VERMONT TECHNICAL COLLEGE

Bachelor of Science in Architectural Engineering Technology

Capstone Senior Design Projects

(2020)

Archive Facility in Mumbai, India

(1) Structural Engineering Design
(2) Heating, Ventilating, and Air-Conditioning Engineering Design

The following project summaries describe engineering designs completed during their spring semester by Vermont Technical College seniors.

SJ Structures
Online Project Description

The following descriptions are for the Class of 2020 Bachelor's Degree Architectural Engineering Technology Senior Project (ARE-4720), at Vermont Technical College in Randolph Center, Vermont.

The Team

The team consists of Samantha Daniels and Jacob Beaulieu. We both enjoy structural design and engineering and decided to complete our Senior Project as a structural design team, ultimately creating the team: SJ Structures.

Project Description

The senior project class (ARE-4720) began on January 20, 2020, and the team began the structural design process for a Historical Archive Facility in Mumbai, India. The project building is the ASHRAE 2020 Student Design Competition building. It should be noted that the building has already been designed and constructed in Arizona. For the purpose of the project, new construction was assumed and new designs were created for a Mumbai, India location. The structures team along with the mechanical senior project team determined the appropriate project site for the building to be 3VC4+WC Mumbai, Maharashtra, India. A home appliance repair facility exists at the site, but the teams decided that the existing facility would be demolished to allow construction of the New Historical Archive.

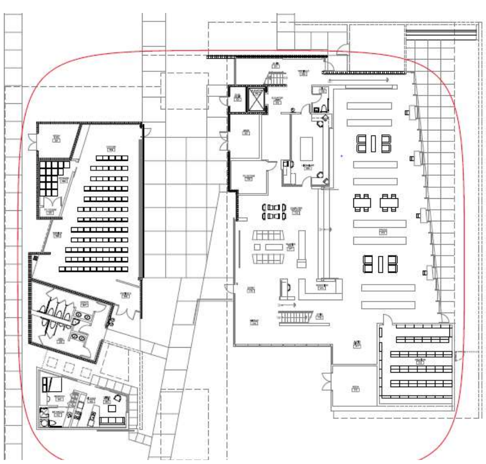


Figure 1: Mumbai Historical Archive Architectural Drawing

The historical archive facility is approximately 17,500 square feet and is a multi-roofed structure with two building spaces. There is the main archive building containing archives, stacks, librarians, mechanical rooms, offices, and conference rooms. There is also a courtyard space, and a second smaller building containing an apartment space, and a lecture hall. The main building contains a total of three floors: basement, first floor, and second floor. The smaller building, with the apartment and lecture hall, is on a single level with the first floor of the main archive building. For the purpose of the project, the India National Building Code 2016 was referenced, but the building structure was designed using American codes and manuals. The ASCE 7-16 and International Building Code were the codes that were mainly used.

The structure experiences numerous loads, or forces on it. The building experiences live, or moveable loads, varying from 40 pounds-per-square foot (PSF) to 200 PSF. The dead loads, or the constant loads, vary from 8 PSF to 72 PSF. The building experiences a rain load on the roof structures at 21 PSF. There are also lateral loads that were considered in the design. The building was designed to resist a wind load of 27,000 lbs. and a seismic load of 37,000 lbs. The building may experience tsunami loads but due to the site being over 2 miles from the Arabian Sea, the load is expected to be eliminated due to the distance and other structures diminishing the loading.

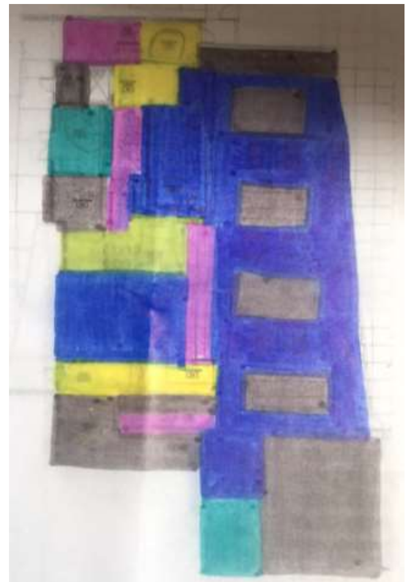


Figure 2: Main Building – First Floor Live Loads

The team had found that concrete was a prominent choice of material for building construction in Mumbai, India but steel construction was on the rise. There were found to be numerous steel manufactures and concrete company's located near the project site. Ultimately the SJ Structures team decided to have the building be prominently made of steel, with masonry shear walls and steel cross bracing to resist the lateral loads. Concrete was used for the slabs, first and second-floor decking, and for the foundation. Pile foundations were decided to be used due to the clay-based soil, with a low bearing pressure, in Mumbai.

