TEL-210A

GATEWAY PARK BUILDING DESIGN

A Major Qualifying Project

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

In Civil Engineering

By

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Submitted: March 5th, 2010

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ABSTRACT

The purpose of this project is to develop a sustainable design for a mixed-use facility located in the Gateway Park revitalization project of WPI and Worcester, Massachusetts. The proposed design includes both a composite and a reinforced concrete design of structural members, as well as a foundation to transfer the load to the ground. Several elements of "green design" were incorporated into the building, including geothermal heating and cooling and a living roof. Cost analysis and energy analysis of the building demonstrate the efficiency and sustainability of the proposed building.

Authorship

In this project, members of the design team worked on all aspects equally, with some exceptions. The work for the following sections was completed by the member below:

Structural Steel Design – Evan Guarino

Reinforced Concrete Design – Dominic Dechiara

Frame Analysis – Jesse Lane

Foundation Design – Evan Guarino

Cost Analysis – Jesse Lane

Computer Modeling & Simulation – Dominic Dechiara

LEED Review – Evan Guarino

The statements above are certified by the following signatures:

Dominic Dechiara

Evan Guarino

Jesse Lane

CAPSTONE CRITERIA

The American Board of Engineering and Technology (ABET), an accreditation body for engineering and technology schools, requires that upon graduation from an ABET accredited institution; a capstone design project must be completed. The capstone design project must demonstrate the student's understanding of the technical material studied, the knowledge gained and the ability to apply this knowledge to real world problems. To achieve this, ABET developed a set of eight criteria that a capstone design project must touch upon for acceptance. These eight criteria incorporate the following areas: economics, environment, sustainability, manufacturability, ethics, health and safety, social, and political. (ABET General Criterion, 2009)

The economic considerations for the project will be covered in making the project economically feasible for it to be completed. This will be done through a close evaluation of a project budget and cost estimation. In order to make the project as economically feasible as possible it is necessary to look at the project's efficiency and cut out unnecessary expenses from the design process to construction. Major factors in the economics of the project include materials used, exterior site design, and the use of the building. In order to reduce costs, onsite parking was not considered for this project. Based on site dimensions, there was not enough space to create on grade parking and underground parking was too costly to be feasible to create. Our proposed building will utilize the existing parking garage at Gateway Park and the proposed parking area at National Grid power station. For the green roof design we chose a "GreenGrid" system opposed to a traditional layered green roof because their modular design reduces the cost of installation and design costs.

Considerations for environmental impact, sustainability, and constructability all hinge on the use and development of the site. The environmental impact of the project will be considered by ensuring the previous contamination of the site will not cause problems with runoff. Sustainability, which closely effects environmental impact, will be addressed in the "green design" of the project. The sustainability of the project will be looked at in regards to LEED certification as well as other areas of environmentally friendly design and construction. Also, the manufacturability of the site will rely on the design of the building and the choices of materials. This will be shown through structural design of the building.

The next set of considerations from ABET are ethical and health and safety considerations. The ethical considerations of the project pertain to the construction of the building as well as its use. For the construction, safe practices should be followed and all regulations and the safety of the public should be considered during the process. Also, the intended use of the building should fit within ethical and social strategy of both WPI and the WBDC. Coinciding with the ethical issues through construction are health and safety issues. By outlining ethical practices during construction, the project will ensure the safety of workers. Good design and construction practices will ensure the safety of patrons and tenants of the proposed building. Safety precautions will be made in the design of the building including proper structural design and the use of correct rules and regulations on fire codes, building codes, and occupancy laws.

The social and political considerations of the project affect the design, construction, and use of the proposed building. These considerations include following the development plan created by WPI and the WBDC. Also, the use of the building has to coincide with what is socially acceptable and relevant for the area. This is somewhat determined by the zoning laws and codes that limit what the buildings can be used for.

We have demonstrated within this project sufficiency in the areas set forth by ABET criteria. Economic criteria were considered through the use of cost effective measures of design and construction. Environmental criteria were considered by the implementation of green technology. Sustainability criteria were used in the inclusion of green technologies including green roof design and geothermal energy. Manufacturability criteria were followed by using proper materials and technologies in design. Ethical and health and safety criteria were included through the adherence to design codes and standards. Social and political criteria were addressed through the adherence to the development plans set forth for Gateway Park and relevant zoning laws and codes.

