VERMONT TECHNICAL COLLEGE

Bachelor of Science in

Architectural Engineering Technology

&

Bachelor of Science in

Renewable Energy

Combined Capstone Senior Design Projects

(2022)

Performing Arts Facility

Sydney, Australia

(1) Integrated Sustainable Building Design

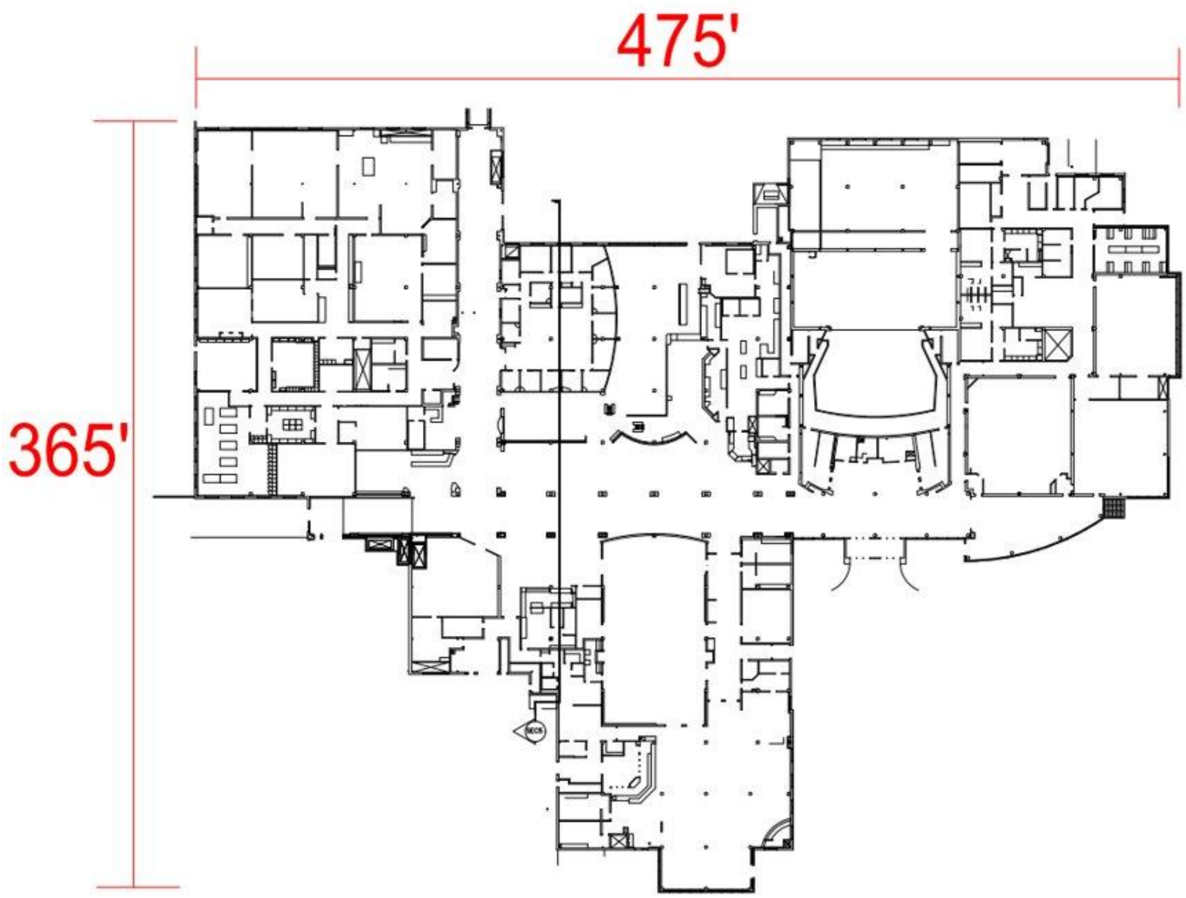
(2) Structural Engineering Design

The following summaries describe two team projects that were undertaken by students from the Architectural Engineering Technology and Renewal Energy programs. For the first project, students from both programs worked together.

