
Letter of Transmittal

May 8, 2023

Professor Ronald Ziemian and Professor Alomir Favero
Project Executives
Senior Design Advisors, LLC.
701 Moore Avenue
Lewisburg, PA 17837

Dear Professor Ziemian and Professor Favero:

This report summarizes the analysis of the feasibility study of Bucknell University's new Bucknell West Apartments and the comparison of an alternative design. The Bucknell West Apartments are located on the west side of Route 15 from Bucknell University's campus, which is located at One Dent Drive, Lewisburg, Pennsylvania. This report has been prepared for Bucknell University in response to your request on August 25, 2022.

This report first provides how JGMA Design and Construction reached an eight-story design alternative to the current Bucknell West plan. In short, our steel structure building will most likely be less expensive and help Bucknell reach a net zero carbon neutral goal by taking advantage of more greenspace, geothermal heating, a green roof, and a greywater recovery system and other key items found in the element analysis.. Furthermore, we estimate that the project will be able to become profitable to Bucknell after 23 years of its construction. The building will also provide extra rooms and a large community space for students to take advantage of. Therefore we recommend that the University follows this plan and begins construction on the eight story, single structure.

Thank you for your time and consideration, and please do not hesitate to contact Mike Devlin (570) 577-1720 with any questions.

Sincerely,

JGMA Design and Construction

Mike Devlin

Mike Devlin

Graham Allardyce

Graham Allardyce

Andrew Matton

Andrew Matton

Jonathan Stiefel

Jonathan Stiefel

Enclosure: Conceptual Design Report Multi-Story Residential Building Bucknell University

**FINAL DESIGN REPORT
MULTI-STORY RESIDENTIAL BUILDING
BUCKNELL UNIVERSITY**

May 8, 2023

Submitted to:

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Prepared by:

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Executive Summary

Bucknell University currently plans to renovate the Bucknell West student residences, known as the Mods, into four apartment-style complexes, similar to the South Campus apartments. However, JGMA Design and Construction has been tasked to find, evaluate, and design alternative plans for the renovation that improve upon sustainability and the cost of the project. The following report thoroughly describes the project objectives. Criteria and constraints were identified, of which the most important are cost effectiveness and consideration of Bucknell University's goal for carbon neutrality by 2030. The new residential building must also be ready by the Fall semester of 2024 to avoid a sustained loss of campus housing. The team assessed the construction of a multi-story building for the Bucknell West Renovation with two main alternatives: a four-story building with a large footprint and an eight-story building with a smaller footprint. Both alternatives were compared to the University's original plan in order to evaluate an improvement in sustainability and cost, and ultimately, the eight-story alternative was chosen through a weighted-ranked based decision matrix.

JGMA then developed architectural and structural layouts from which specific design elements and structural components were designed. The entire development features 286 total beds split into triple and quad apartment-style rooms in addition to common spaces, laundry rooms, an elevator, and a stairwell. The building utilizes a steel gravity frame with composite beams and moment connections, in addition to concrete slabs and shallow foundations. In order to resist lateral loading, a moment frame was designed. The structural steel members were designed using the Load and Resistance Factor Design approach with loadings specified by ASCE/ SEI 7-22 and meets the specifications outlined in the AISC Steel Construction Manual. The foundations were designed using information given to us from a set of boring logs. Using the General Bearing Capacity Equation, specifications from NAVFAC DM7-02, and Terzaghi and Peck's Method, the spread foundations were designed to not exceed the bearing capacity of the soil while maintaining a settlement of under 40 millimeters.

A cost estimate for the entire project was developed using RSMeans templates that were altered to consider specific design elements. The total projected construction cost is \$42,911,320, and an income analysis estimated that the project will break even after 23 years. Additionally, a project schedule was created to display the sequence and time to complete individual components across the entire project timeline, including structural components as well as interior and exterior finishing.

A sustainability analysis of the project was conducted to determine the environmental impacts associated with the construction of the structure. Specific elements with high impacts were identified, and alterations were found to improve sustainability.

1.0 INTRODUCTION

In recent years, Bucknell University has experienced a simultaneous need for a slight increase in bed capacity and an update to the Bucknell West residential units, known as “The Mods.” Built in the 1950s, the Bucknell West Mods have been a housing location for sophomores, juniors, and seniors. However, they have become outdated due to their discrepant style when compared to the rest of the campus, and they lack a common quad area. Bucknell has given the green light for a replacement development that will provide an eight bed increase in bed capacity, an improved standard of living for its residents, and additional recreational amenities. The current design features four three-story apartment-style residence halls that will feature the traditional Bucknell colonial brick aesthetic, recreational quad area, and features geothermal heating to reach the University’s goal of carbon neutrality by 2030. JGMA Design and Construction has been tasked with creating alternative designs that improve upon the efficiency and sustainability of the original plan, by combining the four buildings into one multi-story building and comparing its efficiency and sustainability to the original plan. Our report should help the University explore other options as they are designing future campus buildings.

1.1 Project Setting and Background

Bucknell University is a private liberal arts college located in Lewisburg, Pennsylvania, in between the west branch of the Susquehanna River and US Route 15. Bucknell’s campus is split by Route 15 with the majority of campus located on the east side and some student housing and athletic facilities located on the west side. This project is located across US Route 15 in Bucknell’s West Campus. These units currently house 272 sophomores, juniors, and seniors, and they can be seen by the “H” footprints in the bottom right portion of Figure 1.1. The area is located in East Buffalo Township in Union County. According to the East Buffalo Township Zoning Map, Figure 1.2, this location is within zoning district B-U (for Bucknell University).

According to Bucknell’s plans, the new residential complex to be built will have four apartments that can house 70 students each, combining to house 280 students in total. (Ferlazzo, 2022). Bucknell’s plan for the layout of the four apartment buildings will be similar to those of the South Campus Apartments, with apartments of various sizes and configurations that have single bedrooms with a shared kitchen and common space. The four buildings will be the border for a recreational quadrangle space, which will meet students’ desires for more outdoor spaces. JGMA Design and Construction is creating a design that will replace the current plans for the new West Campus Apartments. This design will be a single, multi-story residential building with common areas on the ground floor. The building needs to accommodate the same number of students as the four apartment buildings.

The new campus residency would remain close to campus locations such as the athletic facilities, the art barn, and the golf course. This advantageous location would encourage students to visit these campus spots as it would act as a hub for those students living there. The vicinity to these campus spots is seen in Figure 1.1. Funded by University funds and donations as

referenced by the campus master plan, (Bucknell Master Campus Plan, 2017), the renovated Bucknell West will breathe life into this outdated part of campus. The building will also act towards the university's carbon neutral goal by implementing several environmental benefits that will help reduce the footprint of the project.

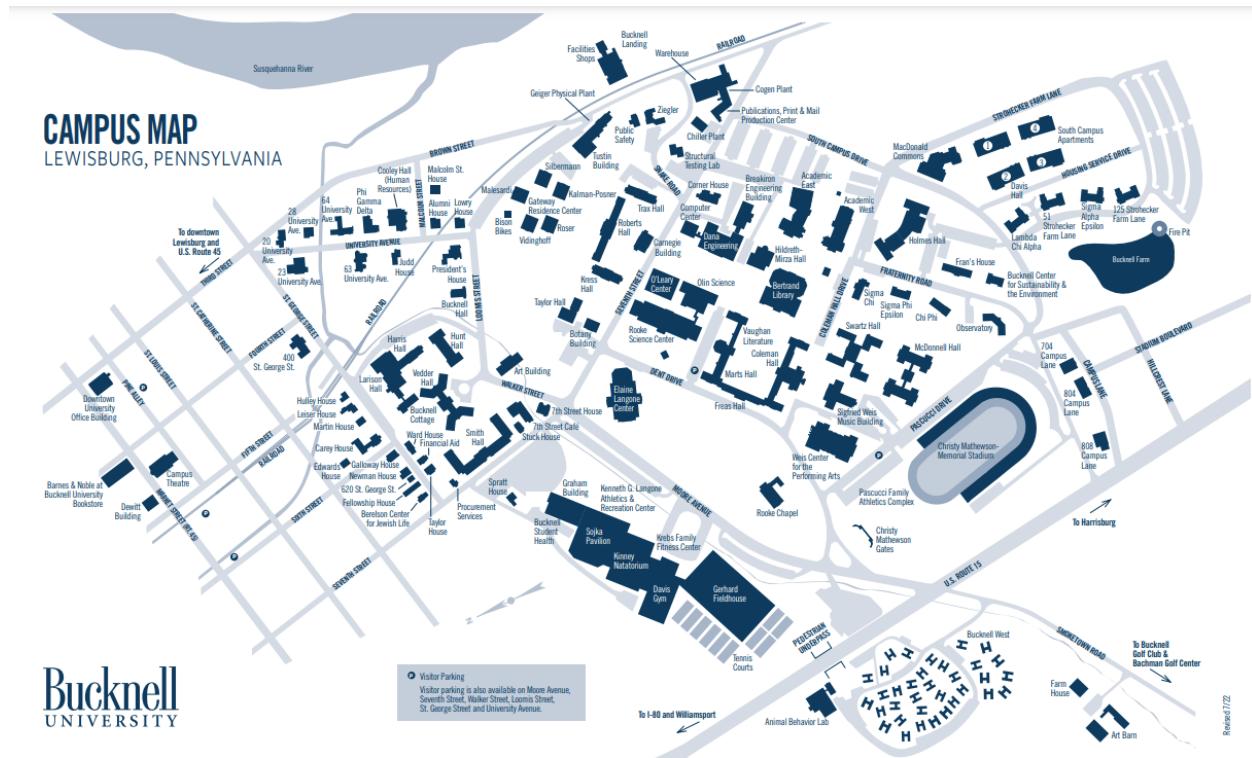


Figure 1.1: Location of project site on Bucknell University's Campus located at the bottom right of the image, with the "H" shaped footprint (Bucknell University, 2022).

1.2 Project Objectives

The initial two of the four proposed buildings are scheduled to be completed by the start of the 2023 academic year to simultaneously add more living spaces on campus and significantly revitalize Bucknell West. Additionally, the project will highlight several environmental features that will limit its environmental footprint as well as the landscaping footprint which will be discussed further in the report. JGMA Design and Construction has been tasked with evaluating any advantages to combining those four buildings into one multi-story building in order to compare for sustainability and cost. Ideally, this would be the more beneficial solution in terms of both environmental and economic aspects. In order to comprehensively evaluate our alternative solutions we aim to understand the project setting, site characteristics, local restrictions and constraints, and building codes. Once the underlying conditions have been made we can pursue the analysis of the different alternative design options to fully realize the best option. From there, the team can move forward with the design and early project management of

the project. JGMA will need this understanding to effectively evaluate each design as the better alternative under the criteria of sustainability and cost.

1.3 Report Organization

The report is organized in five sections. Section 2 introduces the site in more depth and explores the history of the area as well as its current characteristics. Section 3 details the governing constraints and criteria that set the guidelines and assessment of alternatives for the project. These constraints are broken down into different categories that are applicable to the project such as: environmental, geotechnical, structural, architectural, and construction. Section 4 describes the identification and consideration of the alternatives which discusses the three main alternatives that are being evaluated. Finally, Section 5 discusses the conceptual design of the project, which incorporates the overview of the project and the scope of work for the next phase.

2.0 SITE HISTORY AND CHARACTERISTICS

Most of the data will be retrieved from the Pennsylvania department of environmental protection, Bucknell facilities, and data compiled by JGMA Design and Construction. This section will detail the site's location, including the surface and subsurface conditions, general topography, and other important details. Using the information from this section the team will relate it to the design of the structural elements and to the significance of the project's presence on campus.

2.1 Location

The new Bucknell residence at the Bucknell West Mods, shown in Figure 1.2, falls under the zoning district B-U within East Buffalo Township, Union County, and it is on the west side of Route 15 from Bucknell's main campus. As a result, the design must follow Bucknell University's codes as well as the East Buffalo Township and Union County's codes as seen in Figure 2.1. The site has coordinates of latitude 40.95265 and longitude of -76.88988. For simplicity, we established a rectangular plot of land for building within the site location. From Google Maps, it can be found that the actual size of this plot is 100,674.55 ft² or 2.31 acres, as seen in Figure 2.2. Also, the site is constrained by the locations of the baseball and softball stadiums to the west, the soccer and field hockey fields to the north west, Route 15 to the east, and Miller Run which runs from the south to north east of Bucknell West. The site has a vehicle entrance located on the south east corner at the intersection of Smoketown Road and Bucknell West Drive. It also has a pedestrian tunnel under Route 15 to the north which serves as a pedestrian and bike entrance. Both entrances can be seen in Figure 2.3.

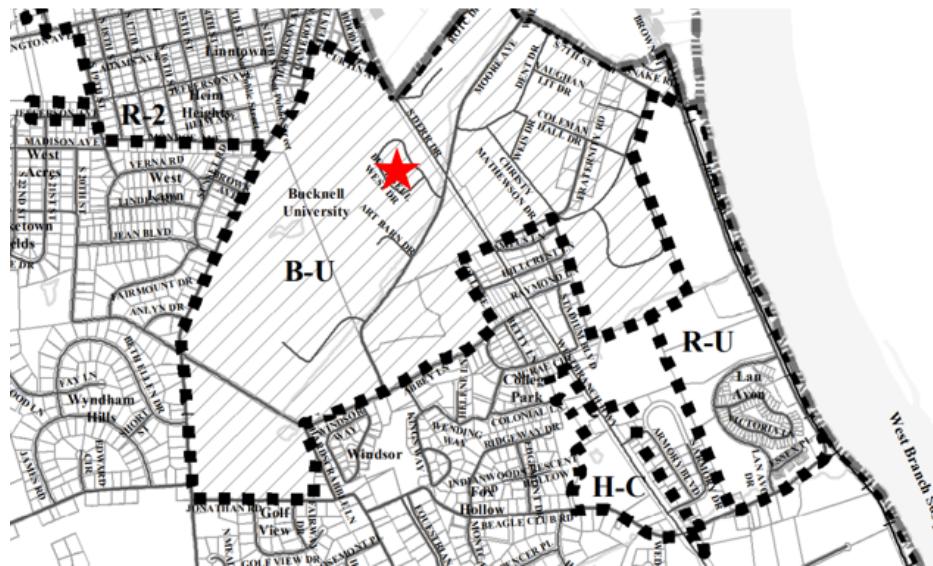


Figure 2.1: Portion of East Buffalo Township zoning map where the site is located (East Buffalo Township, 2022).

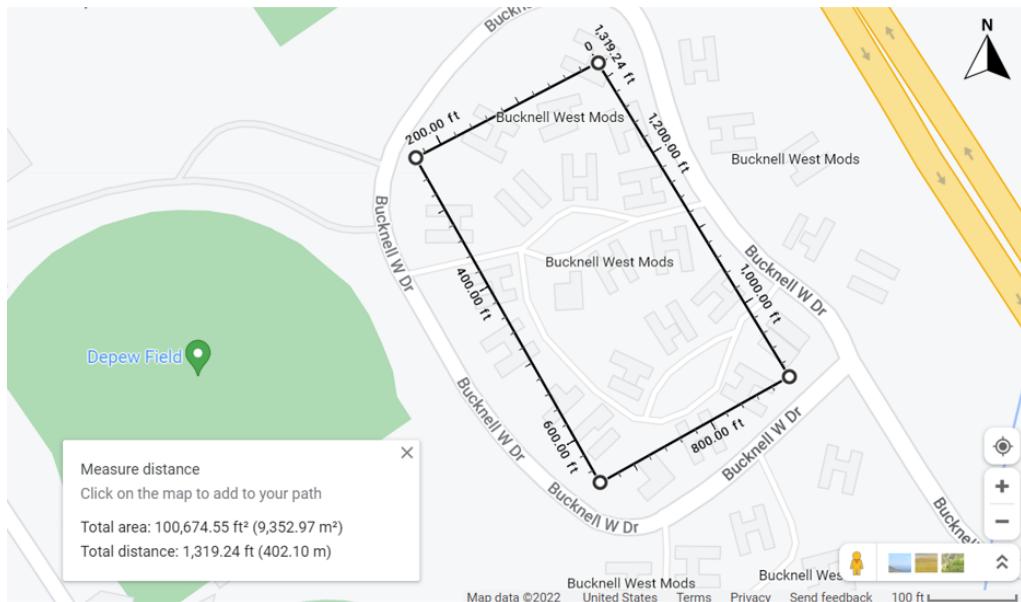


Figure 2.2: Selected plot of land for the site that includes total area and scale. Source: (Google, 2022).



Figure 2.3: Pedestrian entrance (left) and vehicle entrance (right) (Google, n.d.).