1. INTRODUCTION

Institute Park, donated to WPI and the city of Worcester by Stephen Salisbury III in 1887, was an integrate part of WPI's main campus. (Friends of Institute Park, 2008) Now, it serves more as a buffer between the school's main campus and its new redevelopment project, Gateway Park. The university administration has been diligently working to strengthen the sense of community between WPI's main campus and the satellite redevelopment project, as well as the bond between the school and the surrounding community. While Gateway Park has seen tremendous activity over the past several years, it is still plagued with vacant lots and a lack of true community. Gateway Park is one of the most exciting and important areas of Worcester, and the goal of this project is to add some value and insight to the future of the redevelopment through the investigation and design of a new mixed-use facility.

Gateway Park is a joint venture of WPI and the Worcester Business Development Corporation, consisting of 12 acres of land near Interstates I-190 and I-290. This area is comprised of Brownfield sites that have now been designated for mixed-use development, including the newly constructed Life Sciences and Bioengineering Center, completed in September 2007, and an 880 car parking structure. However, this 12 acre site is only a small part of a larger redevelopment endeavor. The Gateway Park redevelopment plan includes 55 acres, beginning at the Northworks building in the north, and stretching south to Lincoln Square. Included in this plan are proposed luxury condominium renovations at the former vocational school, construction of several mixed-use buildings, including space for WPI graduate housing, and construction of three new buildings for commercial space. In addition to this redevelopment plan, Gateway Park is part of the newly established Innovation Square Growth District, one of sixteen sites across the state designed to spur economic growth. The task of our project group will be to use the land located at One Concord Street and develop a plan for the construction of a roughly 100,000 square foot mix use building.

The proposed building, which will henceforth be referred to by its future address of One Concord Street, includes five stories, with each story consisting of approximately 20,000 square feet of livable area. The first story will be designated for retail space, and the four upper stories will be designed as condominiums ranging from lofts to family-sized units. The mixed-use facility will contribute to the community by providing housing, goods and services for people who work and live in the area. In addition, the proposed building will strengthen the WPI community by providing an area for students to shop and eat while on the Gateway Park campus. The building will also showcase some of the newest “green” technologies in the building industry in order to promote energy conservation, environmental efficiency and responsibility by adding a living roof and ground source heat pumps into the design. These sustainable design elements will be incorporated into the design to provide sustainable energy and achieve LEED certified status, a new requirement set forth by WPI for all its new buildings.

This project not only will require a proof of the understanding of concepts learned through our group’s completed studies but also will aid the WPI community by providing a sustainable design for a future building at Gateway Park. The project begins with the design of our building including general floor plans and a design for the exterior. This design was created by following established rules and regulations, zoning laws, and the common design themes already established in the Gateway Park. Next is a section including the structural design components of the building including the design of beams, girders , columns, connections,, and foundations. The elements of “Green design” and sustainability that are incorporated into our building are then discussed. The document will also cover the cost estimating of the building’s construction. The cost estimating is based on the designs already created and gives an idea to the timeline of actual construction, expected costs, and highlights any possible issues that could arise in the construction process. The last section of our building design is the LEED certification. While taking steps to becoming LEED Certified is accounted for in all designs of our building, a section of what could be done with the outfitting of the building to become more “green” is included after the cost estimation.

2. BACKGROUND

2.1 Gateway Park

Gateway Park is a joint venture of WPI and the Worcester Business Development Corporation, consisting of 12 acres of land near Interstates I-190 and I-290. Gateway Park is comprised of former Brownfield sites that have now been designated for mixed-use development. The plan for Gateway Park includes lab space, residential units, and commercial space to create a thriving and diverse community in a underutilized area of Worcester.