(1) Integrated Sustainable Building Design

Project Description

Our team has designed a sustainable and energy efficient building for the 2022 ASHRAE Design Competition. This project entailed designing architectural, structural, HVAC, electrical, lighting, and civil systems. The building is a net zero performing arts facility for the city of Sydney, Australia. This project is a university based performing arts center with two levels above grade and one below grade.



The address for our building site is 1005 City Road, Sydney, Australia. This site ranges from 82 to 85 feet above sea level. This means our site is at a minimal risk of flooding or tsunami activity.

Sydney's weather is seasonable all year, with annual temperatures ranging from the high 40's to the high 70's. The average annual rainfall is 35.7 inches, with winds averaging 7-9 MPH. Tsunami's are not considered a threat, with 4.5 feet of flooding calculated to occur once every 70 years.

Figure 1 Civil & Site Layout

Codes and regulations we must consider while designing are ASHRAE 2019 standards 15, 34, 55, 62.1, 90.1, 189.1, IBC 2015, ASCE 7-16, NEC NFPA 70, Net Zero Energy, and the Building Code of Australia.

In terms of incoming traffic and transportation to our site, we have focused on foot traffic and some motor vehicle traffic. The city of Sydney has a small population of households that own cars compared to the rest of Australia. About 35.4% do not own a car while the total average number of households without cars for all of Australia is 7.5%. The two most popular modes of public transportation in Sydney are train and bus, which this location already has three bus stations within 1,000 feet. We have found that people who own cars are still likely to use public transportation. Based on these statistics, we can expect more traffic to be foot based rather than vehicle based. To this end, we added one more bus stop within the building property lines.

Because we are designing a net zero building, all HVAC devices operate on renewable electricity. With the amount of sun hours Sydney gets, we plan to utilize solar energy to power our building. The photovoltaic system will be grid-tied to alleviate the associated costs of a large battery bank. No additional electrical plants will be added to our design. Due to the complex nature of other forms of renewable energy, we chose not to implement wind, hydro, bioenergy or geothermal. Instead, we chose to have solar arrays placed on the roof, carports, bus station, and in the Northeast field near the facility.

The photovoltaic design can support 1.95 megawatts (MW) of electrical power, which is 117% of the building's HVAC load. The remaining required electricity will be purchased from a local renewable energy provider. This power is supplied by Red Energy, a hydropower provider that diverts water flowing east to the coast through trans-mountain tunnels. If more power is required in the future, there is enough space for an additional 150,000 kWh production to the Northeast of the facility.