2.2 Site History

The site was acquired by the University in 1920 as part of its expansion plan. It was part of a 170-acre parcel of land bought from the George Barron Miller Farm (Dennis, 1996). From 1946-1947 construction began to create the Bucknell Village on this land with funds allocated from the Federal Public Housing Authority. The 16-building complex accommodated 50 apartment units for veterans and their families as seen in the left panel of Figure 2.4. This construction was built on a greenfield as there were no pre-existing buildings on the site. In 1961-1962 half of the units were demolished and reconditioned until Bucknell's next phase in 1972. After the deconstruction of Bucknell Village in June of 1972, 21 temporary buildings, each housing eight students, were built. Bucknell subsequently added 14 more units, adding 112 beds by 1985, and created what is now known as Bucknell West. Figure 2.4 displays a satellite shot of the current site on the right hand side. Since the site was no longer a greenfield, some earthwork was needed for completion, but the records could not be recovered.



(a)

(b)

Figure 2.4: (a) Photo of pre-existing site conditions, Bucknell Village circa 1965 (Dennis, 1996). (b) Satellite imagery of Bucknell West, current layout (Google, n.d.).

2.3 Surface Conditions

It is important to take into consideration all factors that affect the surface of the site. This may include but is not limited to topographic conditions, flood zones, wind conditions, and climatic conditions. The site was found to have a mild slope in the south to north direction as shown in Figure 2.6. According to the geotechnical report (F.T. Kitlinski & Associates, Inc., 2022), the elevations range from 485 to 493 within the building's footprint. The location of Miller Run to the site could be harmful to the geotechnical work; since Miller Run is adjacent to the site, it is important to analyze the flood zone. The Federal Emergency Management Agency (FEMA) characterizes building sites with a certain likelihood of flooding occurring, and they categorize the proposed site as Flood Zone X (FEMA, 2020). Flood Zone X is characterized as one of the safest flood zones as it is outside the 500-year floodplain, and it has the capability of being outside the 1000-year floodplain if a control system is in place. As a result, the risk of flooding is quite low, and it is of little concern for the project's feasibility. However, preventative measures will need to be in effect during construction to make sure that the stream is not being polluted by rainwater construction runoff.

It is also important to review the wind conditions on the site. According to the US Department of Energy, Lewisburg has an annual average wind speed of four meters per second, which equates to approximately nine miles per hour; a breakdown of the monthly average wind speed of the building can be found in Figure 2.7. During the winter months, there will be snowfall that must be taken into consideration. Lewisburg, which is located below Williamsport in the light blue section, has an average annual snowfall of 30 to 36 inches as seen in Figure 2.8.

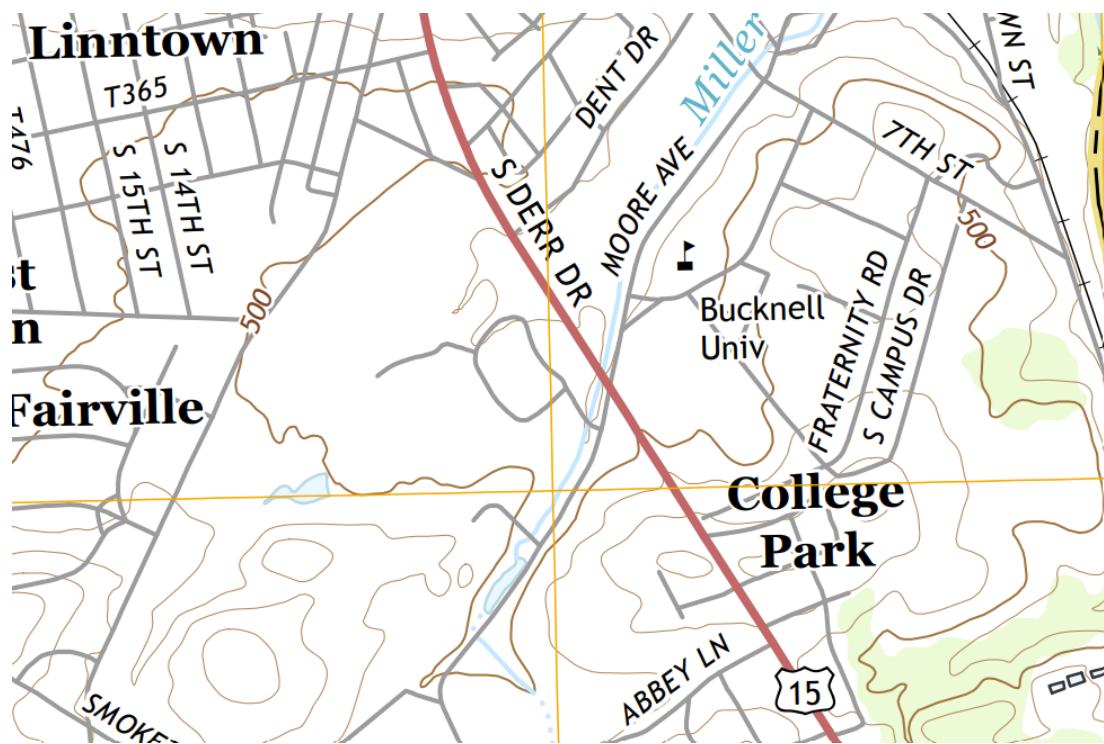


Figure 2.5: Topographic map of the site (*Union County GIS Viewer*).

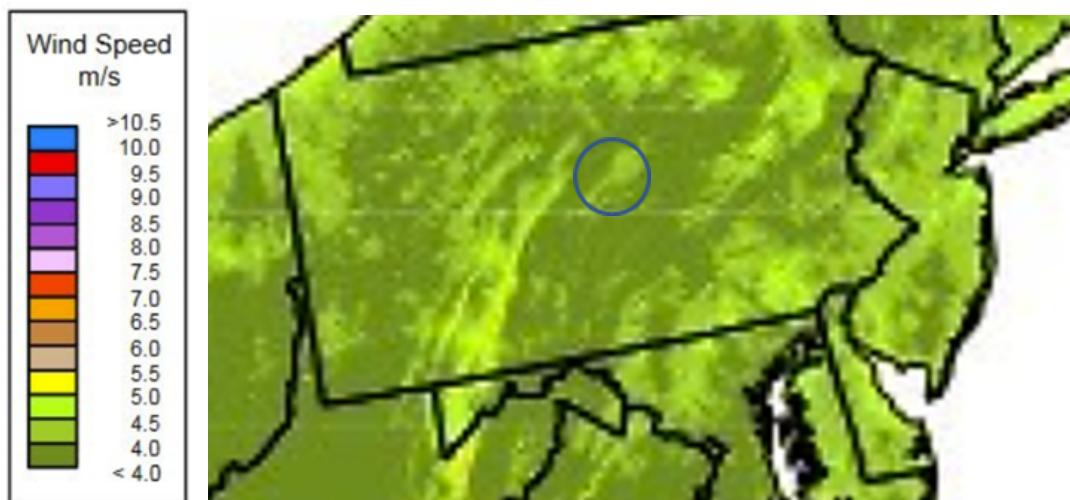


Figure 2.6: Annual average wind speed at 30 meters in Lewisburg, PA (*US Department of Energy, 2022*).

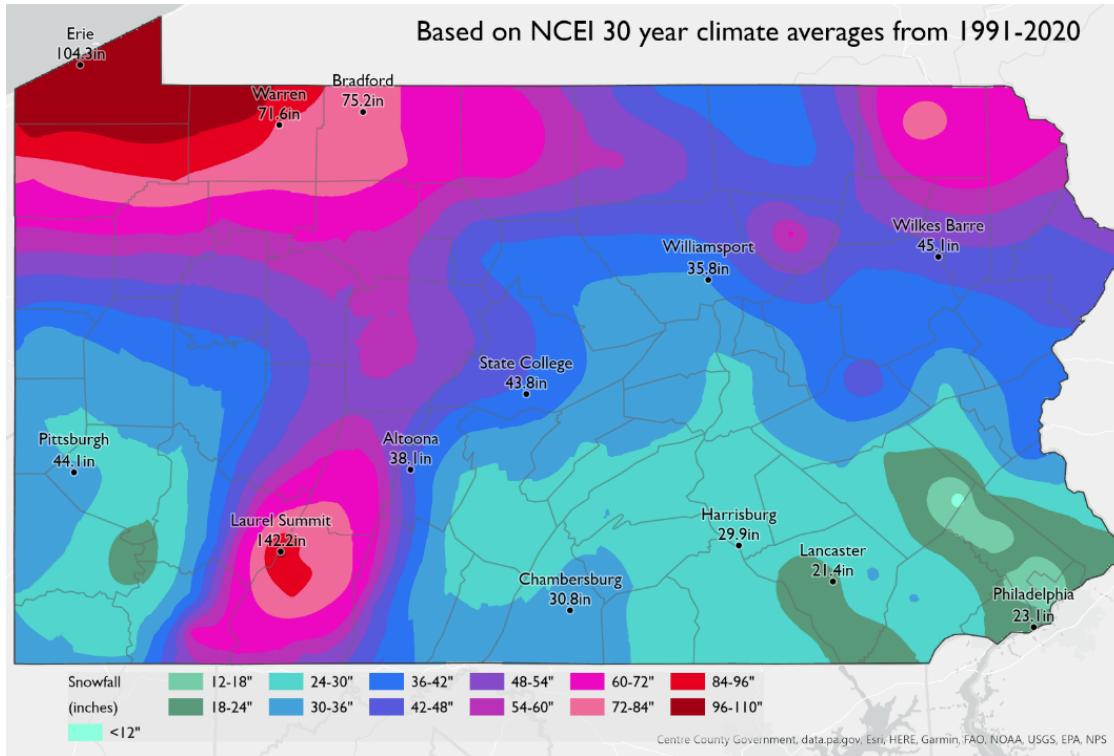


Figure 2.7: Average annual snowfall in Pennsylvania based on National Center for Environmental Information 30 year climate averages from 1991-2020 (NOAA, 2022.).

2.4 Subsurface Conditions

The subsurface composition and strength play a significant role in determining if the site is unsuitable for the construction of the residential building. The type of soil at the project will affect the type of foundation the building will have.

As a part of the subsurface investigation, JGMA collected historical testing on the Bucknell West site conducted by F.T. Kitlinski & Associates, Inc in March, 2022. Ten boring samples were collected from the project site. Two borings were drilled to 15 feet in the stormwater management area and eight borings drilled to 22 feet in the area of the proposed structure (boring locations shown in *Boring Location Plan* in Appendix A). The hollow stem auger method was used and terminated either at reaching the scheduled boring depth or at reaching bedrock. The standard penetration test (SPT) was conducted in accordance with American Society and Testing Materials (ASTM) 1586. During boring operations, groundwater level and presence was monitored through observations and can be found in *Appendix B*.

Additionally, F.T. Kitlinski & Associates, Inc conducted general soil classification tests on the soil retrieved from the borings. These tests were four grain size analyses, four Atterberg Limits determinations, and four moisture content determinations. Tests were conducted in

accordance with ASTM D422, D2216/D4138, D2434 respectively and the results can be found in *Appendix B*.

Structural borings, B-1 through B-10, were found to have a depth that ranges from eight feet to 23 feet with an average depth of 16 feet (F.T. Kitlinski & Associates, Inc., 2022). The overburden consisted mainly of decomposed bedrock, but fill material was encountered at locations of Boring Nos. B-4, B-7, and B-9 through B-12. The fill material consisted mainly of brown silty sand, sandy silt, and sandy clayey silt, but there were traces of cinders and organics. Further lab tests have shown that the larger portion of soil consists of clayey silts and silty clays with varying amounts of sand and fine gravel, while a smaller portion consists of silty sands and sandy silts with increased amounts of gravel (F.T. Kitlinski & Associates, Inc., 2022). Furthermore, bedrock was contacted at a range of elevation varying from 485 ft at Boring No. B-5 to 461.5 ft at Boring No. B-3. Another important consideration is the location of groundwater relative to the surface, and the drilling tools were monitored for signs of groundwater. The groundwater readings show that the phreatic surface, the location where pore water pressure is below atmospheric conditions, is over 20 feet below the surface.

Bucknell University is located in an area that is affected by rock formations creating the Appalachian Mountains. The geology of this area as with much of Pennsylvania contains folds in rock formations. Softer rocks of this area erode and become the valleys while stronger rock formations better resist erosion and become mountain ridges. Bucknell is built over the Keyser, Tonoloway, and Wills Creek formations. These formations contain shale, siltstone, shaley siltstone or limey shale, so this can be expected from boring logs.

3.0 GOVERNING CONSTRAINTS AND CRITERIA

3.1 General Criteria

This development is expected to provide apartment style housing for at least 280 students within a single freestanding structure. This structure is expected to be constructed without implementing significant changes to the existing road network, although there is no exact required plot size.

3.2 Environmental

3.2.1 Governing Agencies

Given that the site is within East Buffalo Township zoning ordinances, it is subject to the Union County Vision and Framework for the Future (EBT, 2022). This document provides a set of sustainability principles by which all new developments must abide. These principles include developing around existing communities, preserving rural resources, and conserving energy and fiscal resources. They work together to foster sustainable growth in the region while maintaining its culture and character. Given that the proposed apartment complex is a replacement of an existing on-campus housing complex, all reasonable alternatives should work under these principles.

Bucknell University has a number of sustainability committees, groups, and councils that work to ensure that all future developments are carried out with social and environmental sustainability in mind. These bodies are made up of board members, administrators, faculty, and students who work to provide strategy, research, and varying perspectives on how Bucknell can meet its sustainability goals. They advise with the intention of following Bucknell's sustainability journey roadmap, which will eventually be expanded on with the introduction of the sustainability plan. For instance, the campus is currently pursuing a goal to achieve carbon neutrality by 2030, and this goal will likely have more facets and requirements in the future. If any proposed alternatives cannot feasibly contribute to the university achieving the goals and expectations set by this plan, they may have to be altered significantly.

3.2.2 Measuring Impact

Preliminary sustainability analyses will be conducted for each alternative to gain a preliminary understanding of the environmental impact of alternatives. For instance, using LEED v4.1 Building Design and Construction (*USGBC, 2022*) swing credits, innovation credits, and location specific credits into account will provide insight towards the end certification of each alternative. Some examples include site management, energy use, and material life-cycle impact reduction. Given the ratings achieved by other recent on campus developments, LEED gold is expected and higher ratings are strongly encouraged.

3.3 Geotechnical

A geotechnical survey performed by F.T. Kitlinski & Associates, Inc. provides the team with key information regarding the design of the foundation. The auger penetrated all borings but only one bore made it the scheduled testing depth of 22 feet. The average boring depth was 16 feet before auger refusal occurred at bedrock. This bedrock is likely highly weathered bedrock due to the nature of the last 1.5 feet of material (F.T. Kitlinski & Associates, Inc., 2022).

As mentioned the fill material also contains varying amounts of cinders and organics, however should not have a significant effect on the structural supports and site development. The fill material in this region must be excavated and replaced with fresh structural fill material. This is the only region that was found to require structural fill replacement, however additional boring is necessary for verification.

The residual soil deposits found beneath the fill material created by in situ weathering of the underlying bedrock had thickness ranging from 8 feet at some locations to 22 feet at others and averages 12.7 feet over all borings taken. Additionally, no correlation was found between surface elevation and the thickness of weathered bedrock suggesting that the bedrock elevation has an undulating profile resulting from differential weathering.

3.4 Structural

3.4.1 Relevant Building Codes

East Buffalo Township (EBT) has designated this site as Bucknell University (B-U) land use according to the Zoning Map provided in the Code of Ordinances (EBT, 2022). This makes this development subject to the codes found in appendix A. Ordinance §407.5 is the most concerning of these codes given intentions to develop a single freestanding structure that would exceed the current building height limits. Amendments or waivers to this ordinance may be possible to acquire through petitioning the EBT.

3.4.2 Design Philosophy

This structure will be designed for superimposed dead loads (HVAC, plumbing, etc), self-weight, live loads, snow loads, rain and ice, wind, and seismic loads according to the material of the superstructure. A steel building will abide by ANSI/ AISC 360-16 *Specification for Structural Steel Building* (ANSI/ AISC, 2016). On the other hand, a concrete building will follow all guidelines outlined by American Concrete Institute (ACI) *Building Code Requirements for Structural Concrete* (American Concrete Institute, 2019). Factors of safety on these loads will be accounted for using the LRFD (Load and Resistance Factor Design) design philosophy. Given that the purpose of this project proposal is to build vertically, horizontal loads that act across the face of the building, wind loads primarily, will become increasingly more important to account for serviceability such as excessive deflections and shear and moment forces.

According to ASCE/ SEI 7-10, the site would be classified as Risk Category II which is any building not classified as agricultural storage, essential facilities, or buildings that can cause a substantial economic impact. As a result, Figure 3.1 should be used to determine the basic wind speed for design. The 2010 edition shows that the wind speed that is needed for design is 115 mph based on the region. This will need to be updated when a new edition of ASCE/ SEI 7-10 is acquired.