This development includes the newly constructed Life Sciences and Bioengineering Center, consisting of four stories and 124,600 square feet, was completed in September 2007. WPI invested $43 million and is home to the Biology and Biotechnology, Biomedical Engineering, Chemistry and Biochemistry, and Chemical Engineering departments. The Life Sciences and Bioengineering Center is also home to several pharmaceutical companies. Tsoi/Kobus & Associates served as the architect for the building, and Consigli Construction Company, Inc served as the contractor. In 2007, RXi Pharmaceuticals signed a 20-month lease for space in the Life Sciences and Bioengineering Center, with the option to become the lead tenant in the future lab facility in Gateway Park. RXi Pharmaceuticals was founded by Dr. Craig Mello, a 2006 Nobel Laureate. Also constructed in the last year is the 880 car parking structure that will serve the current LSABC building and future Gateway Park buildings.

In 2007, Gateway Park received the Phoenix Award for its Brownfield revitalization in downtown Worcester. The Gateway Park properties formerly consisted of blighted and abandoned industrial buildings. The award is given to individuals and groups that transform Brownfield properties into productive new uses. (Mell, 2008)

2.1.1 Gateway Park Master Plan

The master Gateway plan consists of 5 life science buildings creating 500,000 square feet of lab space, 241,000 square feet of condominiums, and several buildings providing retail space. Figure 1, shows the various stages of the Gateway Park development project. Kavanagh Advisory Group will develop future phases of Gateway Park, and was given the opportunity to develop up to four additional new buildings in Gateway Park. It is currently in the design process for its first building, an 80,000 square feet state-of-the-art wet lab facility. KAG is also working toward securing funding for construction and negotiating with potential tenants for the new building. KAG hopes to break ground on a new building before the end of 2010.