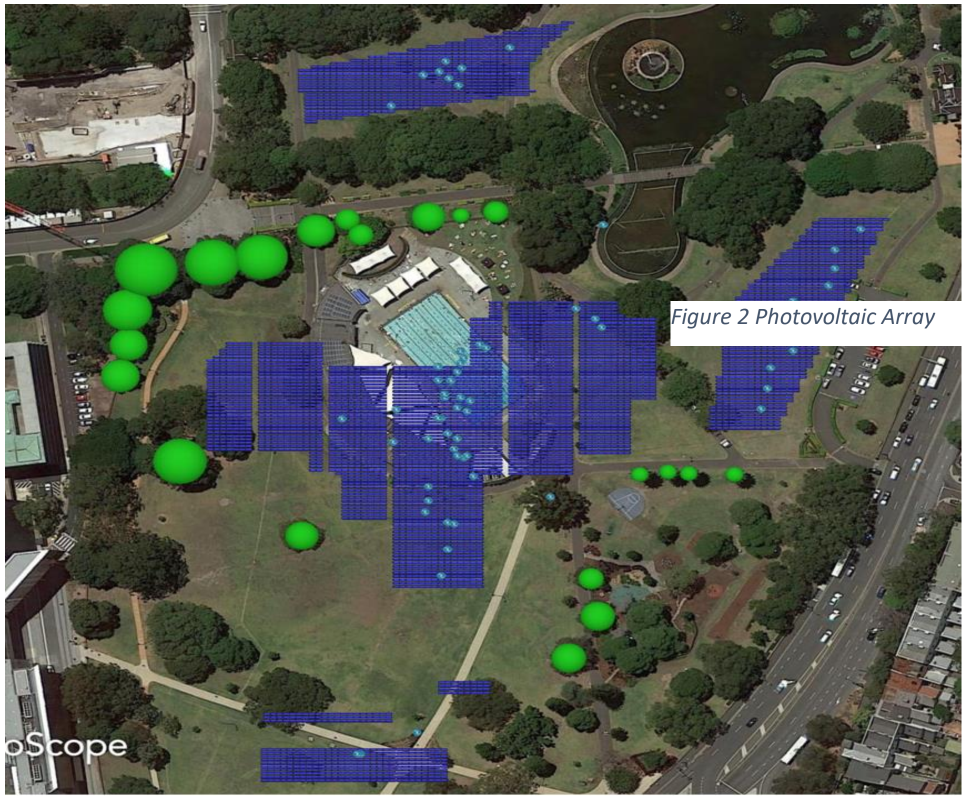


Figure 2 Photovoltaic Array

As this is a performing arts facility, it was important to keep in mind noise when designing our mechanical systems and when selecting our finishes. We had to avoid any sort of vibration, humming, or echoes in spaces where acoustics need to be prioritized. To minimize unwanted noise in the theaters, we have two separate HVAC systems. One system is for office spaces where noise cancellation is not a priority. The other system is for the theaters where noise cancelling, and ventilation are a priority. In Sydney, the humidity is around 70% so using the proper air and ventilation systems, like ones in museums and theaters, will keep the occupants comfortable and the room intact. The air quality in Sydney is "7", which means the air quality is satisfactory, and air pollution poses little or no risk. The office spaces have an air to water rooftop unit with a dedicated outdoor air system (DOAS). The theater sections have a variable refrigerant flow

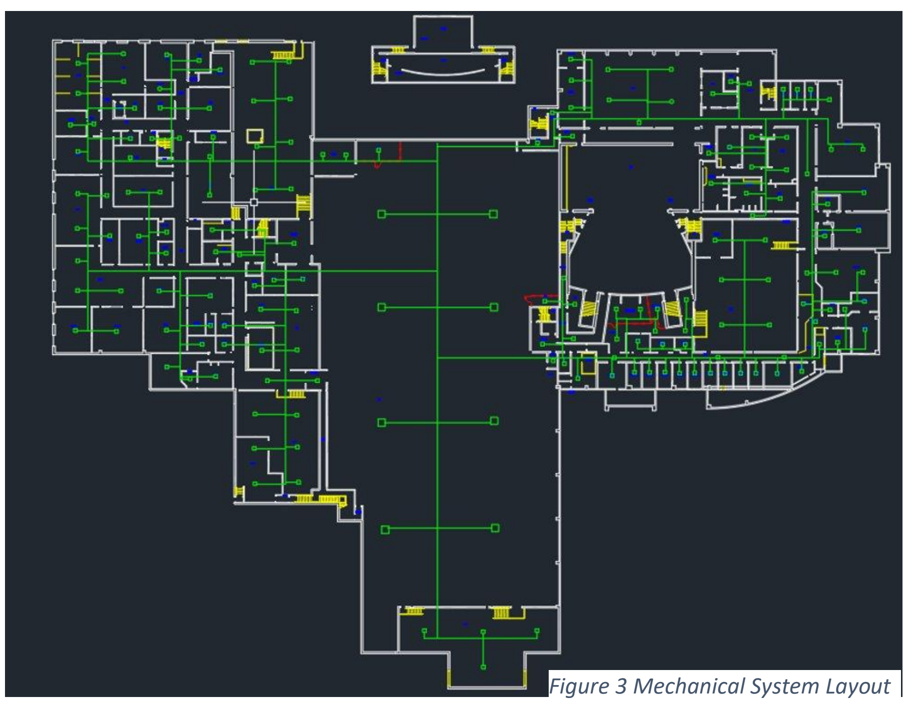


Figure 3 Mechanical System Layout

(VRF) system with DOAS. These are systems with high efficiency and can operate on renewable electricity.

Lighting is an important aspect in any performance space. To minimize energy consumption, we implemented LED lighting in all areas including stage lighting. Additionally, while the indoor lighting needs are what draw the most attention, we provided exterior lighting for sidewalks, parking lots, public transit zones and shared areas. By using efficient lighting, more electricity from our photovoltaics can be used for the building's equipment.

