concept
After reviewing many options for how spaces could be organized, I searched to create a structure that would excite the community and tie the this organization into the trends of the development in Midtown Oklahoma City.

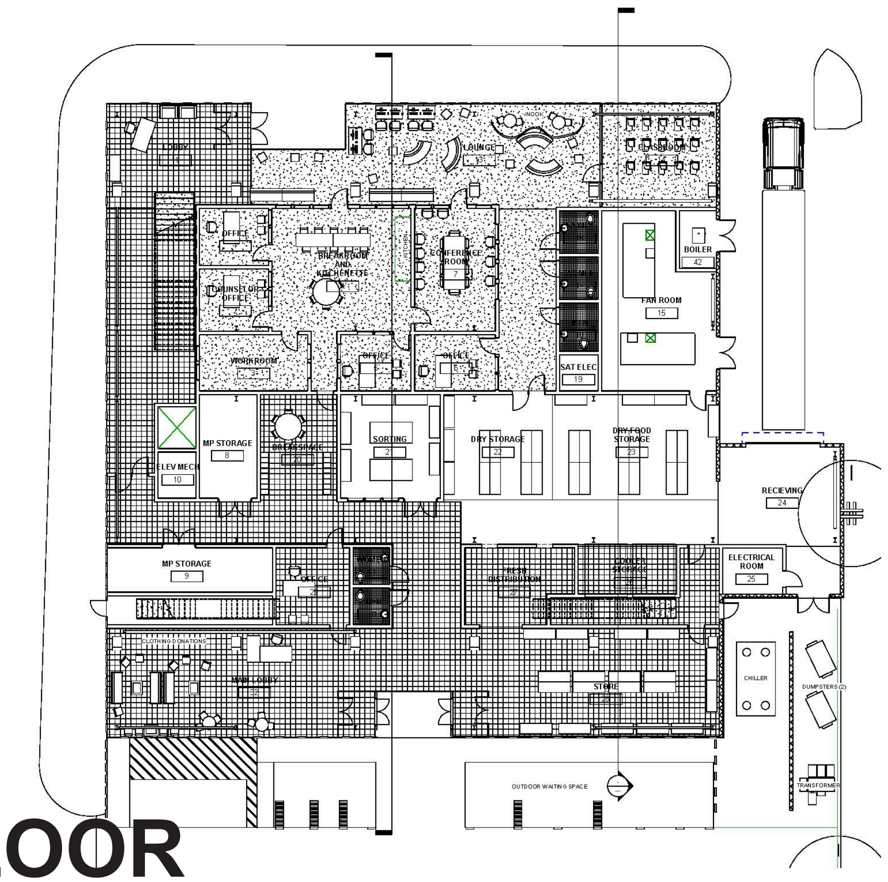






CONCEPT SEARCH

OtherOptions Food Pantry and LGBT Teen Center



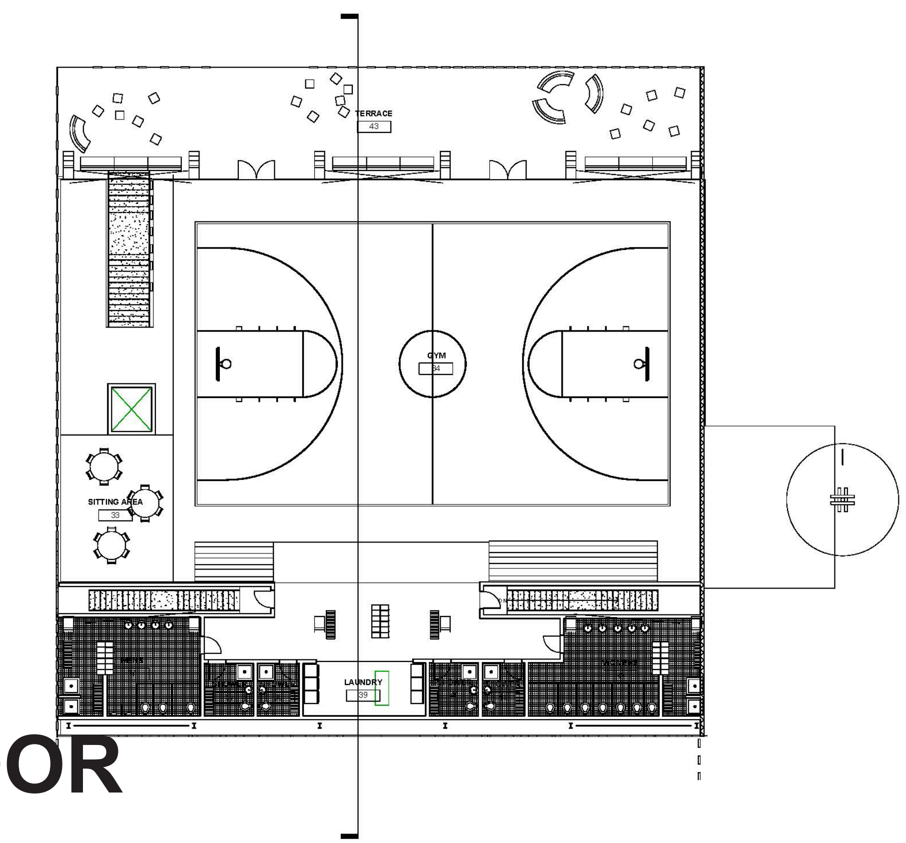
GROUND FLOOR

Ground Floor

Spaces for LGBT Teen Center are at the north end of the facility, between the arches and the street. The lobby welcomes at the corner of Robinson and 11th, with direct access to the classroom and the gym on the second floor. Below this are the office spaces, wrapped around the breakroom. The next row of services spaces are the food delivery and storage, located alongside the public pantry spaces on the south edge. These connect directly to an outdoor waiting space for clients and their children.