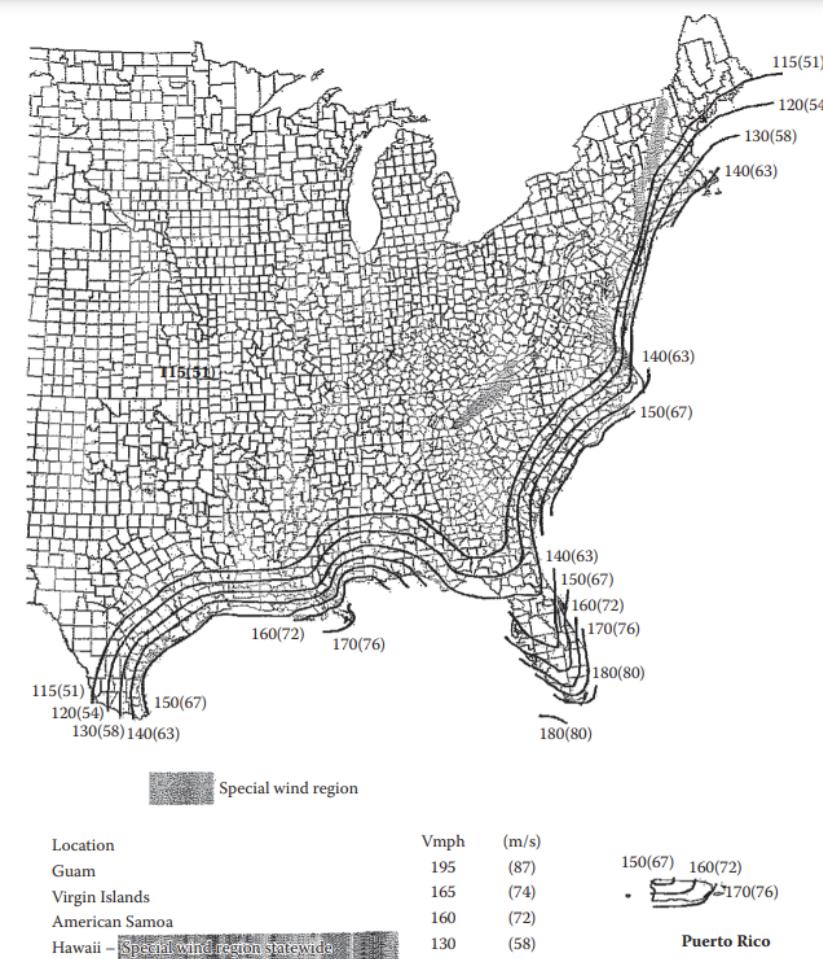


Figure 3.1: Basic wind speed for risk category II buildings (ASCE/SEI-7-10, 2010).

3.5 Architectural

3.5.1 Amenities

Given that this development is intended to be a significant improvement to the living experience in Bucknell West, there will be a raised standard for provided amenities. Each apartment is expected to have heat and air conditioning, single bedrooms, a small shared kitchen, and a living room. Several public lounge rooms and laundry facilities are also expected. Outdoor amenities include green space, seating, paths, bike storage, game tables, and volleyball or basketball courts.

For energy intensive amenities such as heating, exploration into high efficiency systems will be performed within basic architectural designs. For instance, building orientation and material choice, and heat systems could have an impact on the passive heating performance of a design, which would have substantial impacts on energy use and sustainability.

3.5.2 Access

This development is expected to comply with all standards outlined in the American Disability Act (ADA), featuring inclusions such as ramps, parking spaces, bathrooms, and elevators that ensure all are welcome. An important ADA compliance to follow is space allowance to allow those with wheelchairs and their occupants to move freely. According to ADA 224.2, a building containing between 201-300 residences is required to feature seven rooms that can accommodate wheelchair accessibility. This includes a minimum width for two wheelchairs to pass, which is 60 inches (ADA Compliance Directory, 2010). The space required for a wheelchair to make a 180-degree turn is a clear space of 60 inches diameter. The minimum clear floor or ground space required to accommodate a single, stationary wheelchair and occupant is 30 inches by 48 inches (ADA Compliance Directory, 2010). The current site location features a loop of parking spaces around the Mods giving first responders access around the entirety of the development.

3.6 Construction

3.6.1 Governing Constraints

The governing constraints of construction are in place to ensure that the safety, design, and the timeline of the project are maintained which is observed through several stakeholders. Many of these constraints are achieved through approvals by the university and permits from governing agencies, township, and the Union County conservation district. The university will approve the final design and the schedule to make sure it will reach the intention of the project and be put into use within the University's timeline. The township will approve that the project can undergo construction, excavation, and any road closures that are required for the project. Furthermore, the conservation district will provide final approval after it has been approved by the JGMA and the client for the different environmental, geotechnical, and water resources design elements before they can be constructed. Finally, testing and inspections from third parties as requested by the client to ensure acceptable work from all trades must be conducted.

Based on the soil, along with the nature of the proposed construction, the foundation system will not be required to extend to the bedrock, nor is the position of the bedrock such that it could be economically employed for foundation support. However, in some instances where the durable bedrock surface is positioned above foundation bearing level, it will be recommended that the rock be over-excavated and cushioned in order to reduce the effects of differential settlement (F.T. Kitlinski & Associates, Inc., 2022).

According to F.T. Kitlinski & Associates, the more granular residuum can safely support a unit load of 1,800 pounds per square foot, while the larger part of the residuum can safely support 1,500 pounds per square foot. This must be acknowledged prior to the design of the foundation towards any of the proposed alternatives.

3.6.2 *Safety*

Safety is one of the most important factors throughout the construction process as many people are working both on and near the site where they can be severely injured due to lack of compliance. The Occupational Safety and Health Administration (OSHA) governs the safety of projects and offers guidance to maintain the safety for all trades on the site. Using the 29 CFR 1926 Standard, OSHA provides several regulations and guidelines for the several trades on the jobsite (OSHA, 2022). The intent of OSHA is to prevent and reduce workplace incidents and will often provide inspections at the jobsite to ensure the site is complying with their guidelines. On the jobsite, basic requirements call for all on the jobsite to be equipped with basic personal protective equipment: including hard hats, gloves, eye protection, and closed toed shoes (US Department of Labor, n.d.). A major point of emphasis of OSHA is requirements regarding fall protection which are major sources of injuries and fatalities among construction workers. Fall protection must be supplied whenever a worker is six or more feet above a lower level (US Department of Labor, n.d.). Finally, the jobsite must be secured to prevent any unwelcome guests into the site which could lead to theft or injury. An incident would not only be detrimental due to the human cost but it could also cause a shutdown delaying the schedule.

3.6.3 *Timeline of the Project*

The most significant constraint that must be addressed during the construction phase is remaining within the timeline of the project. The Bucknell West plan notes that two of the buildings will be ready for Fall 2023 and the next two will be completed in the following Fall (Bucknell University). It is important to remain within the final Fall 2024 timeline to be consistent with the University's original plan.

4.0 IDENTIFICATION AND CONSIDERATION OF ALTERNATIVES

4.1 General

4.1.1 *Evaluation Techniques*

As the project's constraints have been thoroughly recognized the team can use them to evaluate the different alternatives to the University's original four building plan. Combining different studies, JGMA will be able to move forward with the strongest alternative.

Prior to exploring the multi-story alternatives, the University's original four building plan would be a do nothing alternative. This is used as a control to compare with the other alternatives. Each proposed alternative will be evaluated on cost and sustainability and will be viewed through several lenses, such as environmental, geotechnical, structural, architectural, and construction. After these evaluations have been completed, a decision matrix will be created to identify the alternative with the best overall performance. Each category will be evaluated and ranked comparatively based on two factors: sustainability and cost. However, the sustainability category has been given greater value with a weight factor of 2 compared to cost's weight factor of 1. This weighting ratio was determined based on the University's current long term plan to achieve net carbon neutrality by 2030. In a study exploring the economic challenge of

sustainable construction, the authors claim that sustainable construction is obtained through higher capital costs that are returned in the long term (Zhou, L., & Lowe, D. J. 2003, September). This means that a high upfront cost of the project can be paid off by offsetting sustainability.

4.1.2 Material Choice

When designing the core and shell of the building JGMA Construction must select the material with which the building will be constructed. The two leading materials in the industry are steel and concrete. To select either, they must be compared through sustainability, cost, and ease of construction. A study conducted by Angela Guggemos and Arpad Horvath compared the environmental effects of steel and concrete framed buildings. Within the study the authors conducted a life cycle analysis during the construction phase of two and four story buildings. The energy use, carbon monoxide (CO), nitrogen dioxide (NO₂), particulate matter, sulfur dioxide (SO₂), and hydrocarbon emissions were measured to compare the two buildings (Guggemos, A. A., & Horvath, A., 2005), and based on these impacts, the authors found that both materials had similar environmental impacts that do not give either material the edge in sustainability.

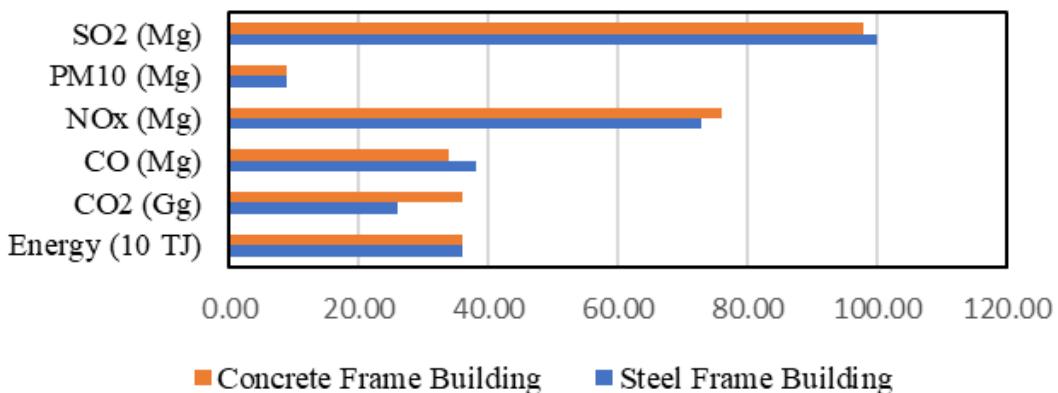


Figure 4.1: Sustainability comparison of Steel and Concrete Buildings. Source: (Guggemos, A. A., & Horvath, 2005)

The comparative values shown in Figure 4.1 display that the construction phase impact of either material has no significant difference on the sustainability of the project. JGMA aims to complete this by incorporating sustainable energy use, and mechanical, electrical, and plumbing systems of the building. When evaluating the cost of each material, concrete is a lower cost material, and requires less specialized labor while steel saves time and money through a fast erection time that is handy for schedules heavily constrained by time (Natsoulis, N. 2022). The time saved through the steel erection would allow a steel building to be completed faster than the concrete building, assuming they remain on schedule.

JGMA acknowledges the advantages of the quick installation of steel and its high strength to weight ratio, making it the perfect material for the superstructure. A steel shell design was chosen due to our team's strengths and confidence through the steel design classes taken at Bucknell. We believe that it will make for a more exciting and thoroughly executed project for the upcoming spring semester.

4.1.3 Identification

JGMA arrived at two different alternatives to the University's plans; the first being a tall eight-story building with a small footprint and the second being a four-story building with a wide footprint. Both buildings will have a total area of 120,000 square feet, but feature different layouts, which will be described in the architectural section. We are tasked with determining which alternative would be more effective regarding the sustainability efficiency compared to the four separate three-story buildings, while maintaining cost and constructability.

4.2 Architectural

The original plan for the Bucknell West Apartments consists of four separate buildings. Each building is to have three stories in height and no basement levels, only a crawlspace (F.T. Kitlinski & Associates, Inc., 2022). According to the proposed construction section of the geotechnical report, the four residential buildings' footprints will vary from 6,750 square feet to 12,000 square feet. The other two alternatives would have different footprints. The eight-story, more slender building would have a footprint of 15,000 square feet, while the four-story, wider building would have a footprint of 30,000 square feet. As seen in Figure 4.1, these footprints were determined using the size of each apartment, the amount of apartments on each floor, and the assumption that 80 percent of the entire floor plan corresponds to apartments. Based on the design of the current South Campus Apartments on Bucknell's campus, each apartment will have an area of 1,200 square feet and house four students. The eight-story, slender footprint building will have 10 apartments on each floor ranging from the second to the eighth floor with the first floor only being allotted for amenities. The four-story, wide footprint building will have 20 apartments ranging from floors two through four, while the first floor will only have 10 apartments to allow for an amenity space.

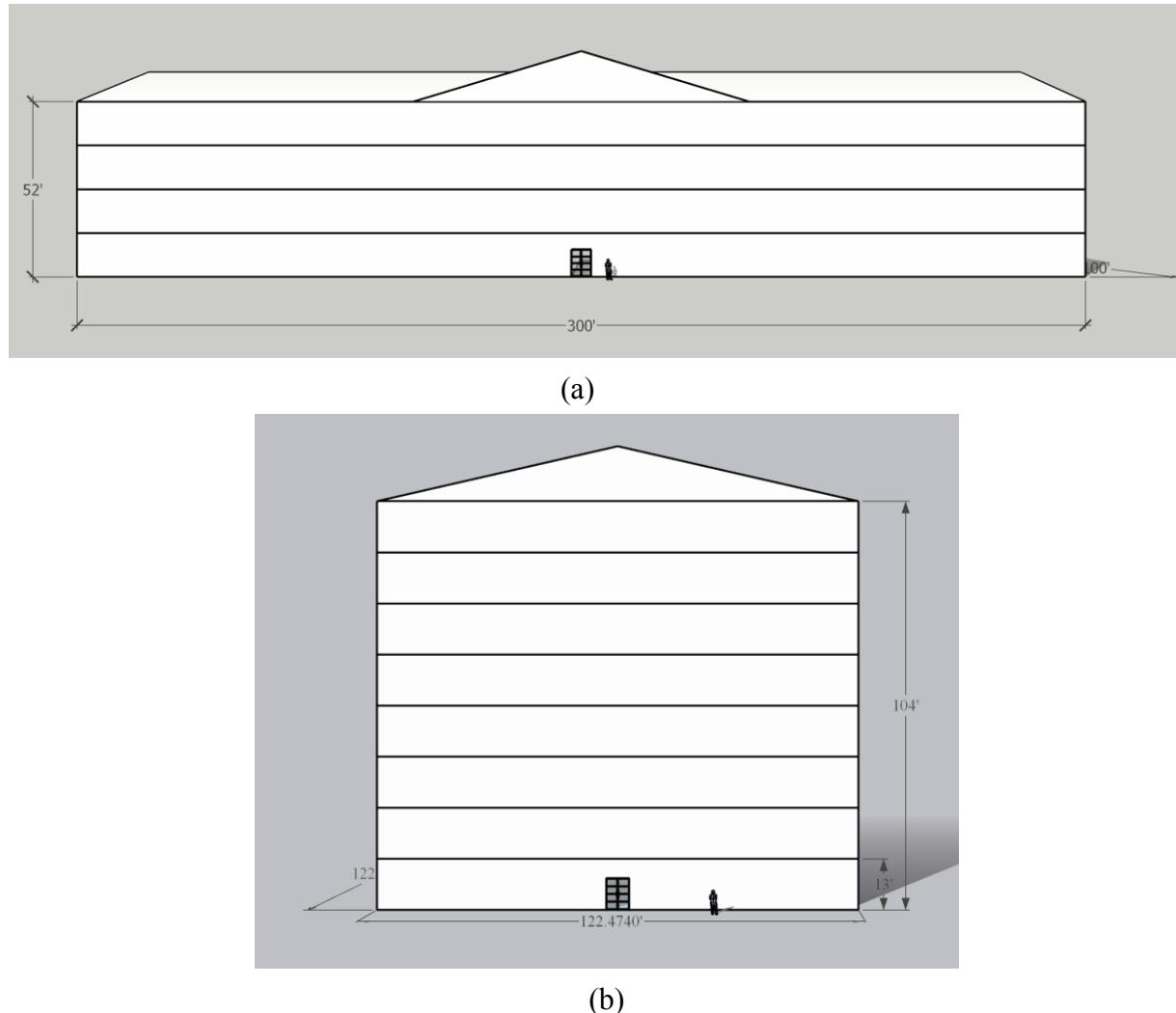


Figure 4.2: (a) Model of the four story, wide footprint alternative. (b) Model of the eight story, slender footprint alternative.

4.3 Environmental

To create a reasonable approximation of each alternative's environmental impacts, a preliminary life cycle assessment was created with a program called EPIC (Early Phase Integrated Carbon). EPIC takes a variety of inputs such as building geometry, structure material, use category, and site characteristics to calculate a baseline of categorized impact values based on calculations, projections, and assumptions. Reductions can then be applied to this baseline

with changes such as reused or low carbon building materials, longer refurbishment periods, renewable energy use, and increases in high carbon storage plantings. For each alternative, the same reduction was applied to gain a general understanding of how responsive each alternative is to considerable efforts to improve sustainability. EPIC is capable of generating a variety of plots to visualize this data. Figure 4.2 shows plots of the net tonnes of CO₂ emitted across multiple categories for a 30 year life cycle for both proposed alternatives.