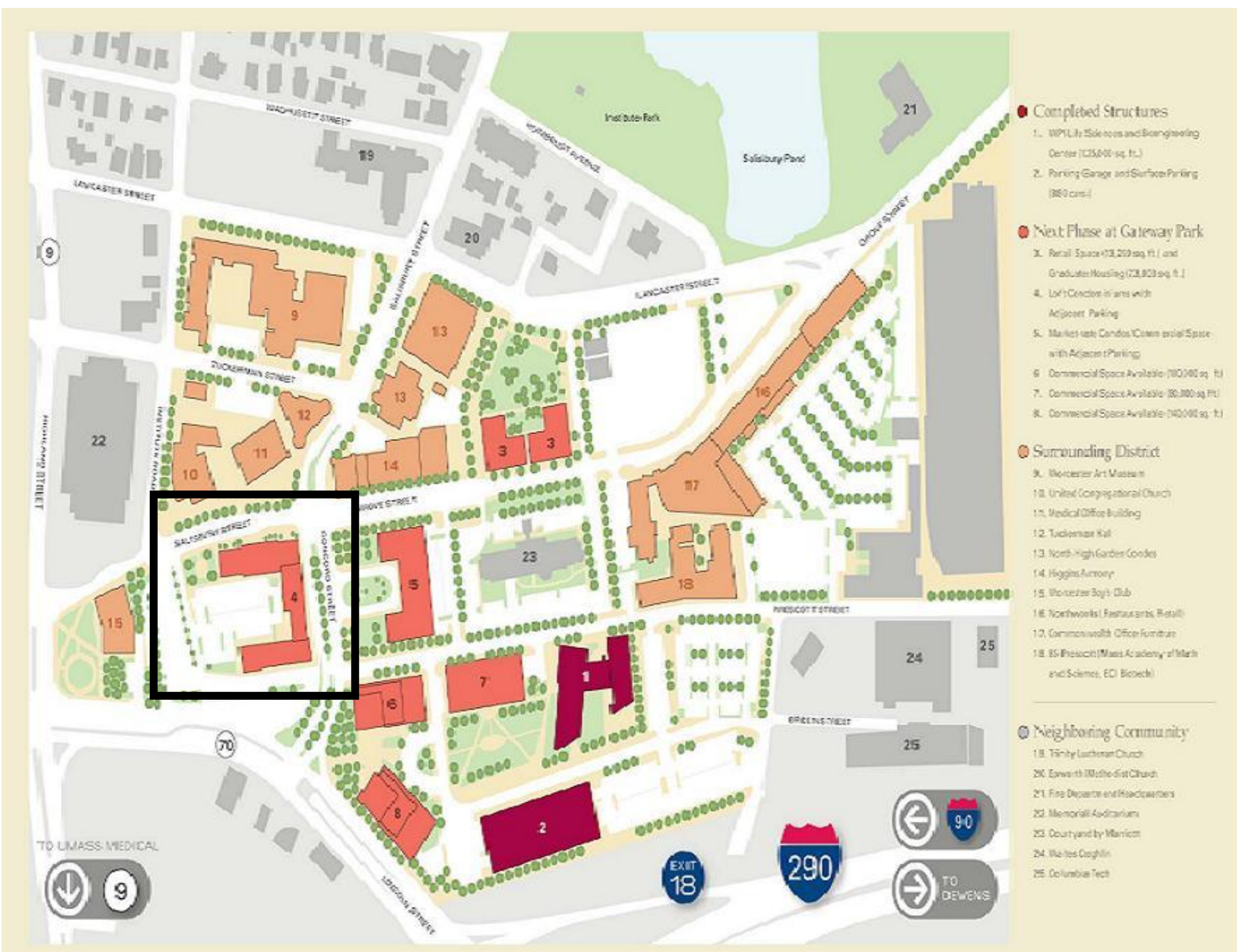

Figure 1: Gateway Park Master Plan Map; Proposed Site in Black Box

This 12 acre site is only a small part of a larger redevelopment endeavor. The Gateway Park redevelopment plan includes 55 acres, beginning at the Northworks building in the north, and stretching south to Lincoln Square. Included in this plan are proposed luxury condominium renovations at the former vocational school, construction of several mixed-use buildings, including space for WPI graduate housing, and construction of three new buildings for commercial space. The Gateway Park redevelopment district also includes the newly constructed Courtyard by Marriott Hotel. In addition to this redevelopment plan, Gateway Park is part of the newly established Innovation Square Growth District, one of 16 sites across the state designed to spur economic growth. (Gateway Park Business Development Office, 2008)

2.1.2 One Concord Street

The Gateway Park redevelopment complex is located at the junction of Route 190 and Route 290 and is most easily accessible from just off exit 18 of Route 290. The site is completely contained by surrounding streets with Concord Street to the south, Lexington Street to the north, Prescott Street to the east, and Grove Street to the west. Gateway Park LLC purchased the site in 2007 for a price of about $1.1 million dollars. Previously the site had been home to the machine shops of Worcester Vocational High School whose main building was located across Concord Street. Since the site has already been developed it is expected that all major utilities have existing connections on or near the site making it easier to connect into the building and also lessening costs to tie in to utilities.

Since acquiring the property, Gateway Park LLC has already transformed it into something completely different. The 55,000 square foot building, seen in Figure 2 that stood on the property was taken down and the site leveled. Also, Lexington Street, the road that bordered the north edge of the site and separated it from the Marriot Hotel, will soon be removed. Lexington Street served as a cut-through from Grove Street to Prescott Street and it has been proposed by the city of Worcester to reopen Faraday Street, on the north side of the Marriot Hotel, to serve the purpose that Lexington Street had fulfilled.