For architectural style and materials, Sydney has a wide range of building styles. Our goal is to create a building that merges the ultra-modern and classical revival styles of architecture seen throughout Sydney that still offers high thermal resistance to reduce our building's heating and cooling loads. Historically, Sydney was known for building out of masonry due to the lack of trees available to build out of wood. Granite, marble, slate, and limestone were popular types of stone used for construction. Nowadays, it is possible to ship in any desired materials from other countries, but we would like to stick with materials that are readily available and sourced from Australia if possible. Some areas of the building lend themselves to having a large concentration of glass while other areas are limited in the use of glass.

We created a wall structure that exceeded current codes in terms of insulation. We have designed a standard wall detail with varying veneer on the outside that exceeds ASHRAE insulation codes. The primary veneer we have picked is a stone veneer that shall be sourced out of Australia. There are various advantages to using a veneer as opposed to a solid masonry wall including being a lighter construction material, which aids in using less steel for the structure, quicker construction times, and a less expensive overall project cost.

For the structural system, the most important consideration is the safety of the occupants and the public. For this system we are using steel and "irradiated plastic" concrete (concrete made with recycled plastic replacing a percentage of portland cement). There are many other considerations such as embodied energy, sustainability, and economical use of material when it comes to the structural system. The sustainability of the structure should be able to last the lifetime of the building, be ready for expansion, and still have the potential to be recycled or reused in the future. The embodied energy in building materials can be high but can be offset with newer materials such as replacing some portland cement with recycled plastic since cement is carbon intensive. We chose economical members, using the least amount of material that still has the highest load carrying capacity. This drove the decision for using open web joists compared to a W-shape over a long span to reduce the weight of the member but still be able to carry the loads. The decision of using open web joists compared to W-shapes also helped reduce the carbon production due to the lower amount of steel required.

(2) Structural Engineering Design

Project Description 2 ARE-4720

<u>Green Mountain Structural</u>

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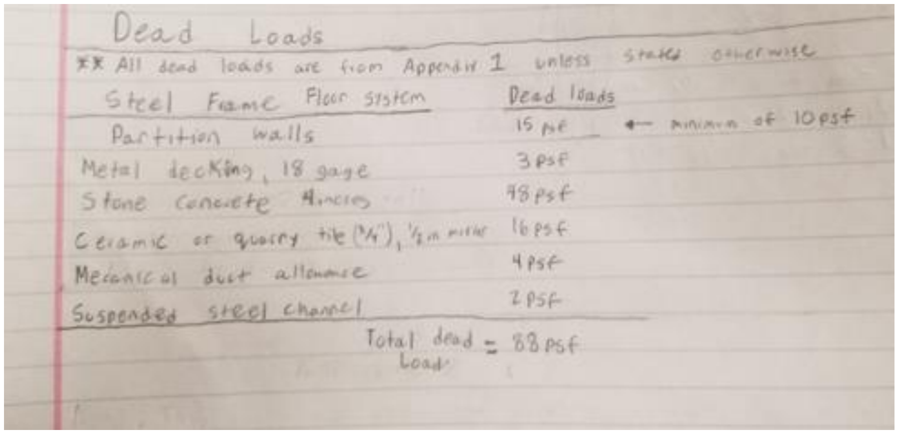
The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has a design challenge where students embark on the "design of energy-efficient HVAC systems" for a pre-designed building, which is in Sydney, Australia for this year's challenge. Our team has not entered the ASHRAE design challenge since we are only designing the structural system of the building in question. Our objective is to design a structure with low embodied energy that accommodates and compliments the function of the building.

We spent the first couple work sessions analyzing the building to understand what it will be used for and collecting data on Australia's typical construction materials and methods to give us more understanding of structural materials, climate, loads, local codes, resilience, geography, and topography. Fortunately, Australia's construction materials and methods are quite like the northern United States. Australia's climate does not fluctuate greatly. The temperature typically varies from 47°F to 80°F (8.3°C to 26.7°C) throughout the year and rarely goes below 42°F (5.6°C) or above 90°F (32.2°C). We are carefully determining the loads that the building will encounter during its life, such as dead, live, rain, wind, and earthquakes. We used ASCE 7-16 to determine the buildings dead, live and rain loads. The floor dead load calculations can be seen in figures 1 below.