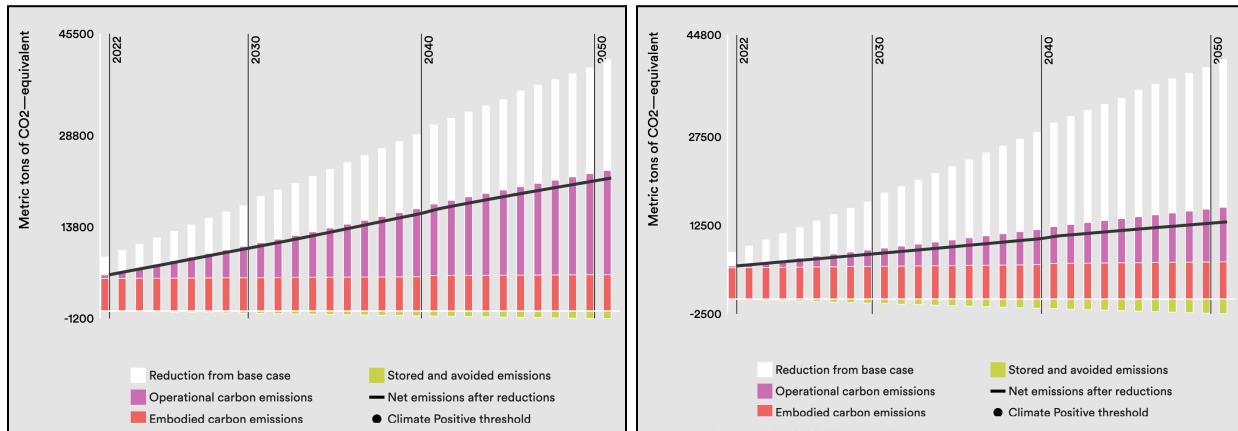


Figure 4.3: Sustainability profile for four-story (left) and eight-story (right) across life cycle

It can be seen that the eight-story alternative benefits much more significantly from the reduction than the four-story. This is largely due to its smaller footprint providing benefits within calculations for operational emissions and stored emissions. Table 4.1 summarizes the net emissions for the base case and reduction for both proposed alternatives and Bucknell's original design.

Table 4.1: Summary of Net CO₂ profile

Alternative	Net Tons CO ₂ Equivalent Emissions	
	Base	Reduced
Original	31800	17400
Single Four-Story	40100	21800
Single Eight-Story	38300	13100

This clearly indicates that the eight-story alternative has the highest potential to benefit from substantial use of sustainable design techniques, making it the most viable alternative from an environmental sustainability perspective. The original proposal was the second most viable, while the proposed four-story alternative lacked significantly.

4.4 Geotechnical

All of the alternatives introduced will have geotechnical consequences that will need to be analyzed to determine which alternative would be the best. In general, there are two different types of foundations used when designing buildings: deep and shallow. Within these categories, however, there are different ways to complete the same goal. It is important to understand the subsurface of the site in order to choose the most appropriate and efficient foundation. According to the geotechnical report done by F.T. Kitlinski & Associates on the proposed Bucknell West site, “employing deep foundation systems for [the original, four-building design] support is not considered necessary or economical” (F.T. Kitlinski & Associates, Inc., 2022). This means that a shallow foundation design will suffice. This is due to the composition of the soil and the fact that the proposed structures will be moderately loaded. For the single, four-story alternative, the foundation design would be similar because the loads are more dispersed over the soil. They are not concentrated over a small area, so the soil bearing capacity would not be breached. As a result, a shallow foundation design would suffice. The same can be determined for the single, eight-story alternative. Since the loads would be more concentrated in a smaller area, the concrete footing would need to be larger based on the net allowable soil pressure.

The different foundation types, deep and shallow, have associated environmental impacts. It is important to take into consideration the sustainability aspects of each foundation to help come to a decision. The four single-story buildings and single four-story building both would have a shallow foundation but large footprints. This would impact sustainability as more land is taken up for the building. Likewise, the single eight story building would still have a shallow foundation, but the smaller footprint of the building would result in lower land use. However, the footings would likely need more concrete as they would need to be larger to not exceed the soil bearing capacity and not excessively settle. The larger footings could impact sustainability, but it is common to use alternative cementitious materials in the concrete to help offset the sustainability impacts. The amount of materials needed would also differ depending on the foundation type, which has sustainability implications. However, it is difficult to compare the materials needed between the different types of foundations.

The costs associated for each foundation type and alternative is important to take into consideration when deciding which alternative to select. Typically, shallow foundations are more cost effective. According to Sivakugan, when compared to shallow foundations, deep foundations “cost more and require specialized equipment and skill” (Sivakugan 2021).

4.5 Structural

When deciding whether to construct a four story building versus an eight story building, the primary structural factor is how the height difference will affect the cost of construction and materials. A ranking can then be determined based on the cost of each alternative with consideration of the height and number of buildings. A more in depth cost analysis is performed in the next section using RS Means.

The structural system of a high-rise building often has a more pronounced effect than a lowrise building on the total building cost and the architecture. High-rise design comes into play

when a structure's slender nature makes it dynamically sensitive to lateral loads, such that a premium is associated with its lateral system development (John Zils and John Viise 2003). In addition to a more robust lateral system design, the high-rise will require more materials to support loads. Constructing a high rise will ultimately require more materials and a more costly lateral system.

4.6 Construction

Evaluating the sustainability through the lens of construction of each design, the team used EPIC to analyze the embodied energy of the construction of each alternative design.

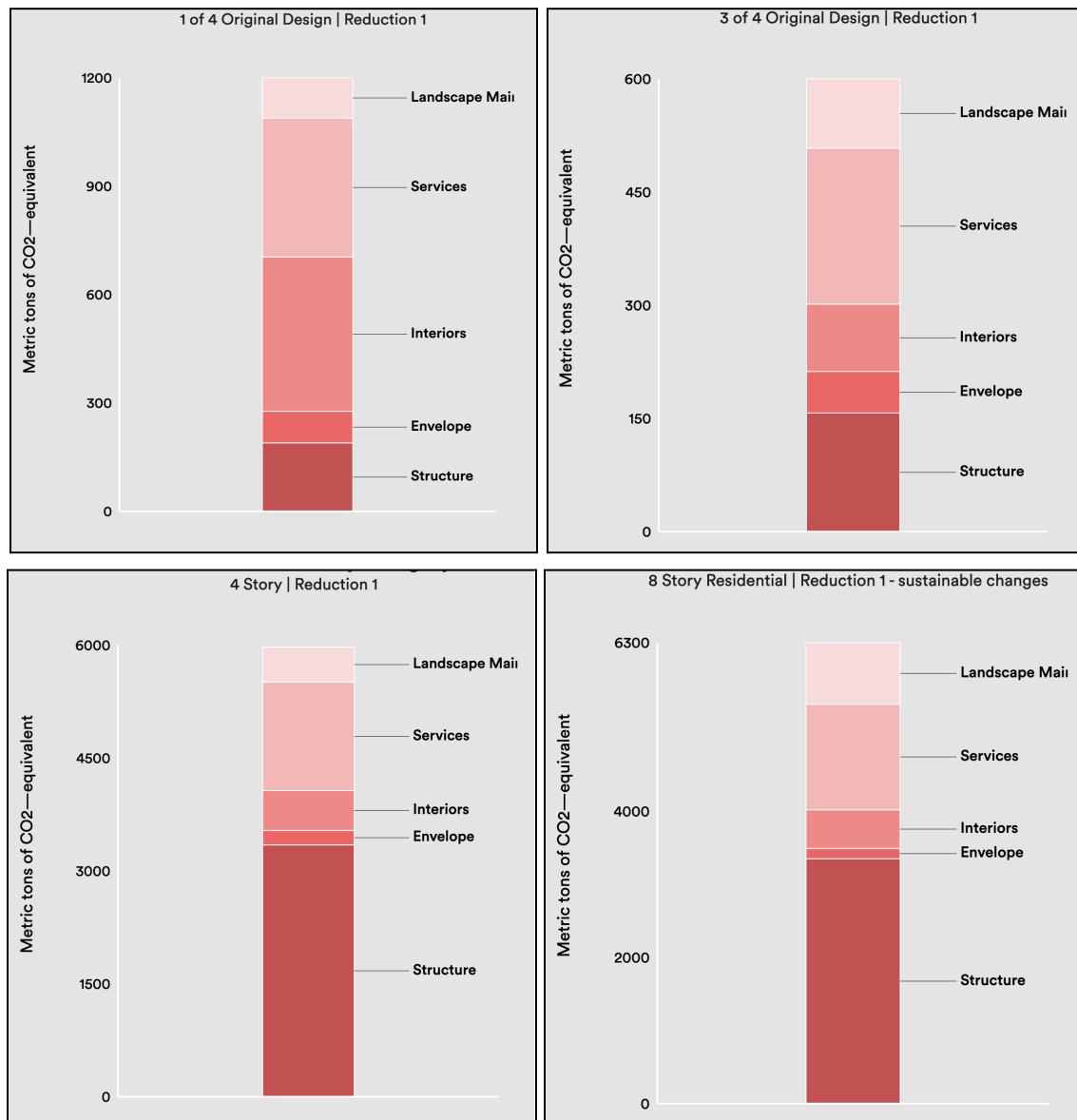


Figure 4.4: Embodied Carbon for the Original Building Plan, Four Story, and Eight Story Building (EPIC, n.d.)

The University's original plan that consists of four buildings includes two differently sized buildings, two smaller and two larger ones. The tonnes of CO₂ equivalent for these buildings are reflected by the top two figures of Figure 4.4. The four story alternative design is represented by the figure on the bottom left and the eight story alternative design is represented by the figure on the bottom right of Figure 4.4. An evaluation of the data shown in Figure 4.4 both of the proposed alternatives are very comparable in embodied carbon, the original proposal does feature much lower emissions, at around 3,600 tonnes compared to around 6,300 and 6,000 tonnes. The original design has the best embodied energy due to the wooden structure of the buildings, yet, there is little impact to the envelope, interiors, systems, and landscape maintenance of the design. However, the much smaller footprint on the eight-story alternative could allow for much more green space and natural high carbon-storage plantings to counteract embodied emissions. Finally, the increased available green space added from the stacked designs allow for future reduction of CO₂ equivalent emissions.

Evaluating the approximate cost JGMA Design and Construction used the square foot cost derived from RS Means (Charest, 2016). RS uses the national averages then interpolates the cost based off of total square feet of the project while also including perimeter adjustments, story height adjustments, and common additives. When comparing each building, the team chose the green commercial college dormitory tables, using the 2-3 story table for the original university plan and the 4-8 story table for the alternative stacked buildings. To maintain a similar frame of reference the University's original plan was estimated using a steel frame. Finally, major assumptions were made for consistency and simplification due to the preliminary design phase. First, the total square footage of each project is 120,000 ft². Second, the perimeter of each building was determined by finding the square root of the square footage of the building divided by how many floors each building will have. This value will be multiplied by four assuming the building is a square to find the perimeter. Finally, it will be assumed each building will have a story height of 14 feet. Once these assumptions are made, a simple preliminary estimate can be made and evaluated for each project.

Table 4.2: Cost per Square Foot from RS Means (Charest, 2016)

	Cost per Square Foot	Required Perimeter Adjustment Cost per Square Foot	Adjust for Story Height per Square Foot	Cost

Original 4 Building 3 Story Plan	\$229.37	+\$21.26	+\$4.77	\$30,279,067
4 Story Steel Alternative	\$226.06	-\$5.11	+\$3.00	\$26,873,742
8 Story Steel Alternative	\$226.06	+\$2.05	+\$3.00	\$27,733,312

Our early estimates show that the original project is the most expensive, followed by the eight story alternative, followed by the four story alternative using RS means (Charest, 2016). It is important to note that this is a preliminary estimate as a frame of reference rather than an accurate cost estimate as additives were ignored as well as future additions the team would like to add.. As each value was calculated using the same method we evaluated each project against each other. With that, the 4 story alternative was the most cost effective, followed by the 8 story alternative, and finally the original University plan. However, the alternatives were very close while very

4.7 Summary

We weighted the decision matrix to favor the better building in terms of sustainability to complete the university's goal of neutral carbon by 2030. However, we did allow cost to play a role in the decision in efforts to protect the financial feasibility of the project. Ultimately, the eight story alternative design scored the best in terms of CO₂-equivalent, followed by the original design then the four-story alternative design. Next, the four-story alternative was deemed the most cost effective followed by the eight story alternative and finally the original university plan. The resulting scores favored the eight story alternative based on our decision matrix in Table 4.2. Within the ranked based matrix the best design scored a three and the worst design scored a one for each respective category. Our team will move forward with designing the eight story alternative and describe the scope for the next phase of our project in the following section.

As seen in the decision matrix in Table 4.3, the eight story alternative was ranked the most sustainable based on its high performance in the environmental category due to its small footprint and potential for high carbon storage. The original proposal was ranked second due to its wood frame construction, and the four-story alternative was ranked last due to its substantial footprint.

The four-story alternative was ranked best on cost, due to it being the most cost effective within the rough RS Means preliminary estimate, which was used as a frame of reference. The eight- story alternative was ranked second based while less than a million more, and the original plan came in at about 3 million more for about 30 million dollars.

Table 4.3: Decision Matrix

	Sustainability	Cost	Total
Weighting	2	1	
Original Plan	2	1	5
Four Story Alternative	1	3	5
Eight Story Alternative	3	2	8

Overall, the eight-story alternative performed best overall considering its performance against other alternatives in each category as well as the weighting of the two main factors, with a total score of 8 compared to 5 for the other alternatives. We determined that the nearly \$900,000 more expensive alternative would be paid off through the more efficient sustainability of the project.

5.0 CONCEPTUAL DESIGN

5.1 Overview

After careful consideration of the three alternatives, the University's original four building plan, the eight story high-rise, and the four story low-rise, JGMA identified a steel eight-story building to be most sustainable and remained a cost and timely effective alternative. An example mock up of the building can be found in Figure 5.1. Various components of the design work were addressed in a detailed design including conceptual architectural layouts of the eight-story high rise, design of the steel superstructure, design of the foundation, cost estimates, and construction scheduling.

5.2 Design Scope of Work

The following subsections describe the scope of work for each trade and the necessary operations that JGMA Design and Construction completed.

5.2.1 Architectural

JGMA produced a 3D model of a basic exterior design that features basic architectural elements as well as an 2D example floor plan produced in AutoCad. Additionally, a comprehensive list of specific architectural elements has been provided, with notes on their functionality as well as any contributions or setbacks to sustainability or cost. Example categories that these elements fall under would be building design elements, landscaping, building operating systems, apartment amenities, and common amenities.

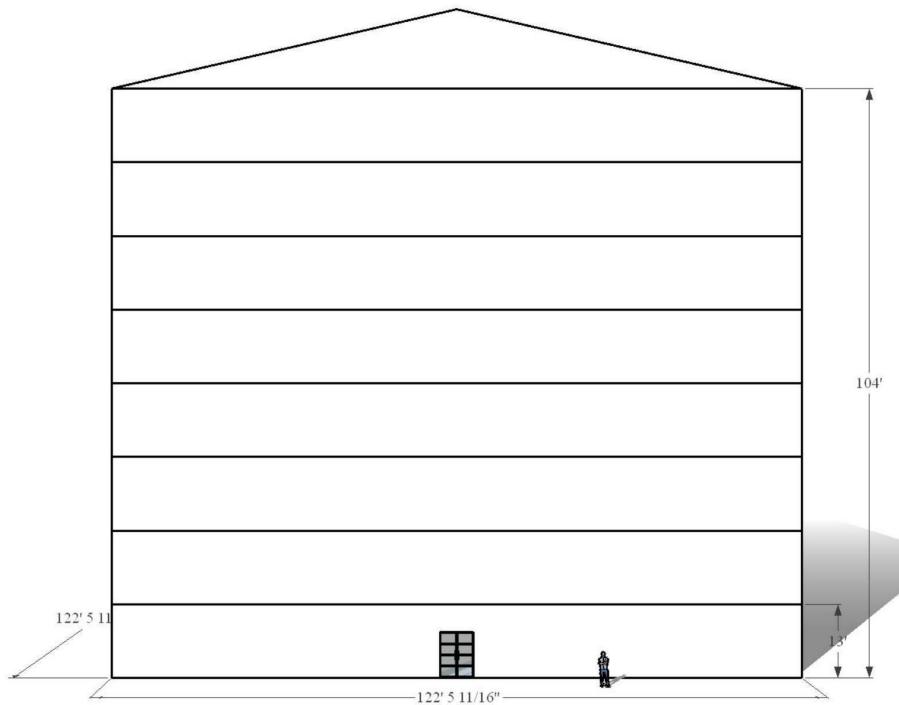


Figure 5.1: Single building eight-story alternative

5.2.2 *Superstructure*

Based on the analysis of the alternatives, JGMA has decided to continue the project as an eight-story, small footprint steel building. We utilized ASCE 7-22 to find the loads associated for each apartment. We needed to use the data on the wind speeds, in combination with ASCE/SEI 7-22 to determine the strength of the building needed to oppose lateral deflections. Per ASCE/SEI 7-22 and the location of the site, seismic loads were not accounted for. Given the region the site is located, the horizontal loads were primarily due to wind. JGMA also analyzed the snow loads when we designed the frame of the building. Using all of these loads, abiding by Steel Construction Manual, 15th Edition we began to design the slabs, beams, and columns for the frame system.