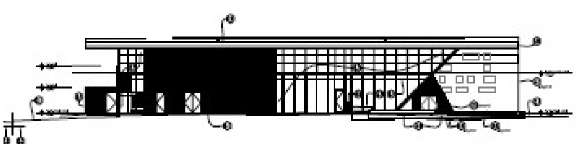


Figure 3: Sloped and Angled Curtain Wall

The building footprint is nontraditionally shaped with curtain walls and sloped and angled curtain walls. The structure has spans as small a few feet, and as large as 40 plus feet. The shape and layout of the facility made it challenging to avoid the large spans. The roof structure was designed to be made of open web joists (OWJ), and w-shape beams. Traditional OWJs can be used throughout most of the roof structures, and range in size from 10K1 to 28LH05. Roof cantilevers require custom steel trusses due to their large span and loadings. The roof beams vary in size from W12x16 to W21x44. The floor systems consist of w-shape joists and beams varying in size from W12x14 to W18x35. The column size was decided to be consistent throughout the building and W10 steel columns are used. The slab on ground depths vary from 4 to 6 inches and are located in both buildings. Concrete floors and decking are located on the first and second floors of the larger building and have a depth of approximately 4 inches. Ultimately, the team decided to use 14”x14” concrete piles because of the potentially corrosive soil, with Mumbai being located near the sea. Two piles are needed at the largest loaded column, and each pile would have a depth of approximately ten feet. It should be noted that the ten-foot depth of the piles is unable to provide lateral resistance, the reason for selecting piles. It is recommended that a small HSS (hollow structural section) steel member be used instead to increase the depth and provide adequate lateral resistance. The masonry shear walls are to be located around elevator shafts and stairwells and along with interior walls that do not contain curtain walls.

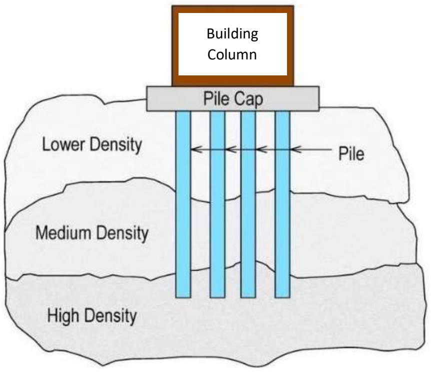


Figure 4: Pile Foundation Diagram

It was estimated that the total structural design cost for the project would be approximately $65,000 for two structural design engineers. The entire construction cost for the building was estimated to be at approximately 3.8 million dollars with the structural construction costing approximately $555,000. Typically, the structure of a building does not require maintenance, but the roofing of the building will likely need upgrades approximately every fifty years. It is estimated that the cost to upgrade the roof after 50 years to be approximately $123,000 with a yearly cost of approximately $2,500.