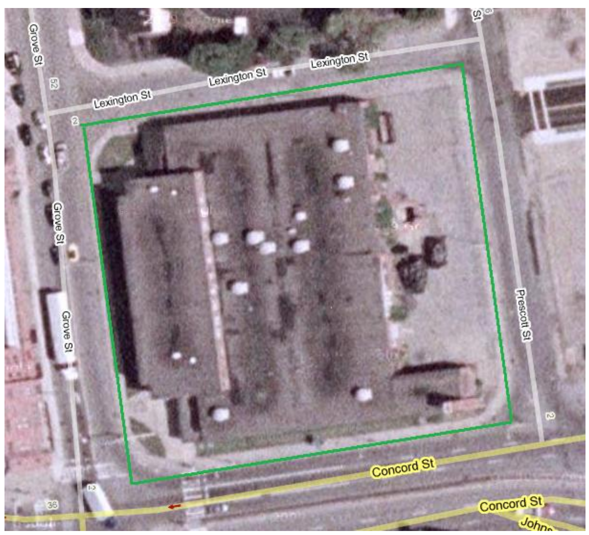

Figure 2: Proposed Site Located Within Green Outline

The proposed site was designated as a Brownfield site prior to its purchase by Gateway Park LLC in 2009. A Brownfield site is a property that is contaminated by pollutants caused by previous site use, nearby industrial areas, or a high number of natural pollutants in the soil. (Environmental Protection Agency, 2009) The site was contaminated by asbestos, lead paints, and solvents that were leached out from the machine shops in the building that made their way into the soil. Because the site was required to be remediated before it could be developed, Gateway Park LLC received $615,486 in funding to help with the costs for remediation based on the plans to develop the site. Currently, the site consists of a bare plot covering most of the lot. This lot is shown in Figure 3. This is because much of the contaminated soil that required removal was moved to a new construction site in the Worcester area. Contaminated soils may be moved to new locations if the soil that is being moved is less contaminated than the soil at the new location. (Kievra, 2007)

Figure 3: Image of Site Located at One Concord Street

This site was selected for the project because, of the planned sites in Gateway Park, it provided the greatest opportunity for open development and individual design. While all buildings in Gateway Park are currently filled with lab space and technology companies, the proposed building in this project will offer a commercial outlet for students that is not currently offered within reasonable walking distance of campus. This site will also offer new housing which not common in to the section of Worcester that will appeal to companies who wish to move to Gateway Park.

2.2 Zoning

The City of Worcester Zoning Ordinance was ordained in 1991 to establish a set of rules and guidelines for development within the city. The document has been regularly amended since its creation and was most recently updated in November of 2008. Covered in the document are comprehensive descriptions and rules regarding specialty building permits, land use regulations, zoning districts, water resource protection, retirement centers, parking stipulations, mixed-use development, and much more. Permits, zoning, and mixed-use development are among the most important topics to those in charge of the expansion efforts at Worcester's Gateway Park.

The purpose of the Zoning Ordinance is designed to encourage the six following aspects of city development: Fulfilling social and economical needs of the future, to secure necessary public requirements including schools and parks, developing and maintaining housing suitable for the present and future, preventing congestion of residents and traffic to promote fire and natural disaster safety, enhance the aesthetics of the city while preserving natural resources, and preserving land significant in historical or architectural nature.

Social and Economical Needs

The vision of the Gateway Park project targets revitalization within the immediate area and proposes a strong turnaround for an area rich in art and music; within just a quarter mile are Tuckerman Hall, Mechanics Hall, and the Worcester Art Museum.   Furthermore, the estate will be home to not only the WBDC and student life, but also restaurants, retail units, and other residential buildings.

Public Requirements

According to the Zoning Ordinances only specific types and sizes of buildings may be built in specific zoning overlays. The proposed facility is in a mixed-use overlay and none of the proposed uses are prohibited by zoning requirements. Furthermore, the nearby Gateway Park parking garage decreases parking demand and the proposed open space will serve to decongest the formerly "bricked-off" warehouse complex.

Suitable Housing

Our proposed residence units will be designed to have a living surface area to be between 1,200 and 3,000 square feet with maximized exposure to the exterior face of the building for increased sunlight and exceptional aesthetic characteristics, which will aid in LEED certification.

Resident and Automotive Traffic

The corner of Prescott and Concord generates a large volume of traffic and it is therefore important that line of sight is preserved, street-side parking does not obstruct traffic flow, and pedestrian flow is maintained. With the recently constructed, 660-space parking garage just a few hundred feet away and our proposed two-story, sub-surface parking garage at One Concord Street, parking space will be sufficient for the residents of the 28 living spaces and allow for the preservation of the existing traffic and pedestrian patterns.

Aesthetics

During the course of construction at Gateway Park, the old Vocational School structure was demolished and the site was remediated. Aesthetically speaking, the site at One Concord Street has already been improved through the demolition processes carried out. The new mixed-use facility and associated green space will serve to enhance the immediate area's visual diversity.

Land Preservation

The land, which was previously abandoned and unappealing warehouses and brick buildings, has been reclaimed through the efforts of the Gateway Park Business Development.

2.3 Building Usage

The mixed-use facility that will be designed in this project is envisioned as an important part of the growth of Gateway Park and the sense of community with the main WPI campus. The commercial space is envisioned as a retail space that would appeal to college students and young professionals. This retail store would provide a place for students to work and shop in their free time, and would provide more incentive for students living on or around the main WPI campus to travel to Gateway Park.