Dead Loads

** All dead loads are from Appendix 1 unless stated otherwise

Steel Frame Floor system	Dead loads	
Partition walls	15 psf	← minimum of 10 psf
Metal decking, 18 gage	3 psf	
Stone concrete 4 inches	48 psf	
Ceramic or quarry tile (3/4"), 1/2 in mortar	16 psf	
Mechanical duct allowance	4 psf	
Suspended steel channel	2 psf	
Total dead load =	88 psf	

Figure 1: Floor Dead Load Calculations

The live/occupancy loads throughout the building change depending on the spaces intended use. When sizing the members, we made the design choice to use the higher live/occupancy load for the area of which the member being designed carries. We did this to make the design of members simpler for us, given our limited time to work on the project. Also, for possible future renovations that may cause the use of the spaces to change, resulting in higher loads. We decided that there will not be ice or snow load because of Sydney, Australia's climate, and no tsunamis or hurricanes because the site is about 148 feet (45 meters) above sea level and is far enough inland, so the risk of damage due to tsunamis or hurricanes is low. The earthquake and wind loads were calculated using the Ochorn seismic and wind calculator. We chose 2000 Elizabeth Street in Sydney, New South Wales, Australia as a location because it is a cultural hub within the city, just outside of the main downtown area. This is important for our building because we want it to be easily accessible to the public since it has a high occupancy, but not too far into the city where it is overshadowed by huge skyscrapers. We also do not want it in the more residential areas where it would look and feel out of place. This location is perfectly balanced because it is in the transition area between the inner city and residential neighborhoods. The soil type has been determined to be ash field shale, which is a soft rock. Soft rock can withstand a maximum allowable bearing pressure of 8 TSF, which is plenty because our intended foundation piles can support 1-6 TSF. Figure 2 below shows a soil map of the site.

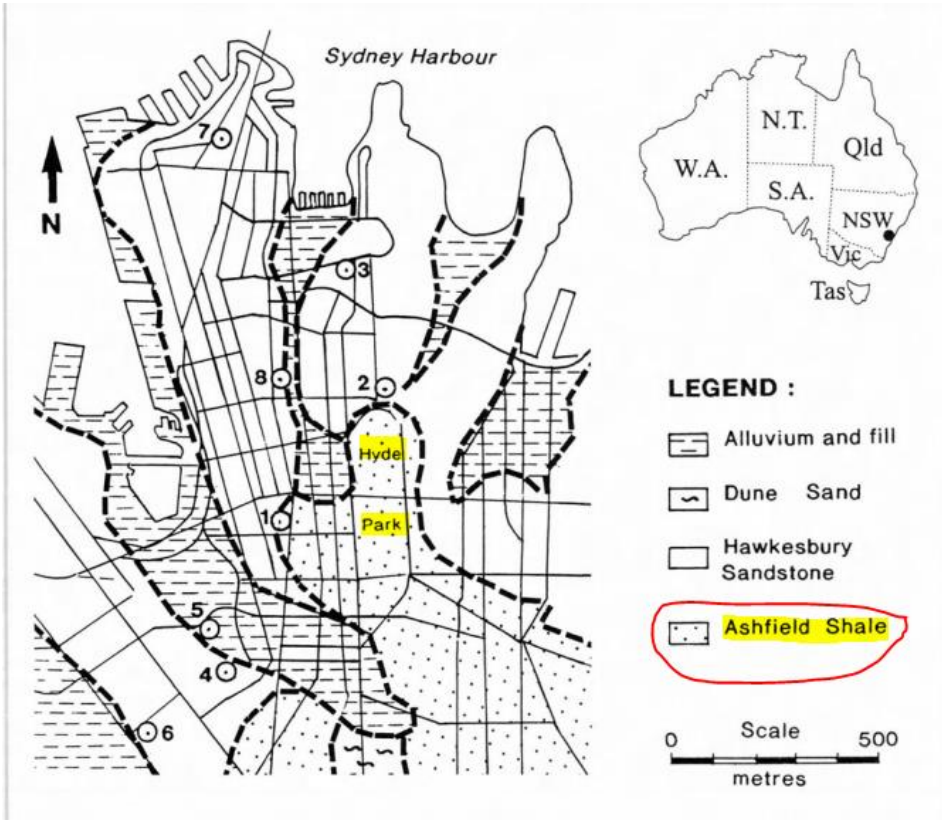


Figure 2: Soil Map (Lawrie, 1999)

Northeastern USA, our building code is the 2015 International Building Code (2015 IBC) but in New South Wales, Australia they use National Construction Code 2019 (NCC 2019).