Second Floor

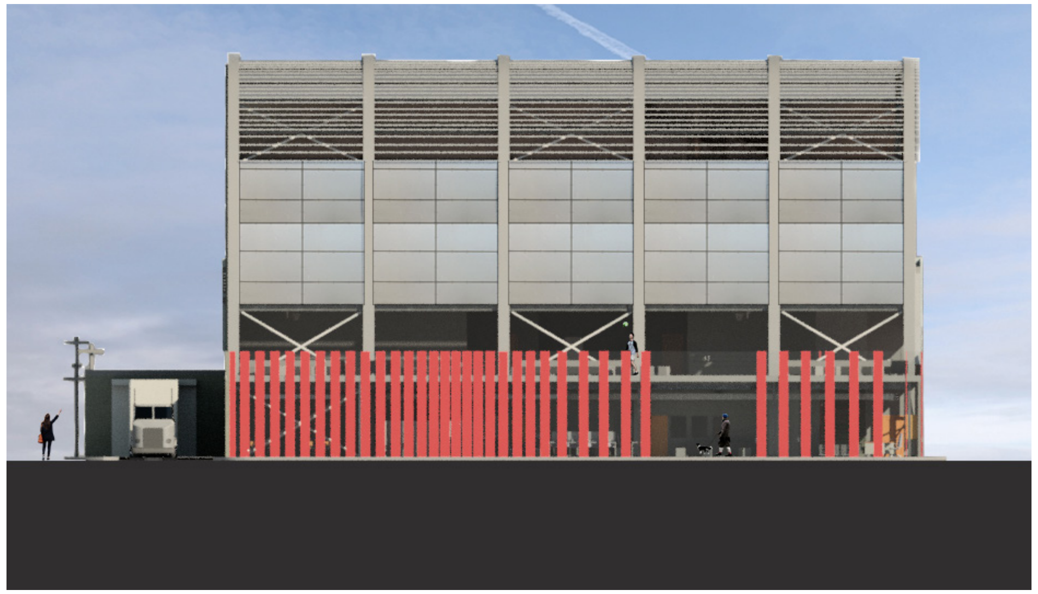
The second floor is reserved primarily for the gym space, located in the center, this is the large volume under the concrete arches. To the north, an outdoor terrace with views back out into the community. To the south, a block of support spaces: the bathrooms, lockers, and laundry facilities.



SECOND FLOOR

SCHEMATIC DESIGN

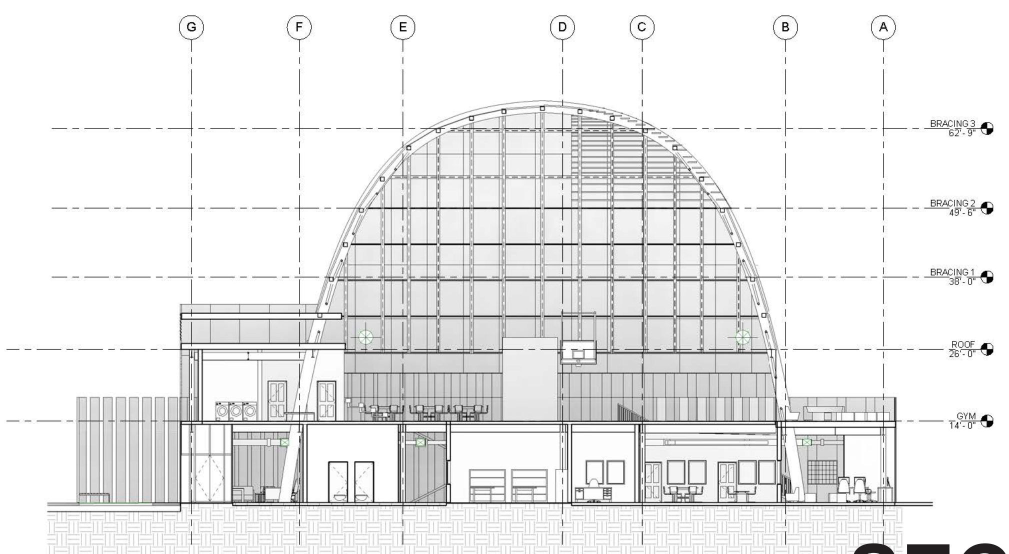
OtherOptions Food Pantry and LGBT Teen Center