The market-rate condos, which will make up the second through fifth floors, would appeal to young professionals working in the various life science companies that are tenants in the existing Life Sciences and Bioengineering Center. These condos ranging in size as well as design would provide housing for tenants of the future life science facilities that are in development for Gateway Park. Our proposed building would further the development of Gateway Park and help create a greater sense of community in the area.

2.4 Local Geology

The local geology of a proposed building site is extremely important to the design and construction of the building. An understanding of the soil mechanics and properties of the area are required to design a foundation that will transfer the building loads to the ground without significant settlement or shear failure. The type of soil present may often dictate the type and size of the foundation required for a building, as granular soils and cohesive soils interact differently with deep and shallow foundations.

In 2005, The Maguire Group, Inc. performed a subsurface investigation and geotechnical report used in the design and construction of the current Gateway Park parking facility. The information provided in this report is the most current information available for the local geology of One Concord Street. The report includes a soil profile, subsurface investigation, lab testing results, an explanation of the results, and a recommendation of foundation systems for the various planned buildings.

The subsurface investigation performed by the Maguire Group consisted of 20 shallow borings to an approximate depth of 15 feet, and five deep borings to an approximate depth of 60 feet. Cullinan Engineering Consultants developed a boring layout for the subsurface investigations, and New Hampshire Borings, Inc. conducted the borings using two truck-mounted drill rigs working simultaneously. The deep borings provide information on the depth of bedrock in the area. In addition to these borings, several groundwater observation wells were utilized to determine the average depth to groundwater in the area. The borings were drilled using a hollow stem auger and samples were taken using a split-spoon sampler. All subsurface investigations were performed using ASTM standards.

Using the data provided in the geotechnical report, a soil profile for the area of One Concord Street was created. The soil profile represents a cross section of the land around One Concord Street based on the borings drilled in the Maguire Group subsurface investigation. Figure 4 shows the boring locations of the Maguire Group subsurface investigation.