5.2.3 *Substructure*

JGMA provided calculations for a spread footing foundation based on comparable soil data from the geotechnical report by F.T. Kitlinski & Associates. Prior to any foundation calculations, JGMA extrapolated the information from the boring logs to create a soil profile of the site. We calculated the unfactored and factored loads of the building and determined the footing size based on the net allowable soil pressure and unfactored loads. We then checked the settlement failure mode to make sure the foundation complies.

5.2.4 Cost Analysis

JGMA Design and Construction provided the client with a complete estimation of the cost of the project using RS Means (Charest, 2016). This included the detailed cost of the construction of the building and the expected operation of maintenance of the building. Additionally, a sensitivity analysis of the building's rate of return was performed to evaluate the financial severity of the project for the University. Each analysis was compared to the cost of the original plan along with the impact of the sensitivity analysis.

5.2.5 Sustainability Analysis

JGMA Design and Construction will perform a detailed life cycle assessment of the structural design and determine whether it is advantageous towards the university's original plan by evaluating the embodied energy and CO₂-equivalent emissions produced throughout the lifespan of the building. Additionally, a qualitative analysis of specific architectural features or complex design elements will be conducted to gauge the overall sustainability profile of the development. These features could include building layout, HVAC systems, landscaping, or any other features deemed to have the potential for a significant impact.

5.2.6 Project Management

JGMA Design and Construction will provide several items needed for the construction management scope of work. First, the team will create a detailed construction schedule, a site logistic plan, and an income analysis of the project. The construction schedule will display the construction sequencing and be accompanied with a 3D SketchUp to visually show the process. The construction schedule will begin at the end of the Fall 2022 semester and will aim to be completed by the start of the 2024 Fall semester in accordance with the University's original plan. However, we aim to create a schedule that will beat that overall timeline due to their only being one building constructed. The site logistics plan will be created in order to show how materials will be stored and delivered as well as job trailers and other necessities. The income analysis will display how and when the building will earn money for Bucknell through selling energy back to the grid via the geothermal heating and income from students rent. These items will cover the different phases of construction and will allow us to thoughtfully evaluate the construction management of the project.

6.0 DETAILED DESIGN

6.1 Architecture

The first step of the team's architectural design process was the floor layout. The team designed all rooms to have all living spaces provided with a window for quality of life purposes. This was achieved by placing the common rooms and bedrooms on the outside of the rooms, but this sacrificed a symmetrical design of the building. Each room is given an A, B, C, D, or E

designation as the room of the same letter has the same dimensions. We designed the first floor of the building to have 27 beds, a large common space, and a study space as the layout of the first floor is shown in Figure 6.1.

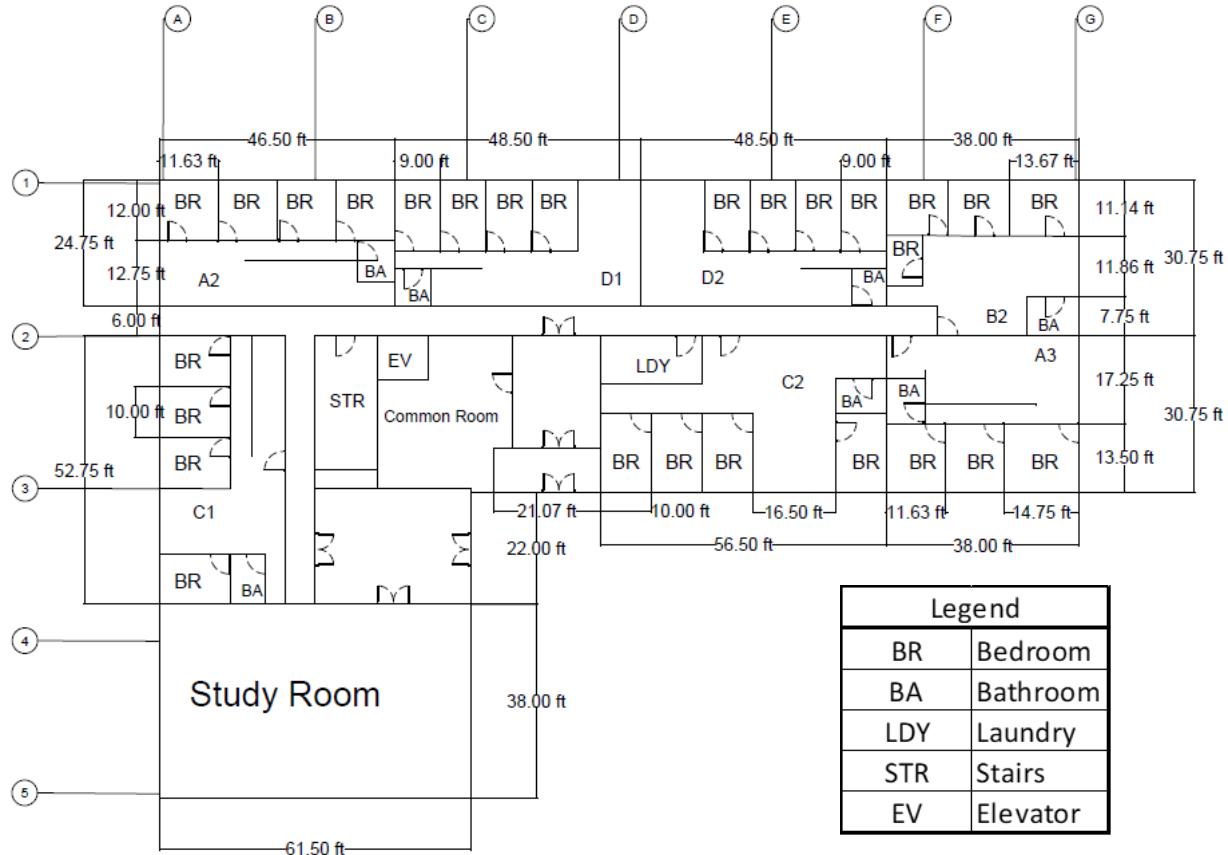


Figure 6.1: Architectural plan of the first floor of the multi-story building.

The team designed the study room to be a large space where all students of the building can meet to do homework or study. The team determined the smaller extra space would work well as a common room as it is near the entrance, stairway, and elevator, which would generate noise making it a poor location for the study room. The apartment style rooms are identical to the rooms of the same designation of the rooms on the higher floors. The architectural layout of the rooms, elevator location, and laundry of our building is seen in Figure 6.1 below.

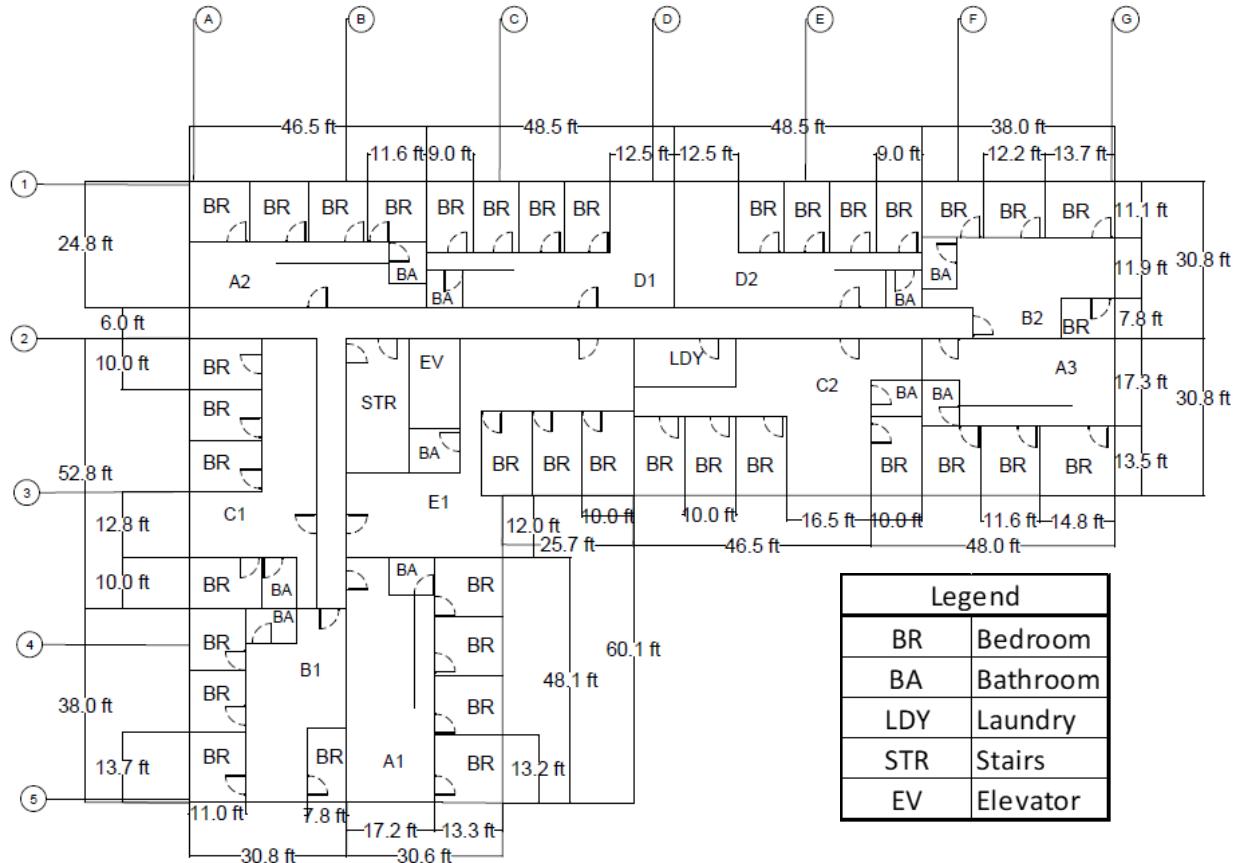


Figure 6.2: Architectural plan of floors two through eight of the multi-story building.

These higher level floors all achieve 37 beds per floor providing the entire building with 286 total beds. Within all of the rooms the hallways range from three and a half to six feet to maintain ADA compliance. Outside of rooms the hallways are designed to be up to six feet, however, we ignored the thickness of the wall. Additionally, our design has an elevator that achieves the 36 inch requirement as it is a four foot by five foot cab.

6.2 Superstructure

The structural grid, composed of the beams, girders, and columns, refers to the framework that supports the weight of the building and the lateral forces acting on it. The structural system we are basing our design on is a gravity system. In this system, the gravity loads are supported by the beams which transfer the loads to the girders, then the columns, and eventually down to the foundation. Figure 6.3 shows the structural grid created for the multi-story building. The open block in the plan for floors 1-8, between frames B and C, is the location of the elevator shaft and stairway. The columns are spaced a distance of 30 feet, creating square bays connected by 30 foot long girders. Within the girders, floor beams span 30 feet and

are spaced every 10 feet. On each floor, there are a total of 27 columns, 42 girders, 32 beams on the roof, and 30 beams on each floor spanning from floor 1-8.

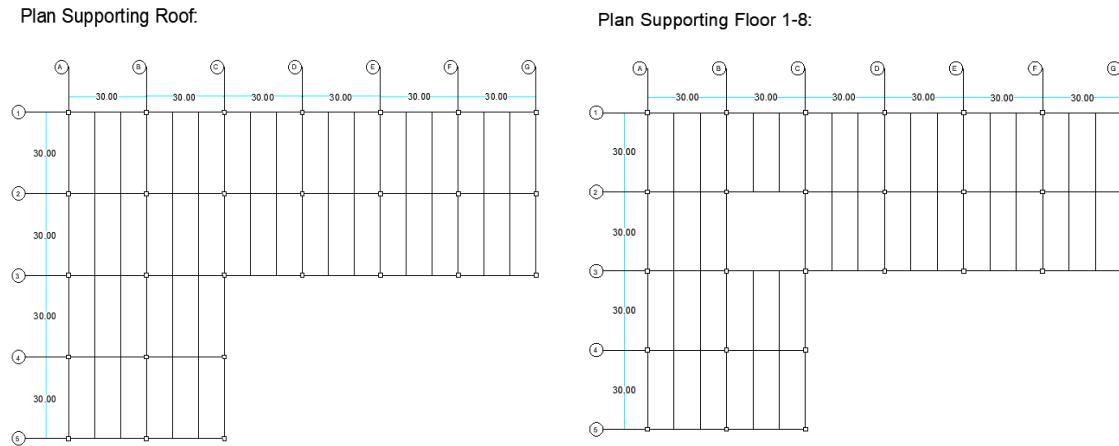


Figure 6.3: Structural plans for the multi-story building.

6.2.1 Beams and Girders

The live loads and dead loads for design were found using Table 4.3-1 in ASCE 7-22, and the ASCE Hazard Tool (Hazard Tool, n.d.) provided snow and wind loads. Due to the design of the building, the live loads varied. The roof had live loads of 20 pounds per square foot because of the green roof. Residential areas of the building were designed for a live load of 40 pounds per square foot. Lastly, the live loads of all corridors and the entire first floor were found to be 100 pounds per square foot. In addition to the live loads, there are also dead loads needed for design. After discussing with our consultant, JGMA assumed a superimposed dead load of 25 pounds per square foot. Given the region where the site is located and the information provided from the ASCE Hazard Tool, the snow load is 61 pounds per square foot and the wind speed required for design is 119 Vmph.

With the loads assessed, JGMA began designing the beams. As seen in the structural plans in Figure 6.3, the beam length is quite long at 30 feet, and JGMA was concerned with the possibility of the beams failing in lateral torsional buckling. To ensure this failure mode would not control the design, we decided to use composite beams, where the concrete slab would be directly attached to the steel I-beams using studs, as seen in Figure 6.4. As a result of this decision, the unbraced length would be zero as the length of the beam would continuously be braced by the concrete slab.

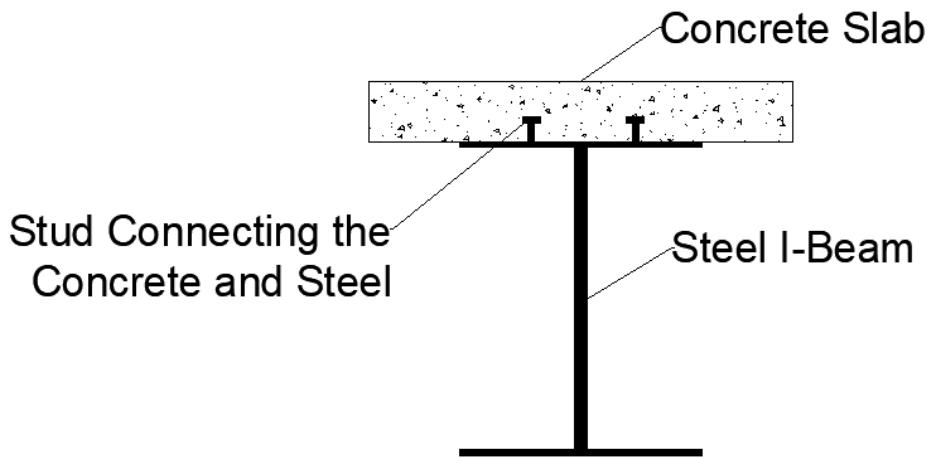


Figure 6.4: Cross section of a typical composite beam (Devlin, 2023).

Similar to steel beams, the composite beams were designed to resist the factored load effects using the LRFD philosophy. In order to find the maximum moment and shear force, we first had to identify the tributary width and area (width and area of effectiveness) of each beam. After that we reduced the live load in accordance with ASCE-7. We then found the factored loads using the LRFD load combinations as seen in Table 6.1. In these combinations, each letter represents a different load; D is dead load, L is live load, L_r is roof live load, S is snow load, R is rain load, and W is wind load. We calculate which combination would result in the largest distributed force for design. It is worth noting that a composite beam is not considered a composite beam until the concrete cures, so there is a brief time where the steel beam needs to support the weight of the wet concrete. In order to take this into consideration, we found the wet concrete load effects by multiplying the dead load by a factor of 1.2. There was no standardized way to complete this, so we followed the example outlined in Paul Richard's book *Build With Steel* (Richard, 2011).