NORTH ELEVATION

Facade Design

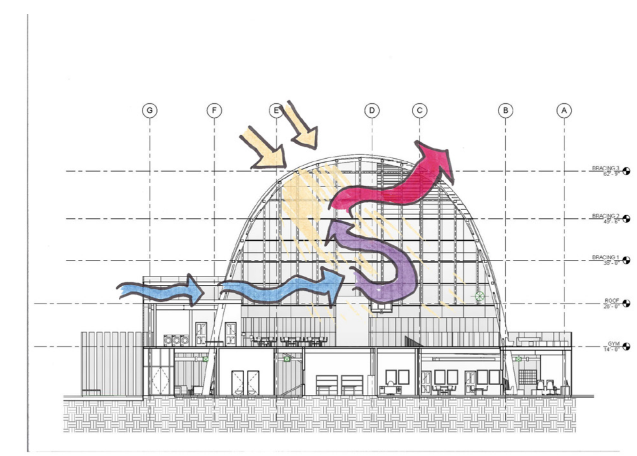
In order to maintain privacy for the user of this building while creating invigorating architecture for Midtown, a curtain wall grid was added. Vertical bands of glass and metal allow views but still over visual protection from pedestrians. The panel spacing varies depending on the use of the space, so the lobby is more open and the lounge is more private, for example. This pattern continues up, and becomes the guardrail for the terrace.



SECTION

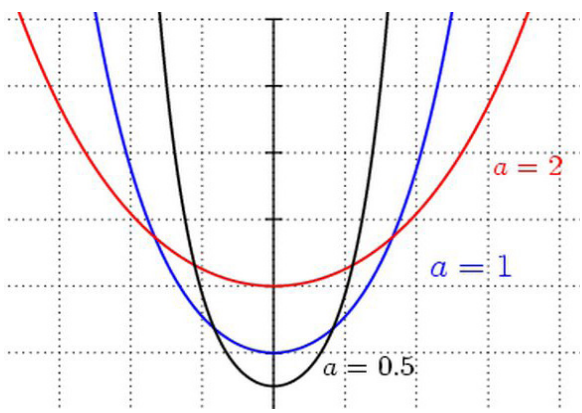
Gym Design

Since this is such a large volume, environmental design would have a large impact on the comfort and cost of the gym. To provide natural light, there is a translucent skylight on the south end of the curtain grid. To reduce the mechanical system, passive ventilation from the south to operable louvers on the north will cool during the summer.