Originally, we had four types of structural systems in mind: a steel frame, a wood frame, a precast concrete system, and a hybrid steel and wood frame system. We were leaning towards a hybrid wood timber and steel frame system for our building, but due to long spans and high loadings. We were forced to seek other options. Then we made the design choice to go with a steel frame over precast concrete because the transportation to the job may prolong the project timeline, the manufacturing of each member, and difficulty if the building were to ever go through modifications or expansions. Some of the reasons why we chose a steel frame system are recyclability, resilience, and design freedoms. A growing concern for the construction industry is the carbon footprint and reusability of the construction materials used in buildings. Today, most steel used in buildings is 98% recycled from other steel products. Recycling steel reduces the carbon footprint, but steel still has a large carbon footprint due to melting the steel down to make different members. Another advantage of steel is the resilience of the building structure. Steel is a non-combustion building material, so the members will not burn, although they need to be fireproofed to prevent them from buckling in a fire. Along with fires, steel is flexible enough to withstand catastrophic failure due to earthquakes. Steel also provides freedom in the design of buildings due to its strength. There are many options for steel members, which allow for fewer support columns or beams for support allowing the building to be more open.

Next, we started sizing members. Beginning with joists, we did a calculation by hand for one joist then we created an Excel spreadsheet to plug in the members characteristics and use the moment (calculated from the spreadsheet) to pick our first trial size by plugging the moment and braced length (Lb) into the Steel Solutions Center Beam Calculator. Then we would add the self-weight of the member in and recheck moment, then shear and deflection. If the member did not pass, we would then repick and try again. We also made a few design choices, which were to ignore the self-weight of the joists when designing beams to simplify the design process. We decided that the joists were strong enough to count as lateral bracing for columns. We used a K factor of 1.0 for the initial sizing of columns. Our framing system would best be classified as an ordinary braced frame even though we have minimal lateral bracing and some fixed connection because the minimal lateral bracing is sufficient for what the building will encounter. There are fixed connections because some of our beams would have had to be 30 inches deep or more if they were simply supported. Changing them to being fixed allows for the beam to be much shallower. In figure 3 and 4 below shows a simplified of member sizing spreadsheets.

Beam Name	Length (ft)	Vu (K)	Moment (K-ft)	Deflection (IN)	Beam Size
A1-B1	27	42.16	281.9	1.1	W21X44
B1-C1	42	61.69	643.5	1.8	W27X84
C1-D1	32.4	49.15	397	1.6	W21X55
D.9 11-F.2 11	56	147.9	1380.4	1.0	W24X176
M2.4-O2.4	37.33	102.49	637.6	0.7	W18X97
A5-B5	26.92	40.08	269.7	1.2	W21X44
B.1 9-D9	48.25	30.48	367.71	2.4	W24X68
G.3 7-I.2 7	50.58	76.78	647.2	1.4	W24X68

Figure 3: Simplified Beam Sizing Spreadsheet

Column Name	Length (ft)	Load (Kips)	Column Size
A-1	24	53.0	W8X31
A-2	24	101.2	W8X31
B-4	36	374.4	W10X45
B-5	36	411.7	W8X48
D-3	36	426.8	W8X48
D-4	36	355.7	W8X40
D.9-10	36	514.3	W12X53
E-4	36	458.9	W10X49
I.7-8	36	338.3	W10X39
J-1.2	36	230.3	W8X31

Figure 4: Simplified Column Sizing Spreadsheet

Overall, we have completed about 90% of the project but there are still some things that need to be taken care of such as designing the foundation which we have decided on piles, a life cycle-cost analysis, carbon footprint analysis, beam/column calculations, size the metal decking, and a few miscellaneous items.