Table 6.1: Load Combinations Considered in Design

	Load Combinations
1	1.4D
2	1.2D + 1.6L + (0.5L _r or 0.3S or 0.5R)
3	1.2D + (1.6 L _r or 1.0S or 1.6R) + (L or 0.5W)

To proportion our beams, we used Table 3-19 in the AISC Steel Construction Manual to find sections that can support the maximum moment determined. For a beam located on the roof,

we calculated the ultimate moment to be approximately 122 kip-ft. Whereas a beam located on floors 1-8 would have an ultimate moment of approximately 189 kip-ft. As a result, different shapes were selected for the roof and floors 1-8. As seen in Appendix D under Roof Beam Design, three trial shapes were recognized as possible sections: W14x22, W16x26, and W18x35. From those three, we selected the least-weight section, W14x22, and began checking the amount of studs needed, the shear capacity, and the moment capacity. The moment capacity for this specific shape in combination with the concrete slab came out to be 255 kip-ft, found from Table 3-19, which is greater than the required strength of 122 kip-ft. In addition to checking the strength of the steel beam and concrete slab together, we needed to check the steel beam section under the weight of the wet concrete load to make sure it would not fail as the concrete is curing. Lastly, we checked the live load deflection of the beam and compared it to the permitted live load deflection of $L/360$. Once all checks were satisfied, we iterated the process to find the best design and computed the required camber for the beam. A summary table for the values checked for the roof beam can be found in Table 6.2. This process was carried out again for the beams on floor 1-8. Using the same approach, we found that a W16x45 would be sufficient. These calculations can be found in Appendix D and the summary table for the values can be found in Table 6.3.

Table 6.2: Summary Table for Roof Beams, section W14x22

Section	W14x22					
Criteria	units	Design Value		Required		Check
Strength	kip-ft	ϕM_n	255	M_u	122	Good
Shear Capacity	kip	ϕV	94.5	V_u	16.24	Good
Studs	-	N	12	N_{min}	5	Good
Stud Spacing	in	s	30	s_{min}	4.5	Good
				s_{max}	36	
Deflection	in	δL	0.54	δ_{permit}	1	Good

Table 6.3: Summary Table for Beams for Floor 1-8, section W16x45

Section	W16x45					
Criteria	units	Design Value		Required		Check
Strength	kip-ft	ϕM_n	486	M_u	189	Good
Shear Capacity	kip	ϕV	167	V_u	25.2	Good
Studs	-	N	12	N _{min}	5	Good
Stud Spacing	in	s	30	s _{min}	4.5	Good
				s _{max}	36	
Deflection	in	δL	0.92	δ_{permit}	1	Good

In a gravity frame system, the loads from the floor are carried by the beams and sent to the girders. The design of the girders were similar to the design of the beams. The area of influence for the girder was the main difference in design between the two. While the beams had a tributary width of 10 feet, the girders had tributary widths of either 15 feet or 30 feet, depending on the location. Four different types of girders were recognized for design: the girders supporting the roof, perimeter girders, interior girders, and girders outlining the elevator shaft. The calculation sheets for all the beams and girders are located in Appendix D. The process was almost identical to the beams. However, in the design of the girders, the live load deflection seemed to control much of the design. Even though the moment capacity was met, we needed to use larger sections to abide by the deflection limits. The sections we ended up selecting were a W18x35 for the roof, a W21x73 for a typical interior girder on floors 1-8, a W18x50 for the girders surrounding the elevator, and a W18x50 for the perimeter girders on floors 1-8. The summary tables of these designs are outlined in Tables 6.4, 6.5, and 6.6 for the roof, interior girder for floor 1-8, and the elevator and perimeter girders respectively.

Table 6.4: Summary Table for Girders for the Roof, section W18x35

Section	W18x35					
Criteria	units	Design Value		Required		Check
Strength	kip-ft	ϕM_n	419	M_u	357.75	Good
Shear Capacity	kip	ϕV	159	V_u	47.7	Good
Studs	-	N	12	N _{min}	5	Good
Stud Spacing	in	s	30	s _{min}	4.5	Good
				s _{max}	36	
Deflection	in	δL	0.55	δ_{permit}	1	Good

Table 6.5: Summary Table for Typical Interior Girder for Floors 1-8, section W21x73

Section	W21x73					
Criteria	units	Design Value		Required		Check
Strength	kip-ft	ϕM_n	921	M_u	506.25	Good
Shear Capacity	kip	ϕV	289	V_u	67.5	Good
Studs	-	N	16	N _{min}	15	Good
Stud Spacing	in	s	22.5	s _{min}	4.5	Good
				s _{max}	36	
Deflection	in	δL	0.88	δ_{permit}	1	Good

Table 6.6: Summary Table for Typical Perimeter and Elevator Shaft Girders for Floors 1-8, section W18x50

Section	W18x50					
Criteria	units	Design Value		Required		Check
Strength	kip-ft	ϕM_n	550	M_u	334.13	Good
Shear Capacity	kip	ϕV	192	V_u	44.55	Good
Studs	-	N	12	N _{min}	5	Good
Stud Spacing	in	s	30	s _{min}	4.5	Good
				s _{max}	36	
Deflection	in	δL	0.88	δ_{permit}	1	Good

6.2.2 Columns

The design process for steel columns involves calculating both the demands on the column and the capacity of the column. The demands on a column are determined by the loads that it must support, such as the weight of the floors and the roof. The capacity of a column depends on its section properties, length, end connections, and the strength of the steel. JGMA chose to utilize a moment frame to resist lateral forces such as earthquake and wind. The implications of this are that end connections for columns can be pin-pin connections as they do not transmit moment, thus columns can be assumed to transmit pure axial force.

To calculate the demands on a column, the idea of tributary areas is used. Tributary areas are defined by lines running halfway between all of the columns in both directions. Once the tributary area for a column has been determined, the load effect is calculated as the uniformly-distributed load multiplied by the tributary area. For multi-story buildings, the tributary areas for columns increase as you move down the frame. Live load reduction is also considered in this process to reduce the design live load for members that receive loads from large areas that are unlikely to receive heavy live loading at the same time. This prevents over designing.

The next step is to choose a column that meets demand requirements. The design process involves selecting a cross-sectional shape based on the loads that the column must support and ensuring that the column length does not exceed its capacity. Since column demands decrease as we move up the frame, JGMA decreases the column weight with decreased demands on the upper levels. The section size however remains the same as a W12 to facilitate splicing. To

optimize section manufacturing costs, JGMA limits the number of column shapes by changing sections every other level instead of changing the sections every level. The end connections of the column must also be designed to resist the loads that the column will experience, which will be discussed in later sections. Once all is considered, JGMA calculated designs for three column sections as detailed in Appendix D. The first and second floor will be constructed with W12x53, third and fourth floors a W12x45, and the fifth through eighth floors a W12x40.

6.2.3 Moment Frame

JGMA has decided to incorporate the use of a moment frame in the design to aid in the resistance of wind loads. This was done using structural analysis software MASTAN2. This involves an iterative process of performing 1st and 2nd order analysis of the windward, leeward, and sides of the building. JGMA chose to design three moment frames to resist each direction of deflection as shown in Figure 6.5. This design includes a moment frame on each side wall to resist windward and leeward deflection and a moment frame on the leeward side of the building to resist side to side deflection. Each moment frame consists of moment connections designed based on the reaction loads from each connection, as discussed further in section 6.2.4.

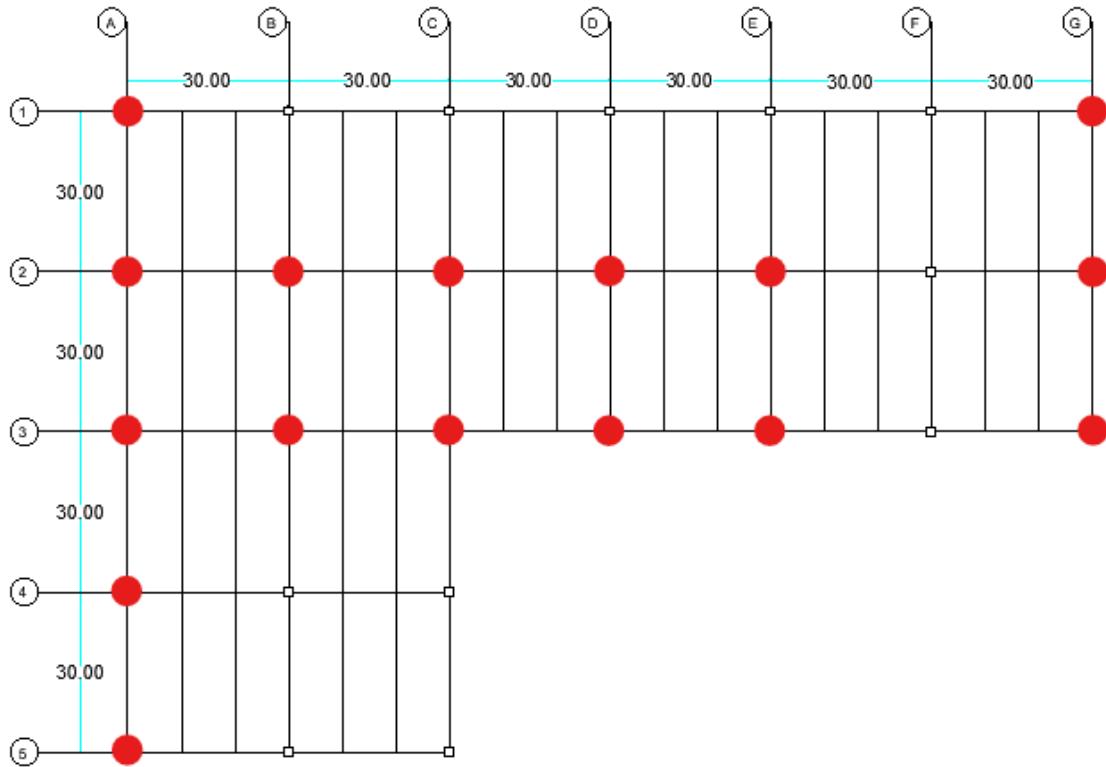


Figure 6.5: Conceptual plan for location of moment connections for moment frame. The red markers indicate a direct-welded moment connection throughout all 8 levels.

6.2.4 Connections

The first step to designing moment connections is to determine the moment and shear demands that need to be transferred between connected members based on structural analysis from the moment frame. The next step is to select the appropriate connection type based on the required moment capacity and the available space for the connection. The direct-welded flange connection (shown in Figure 6.6) was JGMA's choice of moment connection because it is a simple and efficient design that allows for easy fabrication and construction. It's easy to fabricate and construct because it requires very few connecting elements, welds for each flange and a web plate for shear. As the name implies, the flanges are directly welded to the supporting member, in this case the flange of a column. These welds could be either complete joint penetration groove welds or a pair of fillet welds on each side of the beam flanges, however JGMA chose to utilize the fillet welds. This decision comes with one notable drawback for construction and erection that the fillet welds require overhead welding on the bottom of each flange, which requires more time, skill for the welders, and physical space to work. JGMA began the design process with assumptions of electrodes, bolt diameter, and bolt material.

Through an iterative design process balancing the strength of the moment connection with the strength of the beam and local strength of the column (calculations in Appendix D), JGMA utilized three different connections in the design. The beam-column moment connections will be constructed as a direct welded flange connection with two $\frac{3}{4}$ inch A325-N bolts in a $\frac{3}{8} \times \frac{1}{2} \times 6$ inch plate. This connection design transfers load from a W16x45 beam to a W12x53 column, W12x45, and a W12x40 column. For column to exterior girder connections and column to elevator girder connections, another direct-welded flange connection is used with three $\frac{3}{4}$ inch A325-N bolts in a $\frac{3}{8} \times \frac{1}{2} \times 9$ inch plate. This connection transfers loads from the W18x50 exterior and elevator girders to the columns. Lastly, JGMA designed another direct-welded flange moment connection to transfer loads from the W21x73 interior girders to the columns by using four $\frac{3}{4}$ inch A325-N bolts in a $\frac{3}{8} \times \frac{1}{2} \times 12$ inch plate.

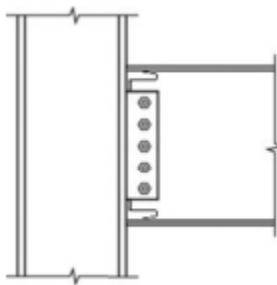


Figure 6.6: Direct-welded flange moment connection (Geschwindner 2017)

6.3 Foundation

6.3.1 Spread Footing

JGMA utilized spread footing as the foundation type to distribute loads from the columns to the soil. Deep foundation was not pursued because of the cost of a deep foundation. A shallow,

spread footing foundation would be sufficient due to the soil characteristics of the building. Figure 6.7 shows a basic example of a spread footing pad and how the load is applied on it.

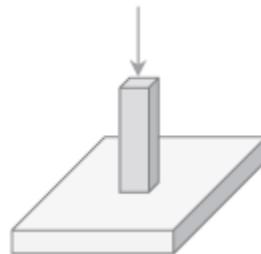


Figure 6.7: Spread footing diagram (Sivakugan 2021)

6.3.2 Soil Analysis

JGMA used the boring log data supplied by F.T. Kitlinski & Associates, Inc to create a geotechnical profile of the soil under the site surrounding the foundations. We first placed our building footprint on the site and identified relevant boring logs for the design. Figure 6.8 shows the specific boring logs that would be the most pertinent to the design as well as their location relative to the locations of the foundation. We identified that borings B-7, B-4, B-8, and B-5 will have the greatest impact on the design. Using the boring logs, we interpreted the subsurface conditions to create a soil profile. We used the number of blows, N value, from the Standard Penetration Test (SPT) to find the corrected blow count or N_{60} value. For hammer efficiency, we used the United States' standard of 85 for an automated hammer release. The boring logs did not specify the borehole diameter so we assumed a standard size which made the borehole correction factor one. We also assumed that it was a standard sampler, meaning there was no sampler liner, so the sampler liner correction factor we used was one. The rod length correction factor we employed depended on the length of the bore. All bores tested were under 20 feet, so we used a factor of 0.75 for lengths up to 13 feet and 0.85 for lengths in between 13 and 20. This process is outlined in Appendix B. Then, based on the N_{60} and the physical description of the soil, we extrapolated the information to create a profile between the bores. These are also located in Appendix B, under "Soil Profiles for Relevant Boring Locations on Site."

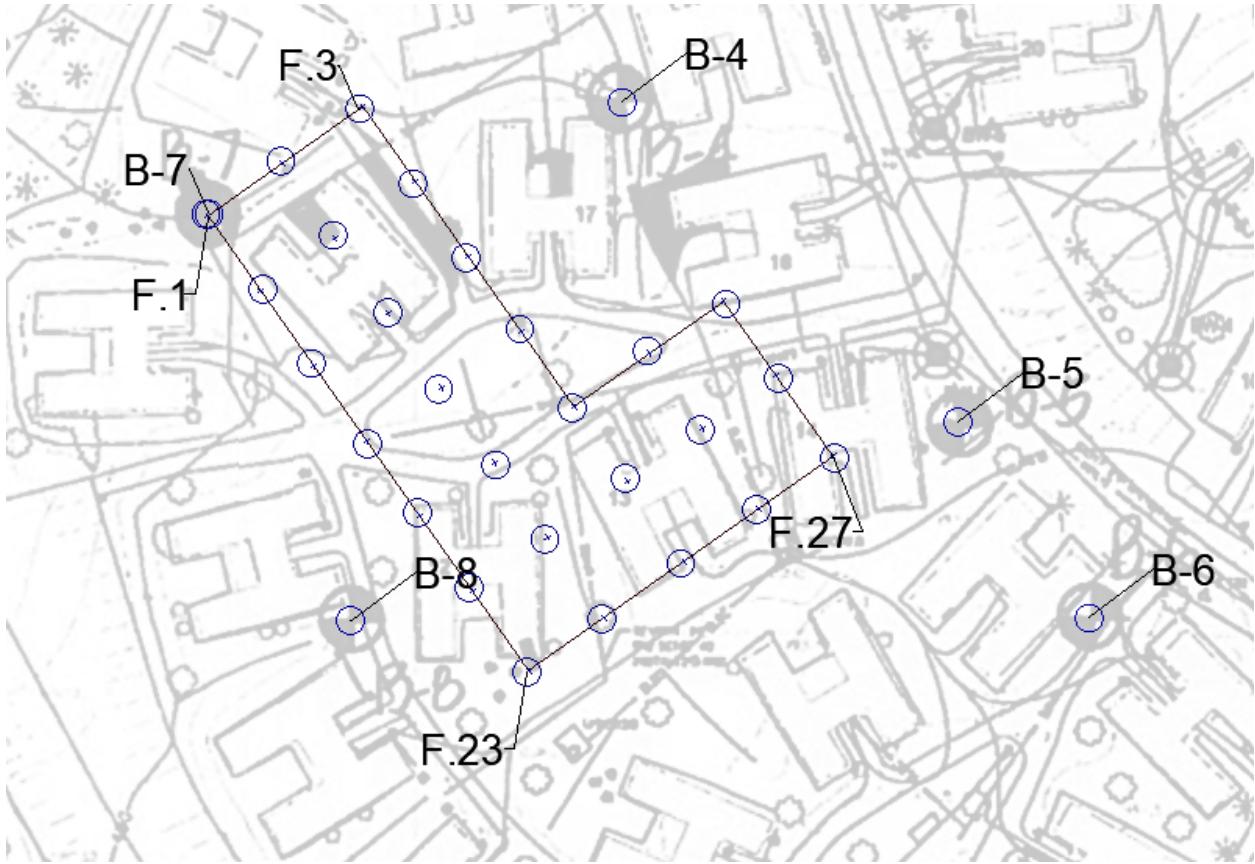


Figure 6.8: Locations of boring logs and foundations relative to the footprint of the building.