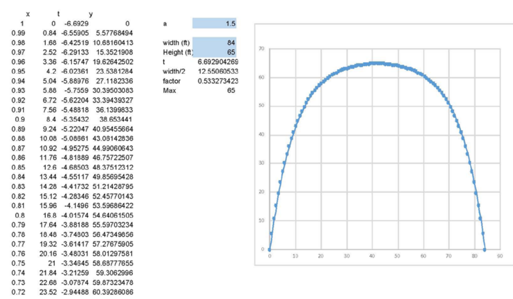


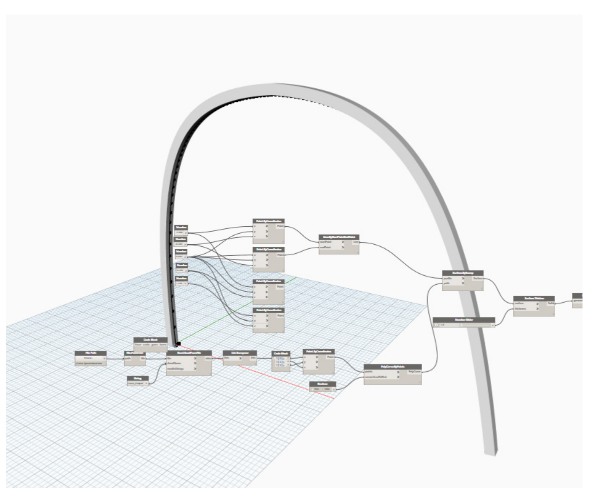
SCHEMATIC DESIGN

OtherOptions Food Pantry and LGBT Teen Center

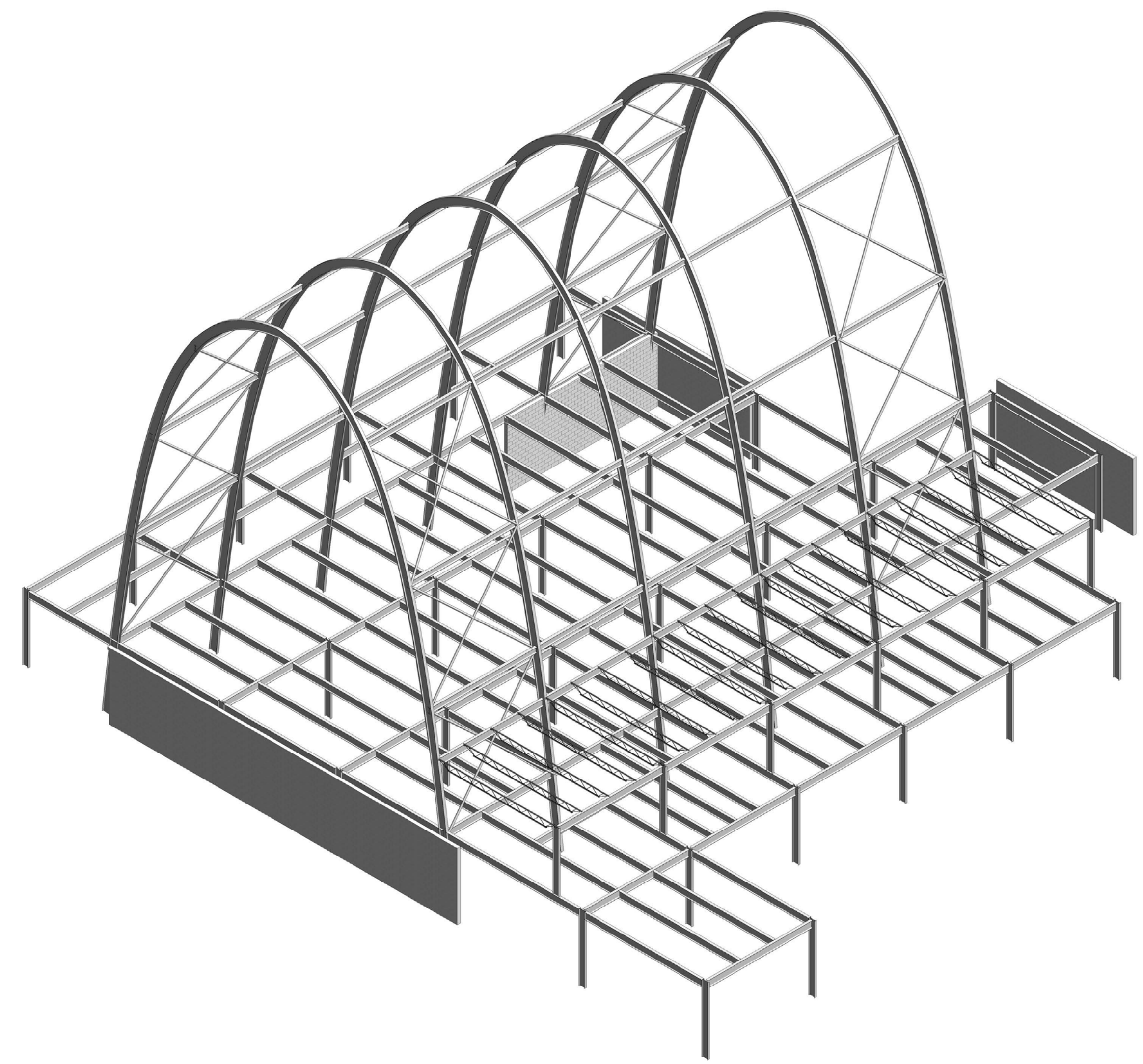


Parametric Modeling
To create an efficient structure, I needed to research how catenary structures are made. I found an equation to determine this curve, but there were options to adjust the form, height, slimness, etc. I set up a spreadsheet that would generate and model these instantaneously as I made changes.