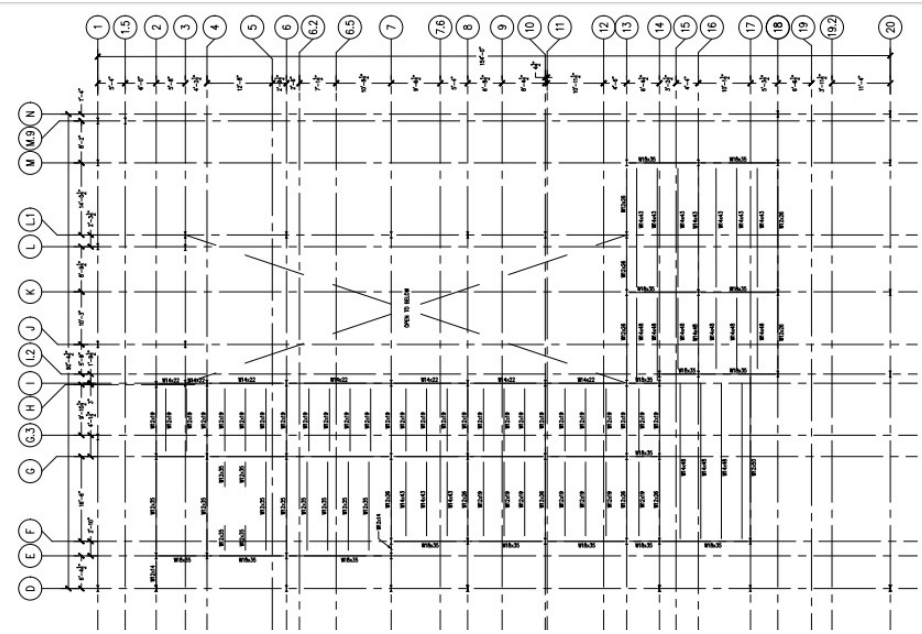


Figure 5: Main Building Second Floor Framing Plan

The project expanded the team member's abilities and knowledge on the structural design process and techniques, as well as techniques for cost estimating. The project was an experience that ends our college careers and began our engineering careers.

2020 ASHRAE Student Competition Building HVAC Design Calculations Team

-Project Team- **ARE 4720**

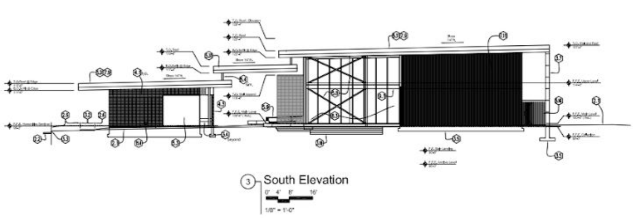
Project Manager: Coleton Loura-Bumps
Budget Manager: Olivia Mendes Machado
Quality Control Manager: Jeff Hobbs

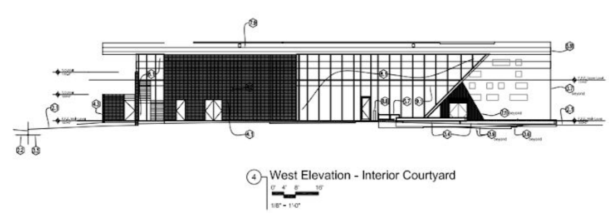
Project Description:

This project is part of a yearly design competition that is sponsored by ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) that aims to challenge students with their acquired skills and learning in the field of HVAC (Heating, Ventilation, Air-Conditioning) engineering. Throughout the competition we have calculated heating and cooling loads, analyzed air volumes and psychrometrics, and designed a building's HVAC system including system type, size, supply type, and layout.

Location:

The building is located in Mumbai, India. Mumbai has nearly a semi-arid climate with average yearly temperatures around 85°F. The building is a rare document storage and sensitive works archive facility. The site also contains a separate building that houses a lecture hall and a residential apartment unit. The main building is a two story structure with a partial basement. The second building is a single story, nearly detached building. The only part of the building that connects them is a roof over the walkway in between. We decided we would place the building in a low rise commercial area of the city. We wanted to make filtration a priority, so placing the building away from the commercial air pollution was an easy choice.





Elevation Views of the competition building.

Objective:

The goals of the competition were for students to demonstrate their knowledge and understanding about the world of HVAC. Then to use that knowledge to design a system that could adequately handle the loads and building code requirements.
The goals of this project were dictated by the owner requirements that are given below. We then aimed to exceed these goals by a margin of 20%. Other goals that we set for ourselves included, utilizing the multiple mechanical rooms and choosing a system type that could be placed indoors.

Challenges:

Some challenges that we faced were, the level of sensitivity of the stored materials, the strict condition requirements, the high level of filtration required, and the needed resilience of the building. The documents and other media stored here are extremely sensitive, requiring controlled and regulated conditions. A difficult thing to do in a public building since foot traffic can be heavy and unpredictable. The air quality in Mumbai is some of the worst in the world, making the filtration of supply air difficult to manage. Mumbai is subject to monsoons often, forcing us to consider the lasting effects of these events. We then designed the building to stand up to the frequent weather.