We converted the N_{60} value to a normalized blow count or $(N_1)_{60}$ value using a correction factor C_N which we calculated to be 1.03 using the Liao and Whitman method as outlined in Table 11.7 of *Soil Mechanics and Foundation Engineering: Fundamentals and Applications, 1st Edition* (Sivakugan 2021) and Equation 6.1. In the equation, p_a is atmospheric pressure and σ'_{vo} is the standard overburden correction factor, assumed to be 1.0 ton per square foot (Sivakugan 2021). Once we calculated the normalized blow counts, we were able to use Wolff's approximation to find the internal friction angle of the soil. Since the soil is cohesive, we were able to calculate the moist density of the soil using the equation in Equation 6.2. Note, this is an assumption and generalization that is not necessarily accurate for our profile. However, it gives us a value to use for foundation design computations. The full calculations for each of the relevant boring locations are outlined in Appendix B.

$$C_N = \sqrt{\frac{p_a}{\sigma'_{vo}}}$$

Equation 6.1: Liao and Whitman method to calculate the overburden correction factor (Sivakugan 2021).

$$\gamma_{moist} = 107 + 0.95N_{60}$$

Equation 6.2: Correlation of moist unit weight of soil using the N_{60} values (Rahman 2020).

6.3.3 Concrete foundation design

The bearing capacity is the maximum load the soil can carry without experiencing failure, which is largely based on the foundation depth, base dimensions, and soil properties. These soil properties include cohesion and friction angle, which are critical to finding the soil's bearing capacity. Using those parameters and the general soil bearing capacity equation, Equation 6.3, we were able to find the ultimate bearing capacity of the soil. For the site, the ultimate bearing capacity of the soil generally ranged from 19 kips per square foot to 24 kips per square foot. Specifically, Foundation 23, located close to boring log B-8 had an ultimate bearing capacity of 18.95 ksf; Foundation 27, located close to boring log B-5 had an ultimate bearing capacity of 19.32 ksf; Foundation 1, located close to boring log B-7 had an ultimate bearing capacity of 22.35 ksf; and Foundation 3, located close to boring log B-4 had an ultimate bearing capacity of 23.04 ksf. The process and values are laid out in Appendix D.

$$q_{ult} = s_c d_c i_c c N_c + s_q d_q i_q q N_q + s_\gamma d_\gamma i_\gamma 0.5 \gamma^* B N_\gamma$$

Equation 6.3: The General Bearing Capacity Equation for finding the ultimate bearing capacity (Sivakugan 2021).

In order to design the foundation, we followed NAVFAC's suggested values for allowable bearing pressure for spread footings in Table 1 of Chapter 4 of NAVFAC DM7-02 (NAVFAC, 1986). We used the allowable bearing pressure with the factored axial load of the columns, 343 kips as well as the horizontal loading from the wind, to determine the area needed for the foundation. We also initially assumed that the final weight of the foundation element was 2 percent of the axial load so we could proportion the size of the footing. Afterwards, we checked to make sure the actual self weight of the footing would be sufficient. This gave us a required area of 69.97 feet squared. Rounding up to an area of 72.25 feet squared, we made the foundation a square of dimensions 8.5 by 8.5 feet. We made sure this was sufficient by dividing the applied pressure by the ultimate bearing pressure and maintaining a factor of safety above 3. The calculations associated with the foundation can be found in totality in Appendix E.

6.3.4 Foundation Settlement

Once we found the ultimate bearing capacity of the soil and found an appropriate foundation size that would not exceed the bearing capacity, we checked the settlement. Settlement is an important parameter to check because the foundation might not fail but excessive settlement can cause structural damage. Since the foundations sat within a sandy layer with only sands or gravelly layers beneath them, we checked settlement using a granular soil approach. Specifically, we utilized the Terzaghi and Peck (1967) method outlined in Sivakugan

2021. This method related the settlement of our initial foundation to that of a 300-mm-wide square plate under the same loading conditions. We utilized Equation 6.4 in combination with the experimental test data of settlement of the 300 mm by 300 mm plate for varying pressures as shown in Figure 6.9 to determine the foundations' settlements. We discovered that our initial design of the 8.5 foot square footings were no longer acceptable, as they exceeded the maximum settlement (40 mm) as outlined in O'Brien's findings (O'Brien, 2013). As a result, we had to increase our footing size to 12 feet by 12 feet. We designed the footings to be a square of 12 feet so that they can be used in all locations. This decision further increased our confidence that the foundation would not exceed the ultimate bearing capacity while maintaining an appropriate level of settlement. The calculations can be found in Appendix E.

$$s_{footing} = s_{plate} \left(\frac{2B}{B+0.3} \right)^2 \left(1 - \frac{1}{4} \frac{D_f}{B} \right)$$

Equation 6.4: Terzaghi and Peck's (1967) Method of finding settlement of a shallow foundation in granular soil (Sivakugan 2021).

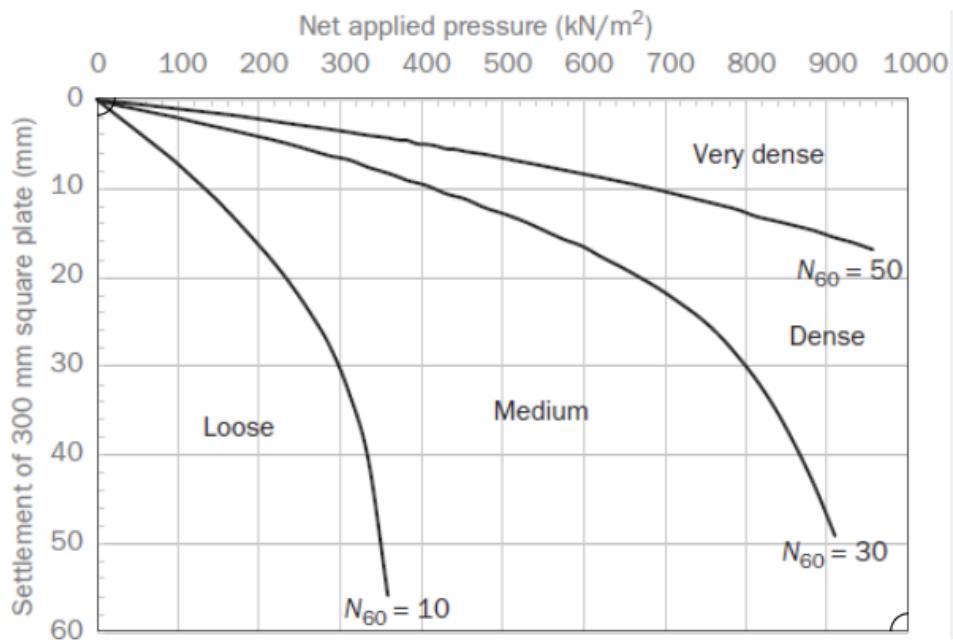


Figure 6.9: Settlement vs. applied pressure plots for 300 mm x 300 mm plate load test used in settlement calculations (Sivakugan 2021).

6.4 Project Management

Project management plays a crucial role in the development of a project that works simultaneously with the structural design team. JGMA has prepared a cost estimate, income

analysis, construction sequencing plan, construction schedule, and a site logistics plan for the client to advise them for our alternative design to Bucknell West. Prior to the constriction of the project, a cost estimate and income analysis will be performed to determine its feasibility. Also, an understanding of the construction sequencing is necessary to understand how the building will go up and how to build a project sequencing. During the project the construction management team will put together a site logistics plan to determine where the materials will be kept, personnel and heavy machinery routing, and entrances and exits for the many deliveries. This is crucial for each phase of the project to maintain efficiency and prevent incidents.

6.4.1 Cost Estimate

A cost estimate is necessary for both the feasibility assessment for the client and can serve as a baseline for the project budget. In order to create a thorough estimate JGMA has used *RSMeans* 2016 (Charest, 2016) to provide Bucknell with a complete estimate of the eight-story steel frame apartment style dormitory. The estimate also assumes a face brick with concrete block backup exterior wall with a steel frame superstructure which matches the design of our building. An advantage to *RSMeans* is that it has a vast collection of projects that use national cost per square foot averages. The project provided by *RSMeans* that best fits ours is the green energy, commercial, college four to eight story dormitory. The primary steps of the estimate are shown in Table 6.7.

Table 6.7: Initial Step in *RSMeans* Estimate

Step	Calculations/Notes				Adjustment in \$/SF	Cumulative \$/SF
	15000 SF, Face Brick on Concrete Block Walls, with Steel Frame					
	Low Estimate	Interpolation	High Estimate			
	110000	120000	135000	SF		
	\$ 227.50	\$ 226.06	\$ 223.90	\$/SF	\$226.06	\$226.06

The first step to starting the estimating process is to interpolate the cost per square foot based on the square footage of our project. *RSMeans* provides several square footage estimates based off of other projects, however we had to interpolate based off of our project's total square footage of 120,000 ft². As a starting point the cost of the project is \$226.06 per square foot. The next step of the estimate requires us to take out the architect and contractor fees due to the additives that are required from our project exhibited in Table 6.8.

Table 6.8: Removal of Architect and Contractor Fees

2	Remove AE Contractor fees				Adjustment in \$/SF	Cumulative \$/SF
	Architect (AE)	6% fee	\$213.26			
	Contactor	25% fee	\$170.61		-\$55.45	\$170.61

This step is necessary because it undervalues the architect and contractor fees before the building additives are added to the estimate. The AE contractor fees are then added back into the project once all additives are included in the estimate. The removal of the fees decreases the cumulative cost of the project by \$55.45 per square foot. Next, to determine the baseline of the building estimate is to evaluate how the required perimeter of the building adjusts the cumulative cost per square foot value which is displayed in Table 6.9.

Table 6.9: Adjustment for the Building's Perimeter

3	Adjust for Perimeter				Adj. in \$/SF	Cumulative \$/SF
S.F. Perimeter \$/S.F.	110000	120000	135000	Actual Perimeter	\$2.06	\$172.67
	540	548.00	560	489.65		
	3.85	3.53	3.05			

The team had to adjust the estimate for the perimeter of the architectural design of the multi-story building by interpolating the square feet of the provided RS Means project into a general perimeter, bolded in Table 6.3 above. Then, using the project's actual architectural perimeter the adjustment in cost per square foot can be calculated and added to the cumulative cost per square foot. The adjustment of the baseline cost per square foot of the building was an increase of \$2.06. The same process is done for the story height of the multi-story building as *RSMeans* 2016 assumes the building to have a 12-foot story height while ours has a 14-foot story height (Charest, 2016). Next, the cost of the basement is added into the estimate as our building calls for 180 square feet of basement for elevator maintenance, which *RSMeans* 2016 assumes that every square foot of basement costs \$34.90. The cost of the basement is then divided by 120,000 square feet so it can be integrated into the cumulative cost per square foot. These initial adjustments provide the building's physical cost per square foot, but the building's additives are required to be calculated into the building's cumulative cost per square foot. The additives that are included in our building are as follows: CCTV system, parking lot and light poles, elevator, furniture, laundry, commissioning fees, energy modeling fees, green fees, greywater recovery system, kitchen appliances, green roof, and remaining sitework. Each additive uses the same method where the cost of it is divided by the square footage of the project so the adjustment of the cost per square foot for that item can be quantified for the cumulative cost per square foot of the entire building. The following steps were taken by the team in order to finish the estimate.

First, JGMA had to adjust the cost for the location of the project. The closest place that *RSMeans* 2016 lists is Sunbury, Pennsylvania which lists the location adjustment factor as 0.96 (Charest, 2016). Second, JGMA had to adjust for inflation as *RSMeans* 2016 does not account for the inflation rate since it was published. In order to adjust for inflation we obtained the January 2023 consumer price index and divided it by the January 2016 consumer price index which is a direct reflection of the accumulated inflation since RSMeans 2016 publication. Finally, the AE adjustment factor had to be reincluded into the estimate.

Once all of this was completed JGMA construction reached a final cost of \$357.59 per square foot and a total cost of \$42,911,320.85 cost per square foot for the eight-story residential building. In comparison to the current University project which costs about \$50,000,000, this design alternative saves Bucknell about \$7,000,000 as per a conversation JGMA had with the project manager of the University's current plan (J. Salyards, personal communication, 2023). The full cost estimate can be found in Appendix A.

6.4.2 Income Analysis

JGMA conducted a thorough income analysis to gain an understanding of the value this project will provide to Bucknell university in the long term. It used the *RSMeans* cost estimate in conjunction with a series of housing and operating cost estimates to produce an estimate on the cumulative net income over time which can be seen below in Figure 6.10. Housing price estimates were based on the Bucknell south campus apartments. The O&M estimate was based on a facilities study conducted by California State University, which produced a cost per square foot estimate that was adjusted to fit the current price index. The analysis predicted that the project would become profitable for Bucknell shortly after 23 years of operation and reach the 100% profit mark shortly after 35 years, which is more than adequate for a project of this magnitude and value. The complete income analysis calculations can be seen in Appendix A.

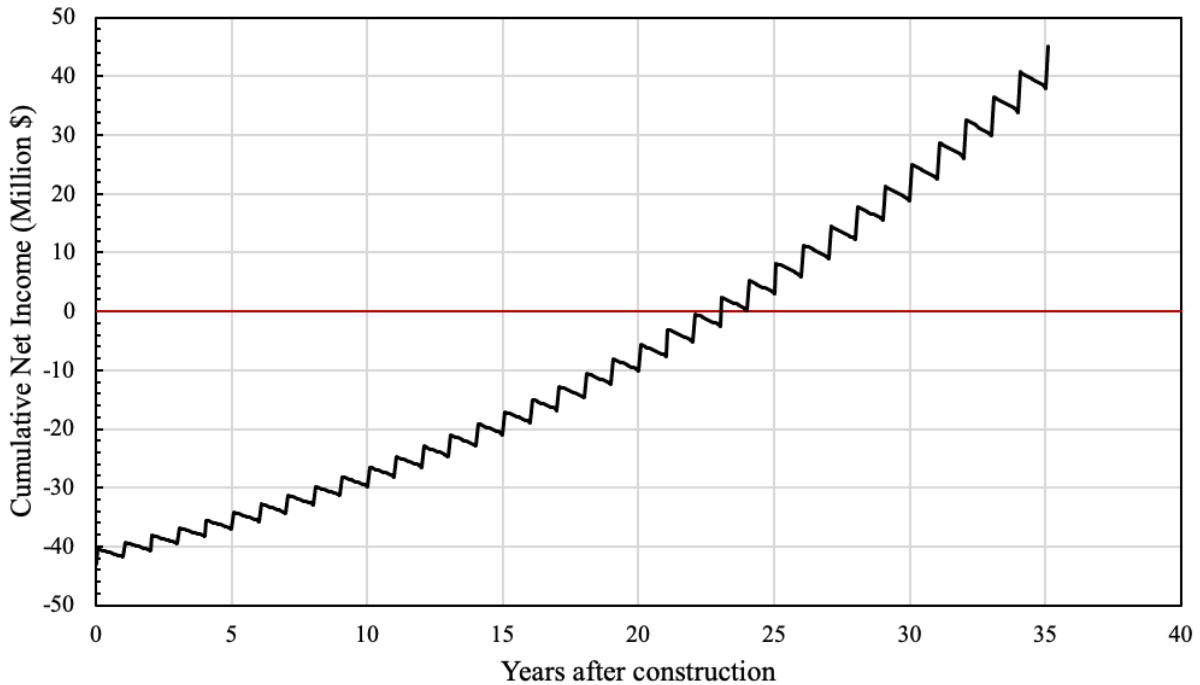


Figure 6.10: Plot of cumulative net income over timespan required to reach 100 percent profit margin.