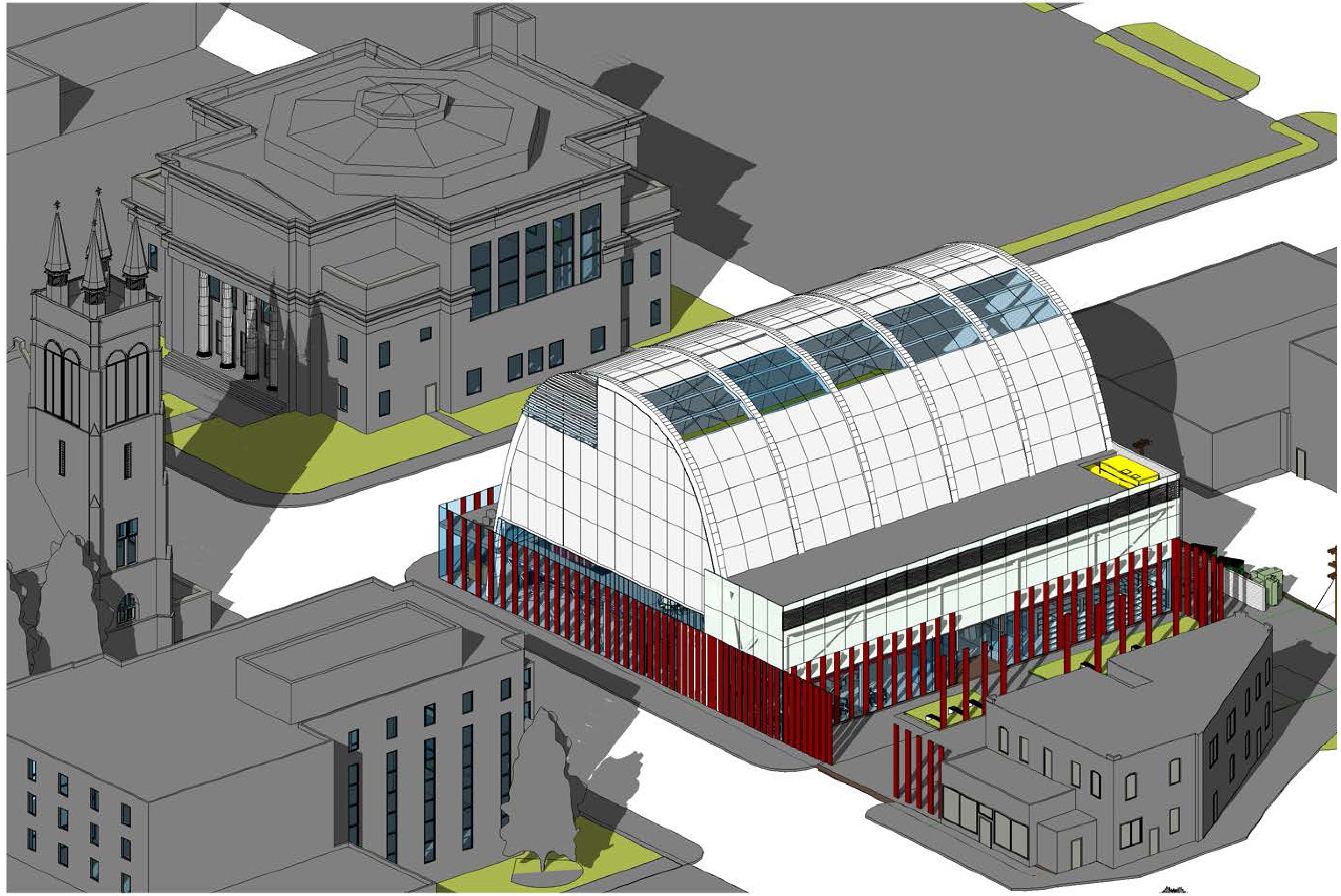


Structural Concept
Once a form was chosen, it was time to select a structural system. I originally choose steel, because I wanted to maintain a lightweight feel to the structure, and for flexibility on my column grid on the ground floor. After my schematic design jury, I decided to use concrete, to absorb the vibrations in the gym and easily create a tapered profile.



SCHEMATIC STRUCTURAL

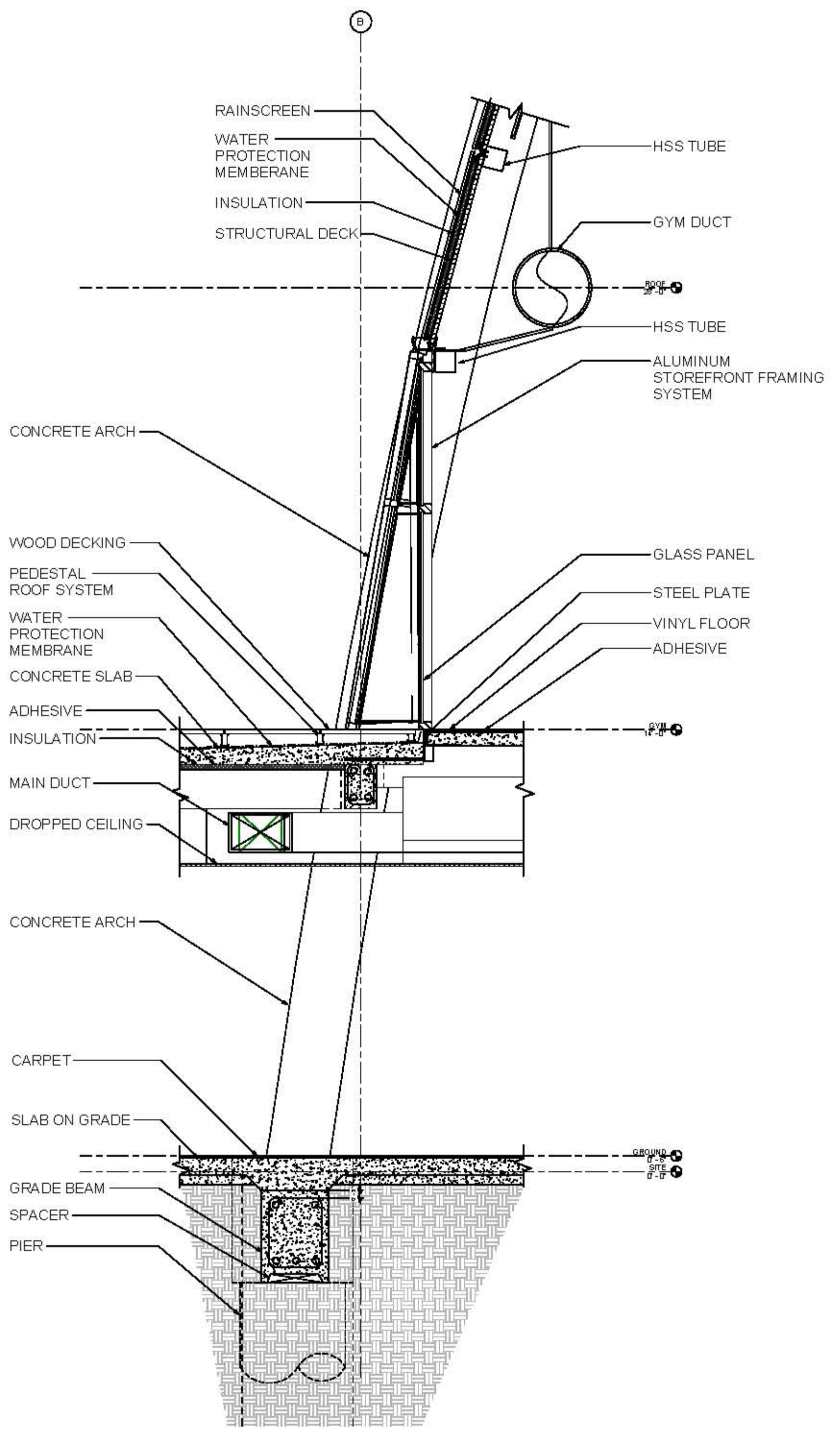
OtherOptions Food Pantry and LGBT Teen Center