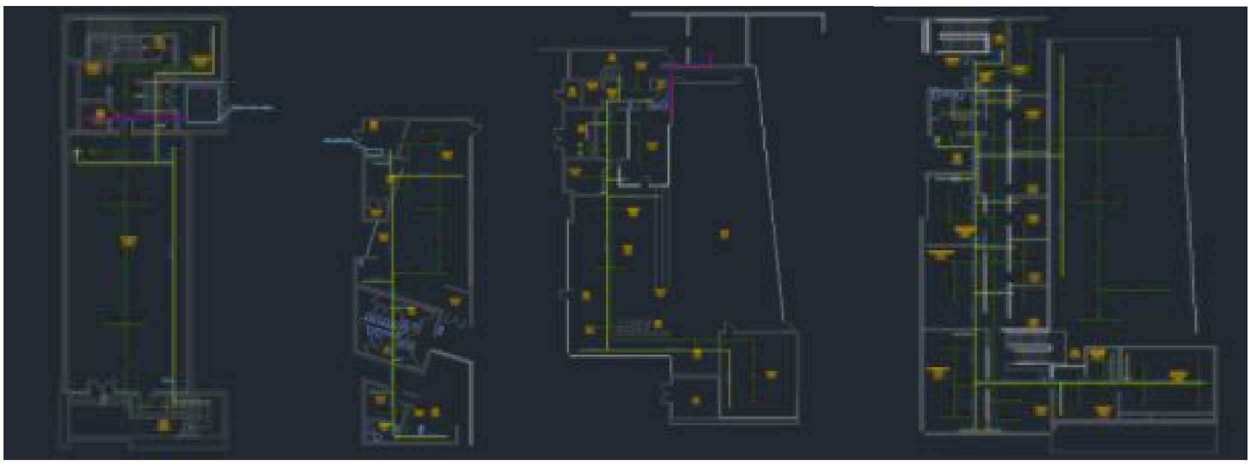
Our System:

	Occupancy	Cooling	Heating	Sound
Archives	08:00—18:00 Monday – Saturday No occupancy on Sunday	65°F ± 2°F 40% RH ± 10%	65°F ± 2°F 40% RH ± 10%	NC 40
Audio/Visual		Occupied: 75°F Unoccupied: 80°F	Occupied: 70°F Unoccupied: 60°F	NC 35
Computer Catalog				NC 30
Conference Room				NC 30
Display				NC 35
Enclosed Office				NC 30
Librarians				NC 40
Lobby				NC 40
Lounge				NC 40
Meeting Room				NC 30
Rare Book Collection		65°F ± 2°F 40% RH ± 10%	65°F ± 2°F 40% RH ± 10%	NC 40
Rare Book Librarian		65°F ± 2°F 50% RH ± 10%	65°F ± 2°F 50% RH ± 10%	NC 30
Rare Book Reading		70°F ± 2°F 50% RH ± 10%	70°F ± 2°F 50% RH ± 10%	NC 30
Reading		Occupied: 75°F Unoccupied: 80°F	Occupied: 70°F Unoccupied: 60°F	NC 30
Stacks				NC 35
Stairwell				NC 40
Vestibule				NC 35

We decided to use a chilled water VAV (Variable Air Volume) system. The chilled water source not only was able to be located inside the building but it also could be placed in the basement, at water and electric supply level. This made for fast and easy connections to these utilities without the use of a lot of piping throughout the building. It also does not use as much refrigerant as other sources do. This means less dangerous material in use, to the people and the planet. The other portion of our HVAC system is the use of VAV distribution. This type of distribution works well for highly controlled areas. This whole building is highly controlled as seen above. Almost any distribution would work well to maintain the total building temperature to nearly 65℉. However the VAV system is capable of maintaining that temperature within a couple degrees. VAV distributes air at varying volumes, this means that the rooms are not always at full capacity conditioning or off. The rooms can be in a reduced conditioning mode, using small amounts of air at a time to maintain the desired setpoints within the rooms. We also included the use of a cooling tower to remove excess energy. The only downfall to using a cooling tower here is that it needs to be externally mounted, most commonly on the roof. We decided against the traditional roof mounting and instead decided to place the one for the secondary building on the ground, north of the second building, and the primary one on top of a nearby shed-like attached structure. We did not want to alter the aesthetic properties of the building by mounting a cooling tower on the roof. This also means that the hot water did not have to be pumped up to the roof, but rather to ground level and second floor height respectively.