6.4.3 Project Schedule

In the creation of a Project Schedule, JGMA needed to understand construction sequencing to create a consistent and realistic timeline for the completion of the project. The basic categories of construction sequencing include excavation, foundation, structure, and finishing. However, within those categories there are several construction tasks that come from the many different divisions of labor. Some examples of excavation include soil tests and site removal of the existing mods. While foundation activities include concrete pouring and beginning the connection to the super structure. Additionally, some major examples of structural construction activities include: erecting steel, concrete slab pouring, and roofing. Finally, some major examples of finishing activities include: completion of exterior, insulation, drywall, floor finishes, paint, mechanical, plumbing, and electrical systems setting, flooring, exterior landscaping, hardware installation, cleaning, and a final punch list.

To effectively create a schedule out of all of those tasks, JGMA used Microsoft Project to display an approximate timeline of the total project and its activities. However, due to the time constraint of the project, JGMA is unable to accurately determine the timing of completion of the entire project and each individual task. As a helpful exercise to idealize a project schedule, the team created a project schedule that displayed how the construction sequencing would be performed with placeholder durations for each activity. The schedule of the project is shown in Figure 6.11.

Resource Names: Floor 1		Tue 11/21/23 Wed 2/7/24
Floor 1 - Framing		Tue 11/21/23 Mon 12/4/23
Floor 1 - Plumbing Rough-In		Tue 11/28/23 Mon 12/11/23
Floor 1 - Rough-In		Tue 12/5/23 Mon 12/18/23
Floor 1 - Electrical Rough-In		Tue 12/12/23 Mon 12/25/23
Floor 1 - Insulation		Tue 12/19/23 Mon 1/1/24
Floor 1 - Drywall		Tue 12/26/23 Mon 1/8/24
Floor 1 - Millwork		Tue 1/2/24 Mon 1/15/24
Floor 1 - Finsh MEP		Tue 1/9/24 Mon 1/22/24
Floor 1 - Flooring Install		Tue 1/16/24 Mon 1/29/24
Floor 1 - Painting		Tue 1/23/24 Mon 2/5/24
Floor 1 - Cleaning		Tue 2/6/24 Wed 2/7/24
Resource Names: Floor 2		Tue 12/5/23 Wed 2/21/24
Floor 2 - Framing		Tue 12/5/23 Mon 12/18/23
Floor 2 - Plumbing Rough-In		Tue 12/12/23 Mon 12/25/23
Floor 2 - HVAC Rough-In		Tue 12/19/23 Mon 1/1/24
Floor 2 - Electrical Rough-In		Tue 12/26/23 Mon 1/8/24
Floor 2 - Insulation		Tue 1/2/24 Mon 1/15/24
Floor 2 - Drywall		Tue 1/9/24 Mon 1/22/24
Floor 2 - Millwork		Tue 1/16/24 Mon 1/29/24
Floor 2 - Finsh MEP		Tue 1/23/24 Mon 2/5/24
Floor 2 - Flooring Install		Tue 1/30/24 Mon 2/12/24
Floor 2 - Painting		Tue 2/6/24 Mon 2/19/24
Floor 2 - Cleaning		Tue 2/20/24 Wed 2/21/24

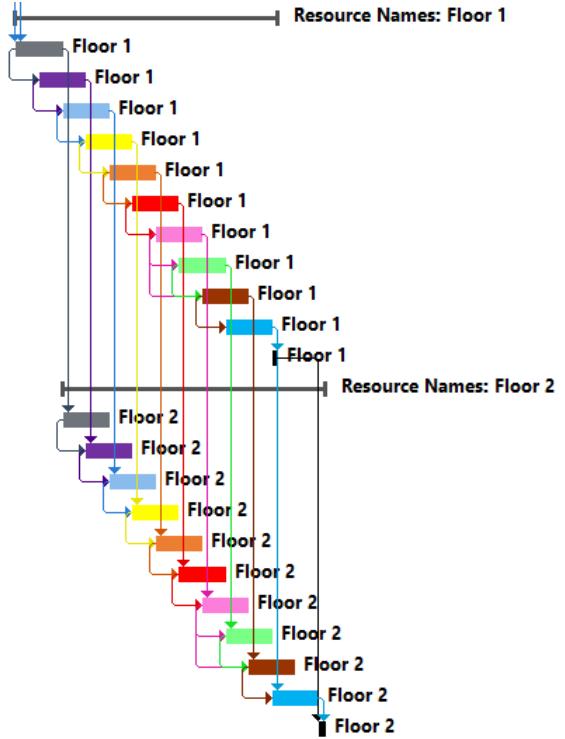


Figure 6.11: Project schedule of the fit-out for the multi-story building.

As the superstructure of the building is completed, the interior trades can begin the finishing process as they work up the building. In the figure above, once a trade is finished on the first floor they will move up to the next one. A start start lag is used in between each trade to speed up for the flow of work so they can take advantage of completed work on a floor so there is less waiting around, which would save money and time. The full project schedule can be viewed in Appendix H.

Another important step of understanding the construction sequencing is determining the layout of the construction site during each phase. This includes where heavy machinery can be placed on site, employee entrances and exits, delivery entrances and exits, on-site job trailers, and materials. A site logistics plan has been created for the construction sequence to efficiently guide the flow of materials and labor and to maintain safety. The multi-story construction site logistic plan is shown in Figure 6.12.

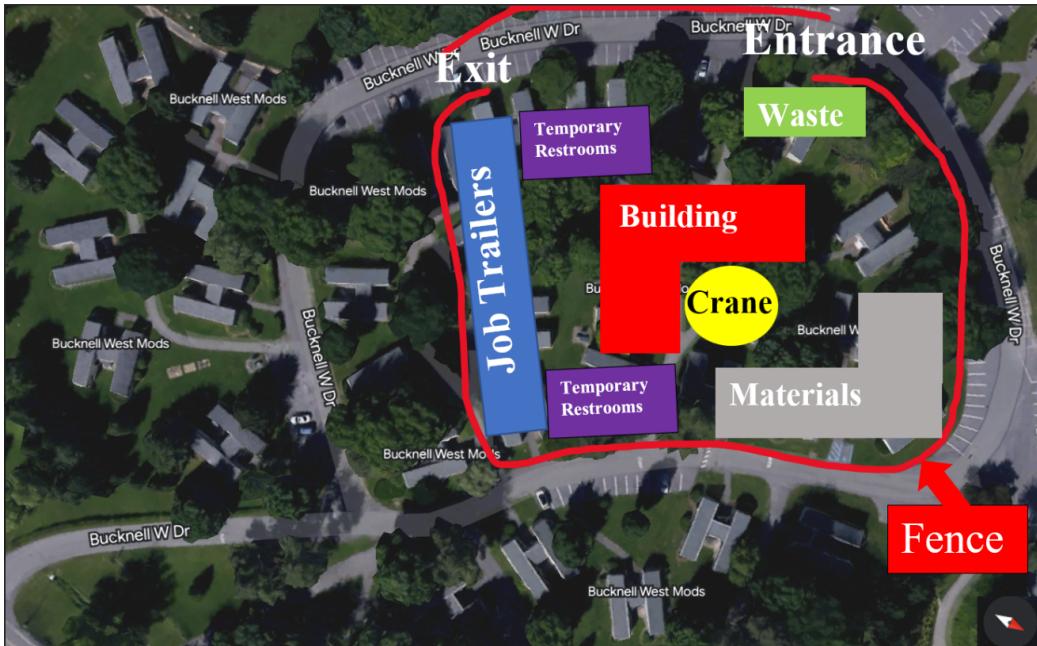
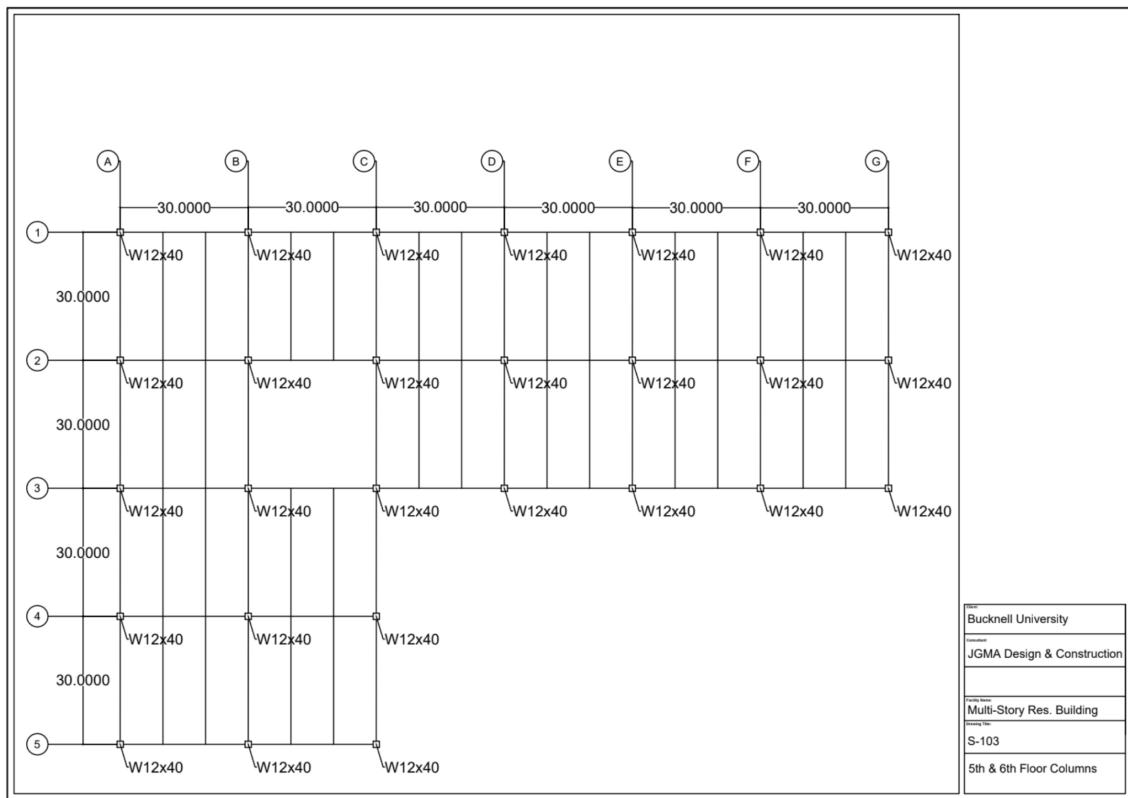
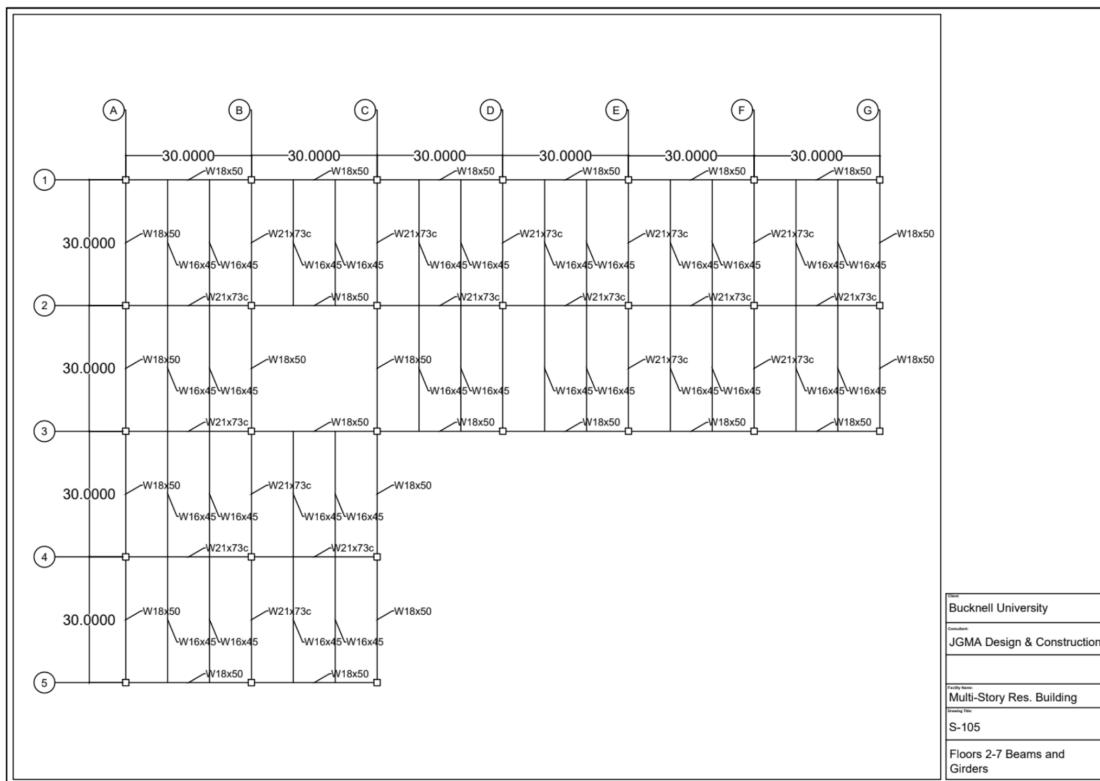
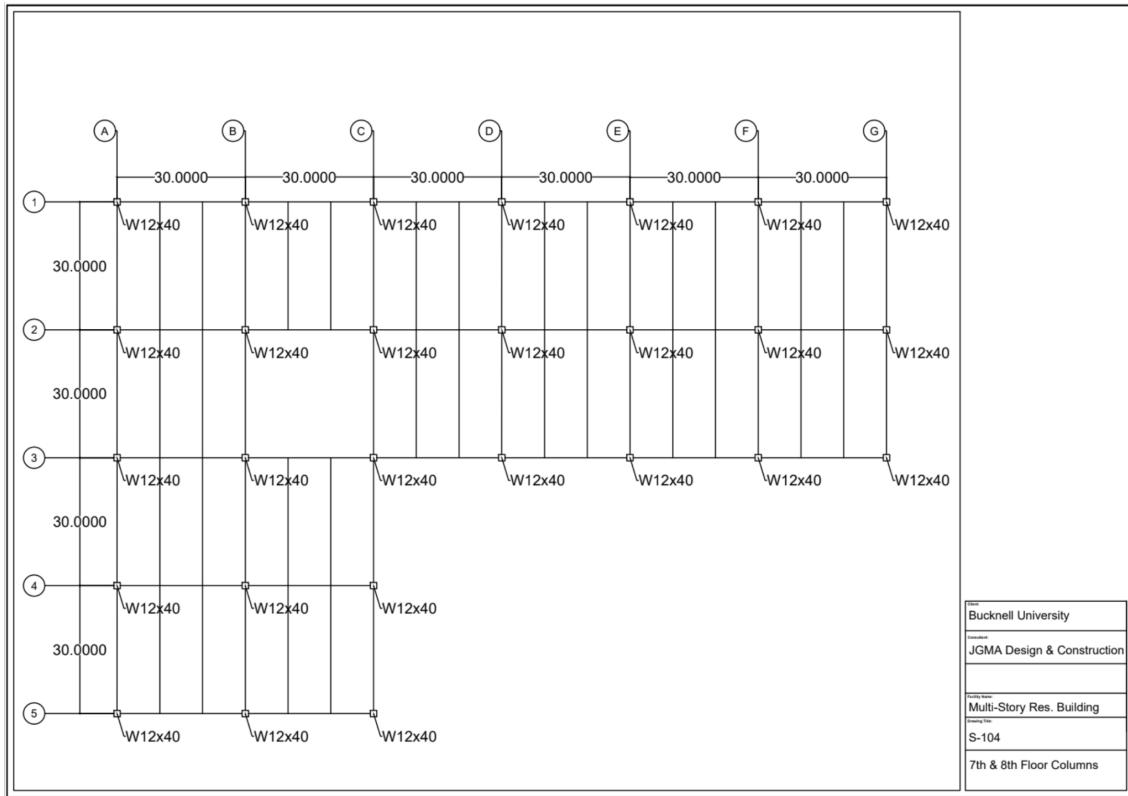


Figure 6.12: Site Logistics Plan

As the construction site is near buildings that students would live in during construction fences with gated entrances and exits must be put up to only allow authorized people to enter the construction site. The construction site of the building takes advantage of the existing infrastructure to transport the materials and construction vehicles to the site. At the gates and along the roads flaggers must be present to guide the flow of construction vehicles and student traffic. In the south corner of the site is where materials will be designated as they are near the building and within a tower crane's radius if needed. A tower crane would need to be used due to the height of the eight story building. On the northwest side of the site is where job trailers and restrooms are located to separate the foot traffic from the construction vehicles using the materials and collecting the construction waste. Finally, in the northeast corner is where the construction waste will be designated so vehicles can collect them upon entrance and leave quickly on the existing road without disturbing the rest of the site. JGMA created a 3D site logistic plan in SketchUp to better contextualize the placement of construction materials and vehicles as seen in Figure 6.13 below.





APPENDIX H: Full Project Schedule