Development
After the first round of juries, there were not many architectural changes to be made. Most of the remaining work focused on structural calculations, but it was also important to advance the mechanical system and one chosen wall section. For this portion, I selected my gym space and it's North curtain wall to develop. One of the most important concepts at this stage is understanding how certain design decisions in the schematic stage affect all of the other systems and consultants.

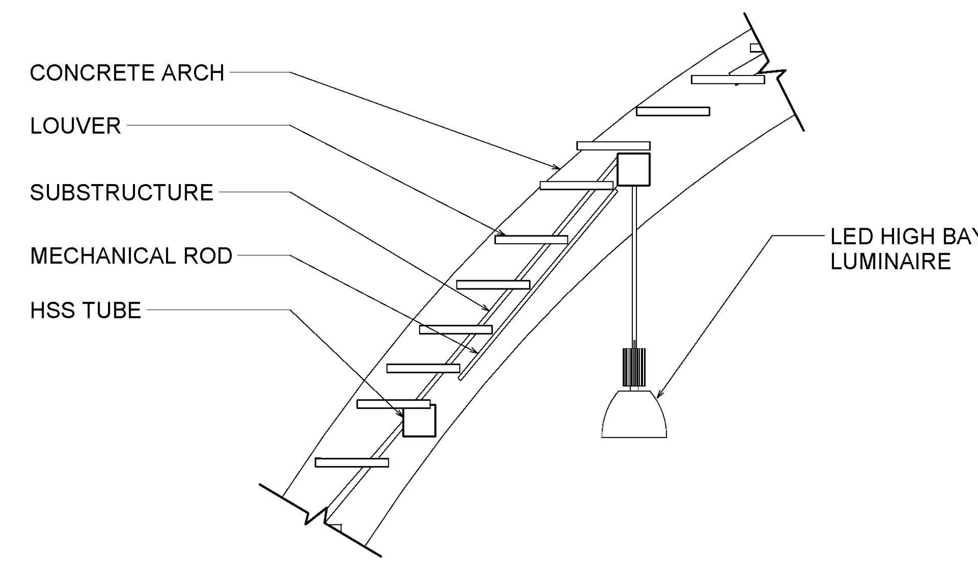
DESIGN DEVELOPMENT

OtherOptions Food Pantry and LGBT Teen Center



Wall Section Design

My wall section spans two levels and over 63 feet vertically, so it was necessary to divide into multiple regions. At the base is the teen lounge, an interior span bordered by the arches. Above this is the terrace, which caused several issues in detailing. Drainage would be complicated, since the slab must be sloped from South to North. This required the concrete structure to be lowered 6” from the rest of the level. To prevent ponding, a pedastol system was used to lift the floor panels. Enclosing the gym is a storefront facade, angled to match the slope of the arches everywhere except the doors. Above this, a panel system slopes across the form. It is constructed of an aluminum rainscreen, covering a water proofing membrane, rigid insulation, and supported by steel decking spaning vertically.



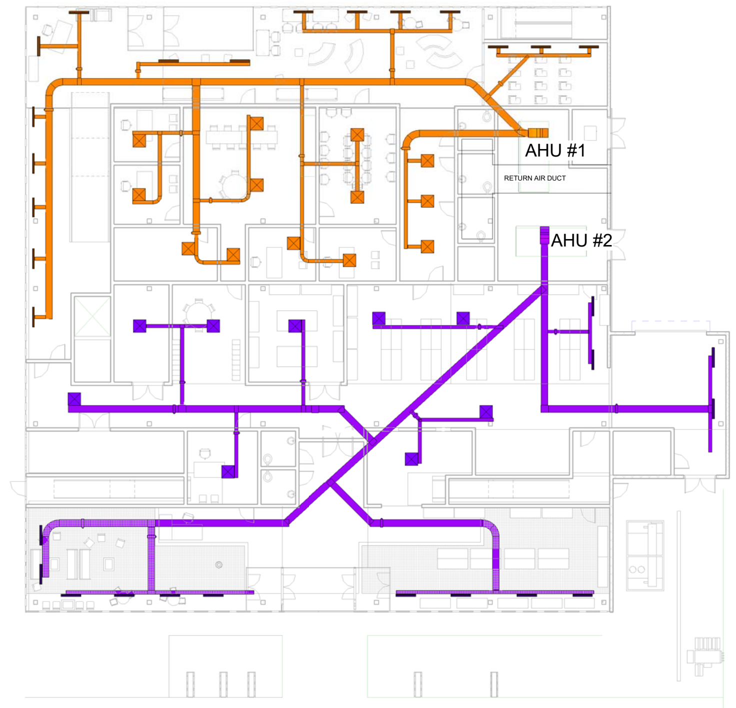
Louvers

Farther above on the section, the mechanical louvers will allow natural ventilation to move through the space. Above and below this are more aluminum panels, and this is the height the luminaires are hanging.