System Sizing:

To size the HVAC system for the rare document storage and archives the team had to take into consideration several components. The intended use of the structure placed a high level of expected performance on the system. There is the need to preserve rare documents in multiple formats in a controlled environment at temperatures ranging from 65 to 70 degrees fahrenheit at a humidity level ranging from 40 to 50% in the archives and rare book locations. In all other locations throughout the building the temperature and humidity has to be kept at 75 degrees fahrenheit when occupied and 80 degrees fahrenheit when unoccupied. Since the humidity had to be at a certain level in specific parts of the structure it only made sense to the team to maintain that level throughout the entire structure.



The owners wanted the occupied spaces to feel open and spacious, which kept to a minimum the space required to run the ductwork and plumbing. The owners also wanted synergy with the surrounding architecture so the components of the system had to be tucked away out of sight which limited the size of the system but not the performance required. Different mechanical rooms provided the opportunity to break the system into its respective components allowing us to meet the cooling load needs of the building as well as the owners requirements. The owners had a noise criteria requirement that the team had to meet. This criteria was to maintain a db level between 30 to 40 dbs. Through proper sizing of the ductwork along with the air supply and return diffusers the team was able to maintain a 30 or less db noise criteria throughout the building.

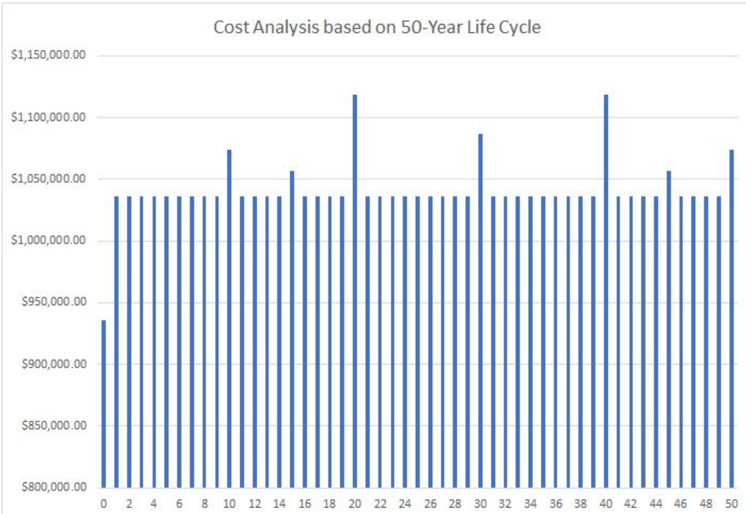
Economic Analysis:

The owner of this project has a budget of $350/sq.Ft, which in turn gives his MEP Budget as $61,250.00. This is 1% of the owner’s budget for the total construction cost.

For a preliminary construction budget, we determined $200/sq.ft to be a reasonable estimate of the cost for a building of this type, and as the building comes up to a total of 17,500 square feet, that gives the estimated as-built construction cost to be $3.5 million.

After the amount of hours we were likely to work on the project were estimated, we determined a budget of $60,480 for the project to be reasonable. This included any extra hours we worked on during submittal weeks. This is 98.7% of the owner’s budget, and is 1.73% of the estimated as-built cost.

Pictured is a cash flow diagram showing the HVAC costs related to the project. These include the design budget and initial construction costs, annual and periodic maintenance costs, equipment replacements costs, and the annual energy costs over the 50-year life cycle of the building. The total annual cost of the building over its life-cycle is $1,086,088.06. As shown on the graph, the yearly cost for the building is quite steady year to year, with only the occasional higher cost for equipment maintenance and replacement.



After performing an economic analysis on the building, the current present value is $23,306,610.82. The owner would like to see a return on investment of 7% over the building's life cycle. Taking into account inflation, which was dictated by ASHRAE to be 3%, that would give the owner's return on investment to be approximately $24,238,875.25.