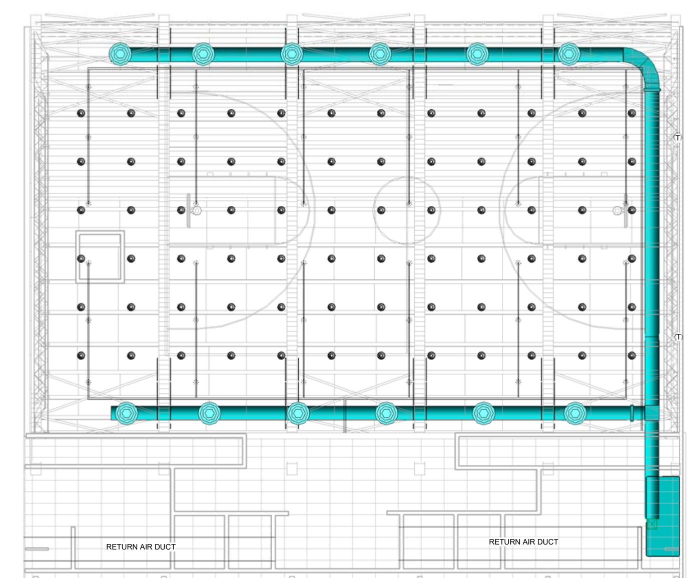
WALL SECTION

OtherOptions Food Pantry and LGBT Teen Center

Ground Floor
On the ground floor, with the majority of the program spaces, I seperated the air handeling into two separate zones. From discussions with the client, I noticed that the food pantry and teen center would be used at different points in the week. This divides the square footage evenly, with two VAV air handeling units serving the lever.



Gym Floor
For this level, only one space required climate control, because fresh air will be pushed into the laundry and bathroom spaces. I selected a VAV system, with one branch on the north and one branch one the south. This will compensate for different cooling loads due to orientation. One other design decision was choosing to have this air handling unit on the south room, which means that there was no need for a mechanical chase through the floor slab.

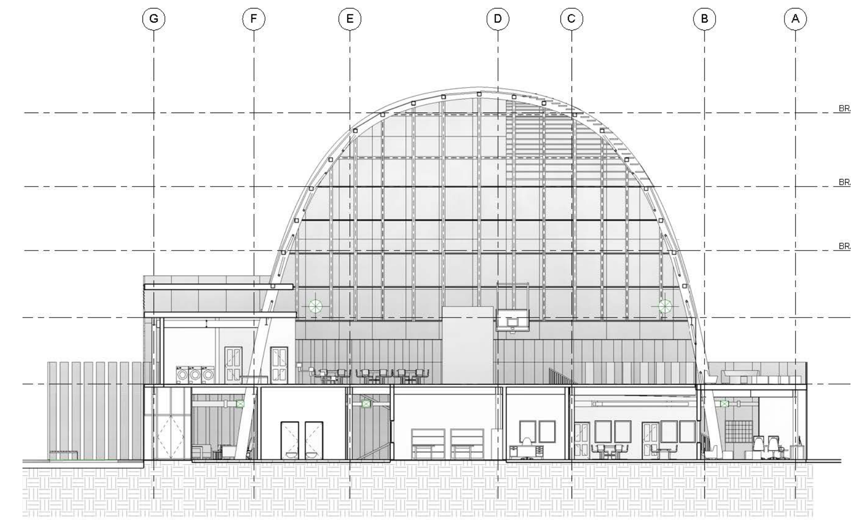


DUCT LAYOUTS

OtherOptions Food Pantry and LGBT Teen Center

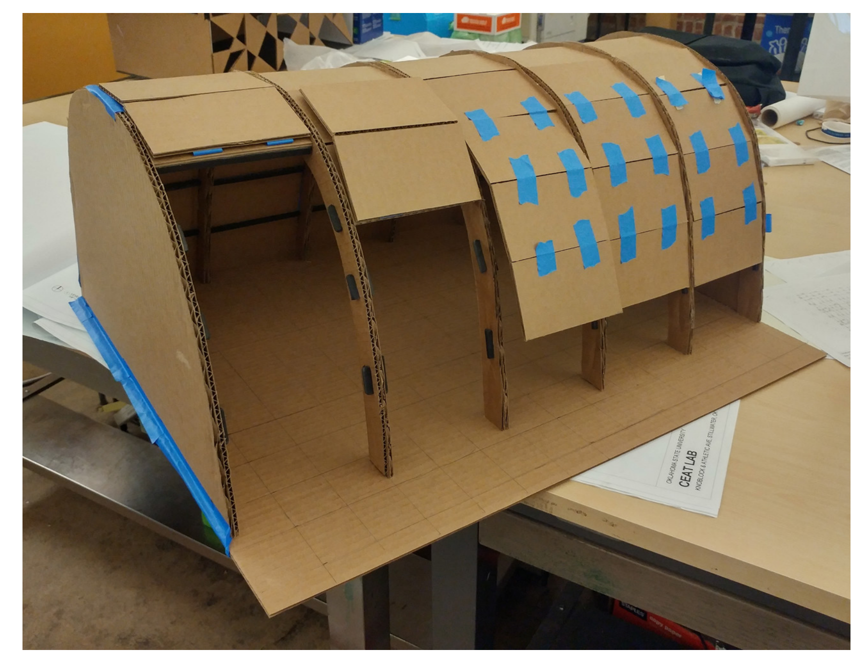
Gym Space Lighting

For gym spaces, there is need for bright, even lighting. We designed the space for 60 - 70 footcandles. To achieve this, I selected a high bay pendant luminaire. One of the important deisgn criteria was keeping the light load under 1.2 Watts/sqft. To help light the space and coordinate with the structural system, I added strip LED lights along the arches.



Daylighting

To achieve lighting in this space using passive systems, I created two locations that would allow sunlight, a storefront system along the north terrace and a skylight along on the south side of the ridge. To calculate the potential of this system, models were constructed and tested in a daylight simulator. Using these results, I selected certain glasses based on their visible transmittance.

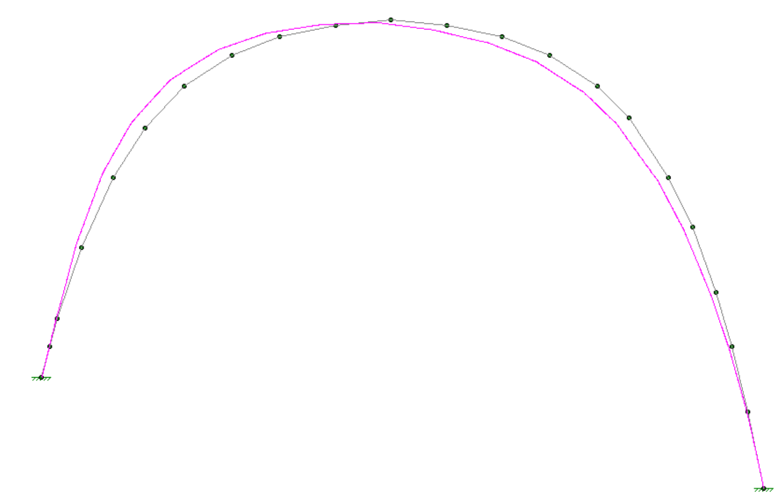


LIGHTING DESIGN

OtherOptions Food Pantry and LGBT Teen Center

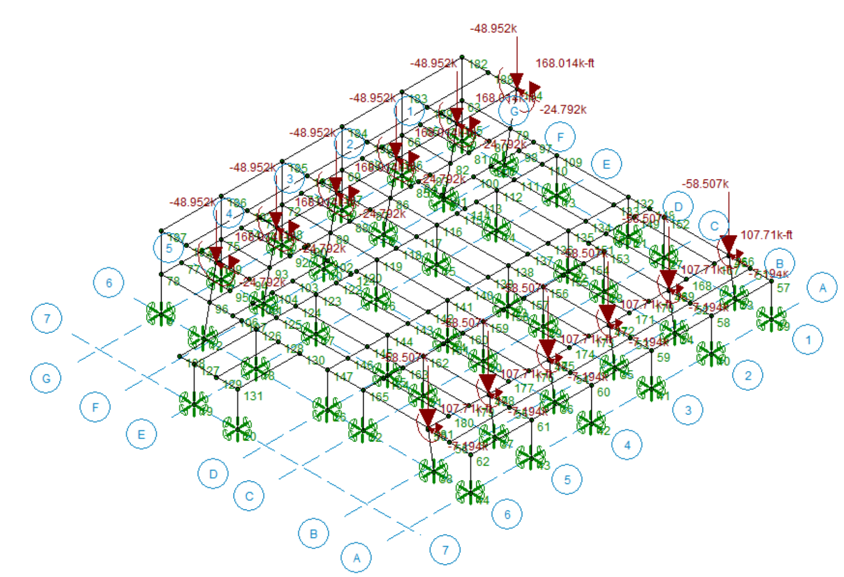
Arch Design

To accurately determine the forces in the concrete arch, I wanted to use two methods to make sure that the forces are the same. I created a stiffness matrix that would take my coordinates and find deflections at every joint. This method follows the principles of parametric modeling, changes made in the input are automatically used in calculations. From this, reactions are put into a larger RISA model, and these internal forces are used to select the sizes of the tapered arch form.



RISA Model

For the rest of the structure, I applied these arch reactions, as well as other gravity and lateral loads. Due to the lateral loads, I had to increase the width of the column and some of the moment frame members. Using internal forces, member schedules were created, and details drafted. One of the concerns with concrete is the development length of the reinforcing bars, which was an important check.



STRUCTURAL DEVELOPMENT

OtherOptions Food Pantry and LGBT Teen Center