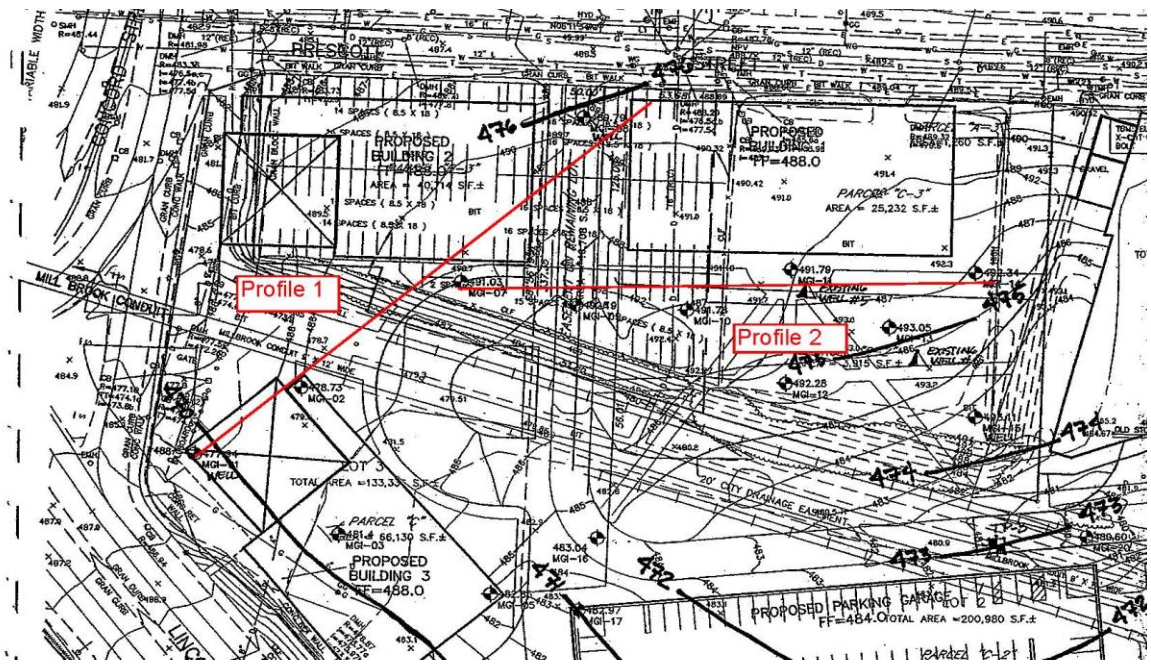

Figure 4: Boring Plan with Soil Profile Indicators for Gateway Park

The soil profiles were created by taking an average strata thickness and elevation for each boring used in the soil profile cross-section. In some cases, not all strata match up perfectly, which can be caused by pockets of soil that occur in some areas but not all. The goal of a soil profile is to create a representative cross-section of the soil on which the structure is to be built. For this project, two representative profiles were created because of the large range of borings available in the geotechnical report, and the foundation was designed using soil profile number two as shown in Figure 6. The profiles are shown in Figures 5 and 6 below. The Unified Soil Classification System abbreviations are used in the soil profiles to indicate the type of soil in each stratum.

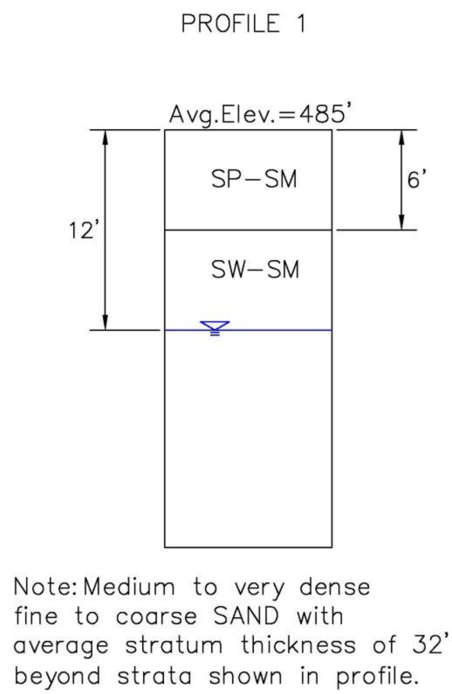

Figure 5: Soil Profile 1, Diagonal Cross-Section in Boring Plan

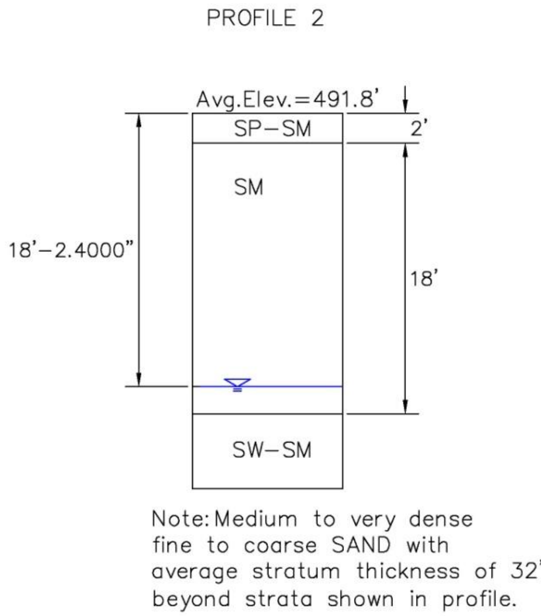

Figure 6: Soil Profile 2, Cross-Section Parallel to Parking Garage in Boring Plan

2.5 Sustainability

Sustainability will be a strong focus in the design of the mixed-use facility at One Concord Street. In the United States, buildings account for 72% of electricity use, 39% of overall energy consumption, and 38% of carbon dioxide emissions. The advantages of sustainable design and green technology benefit the owner, the environment, and the community. Sustainable design places a greater emphasis on efficiency and better management of resources, including land, building materials, and energy.

The use of more green, more efficient technologies make it cost effective to implement the use of new technologies over the life of the structure. Living roofs and geothermal heating and cooling systems, which will both be discussed in greater detail in the following pages, help to lower the costs associated with building climate control by providing efficient insulation and alternative energy sources. Our project will explore some of these green technologies, including living roofs, geothermal heating, solar hot water, and cooling, and recycled and reclaimed building materials.

Living Roof

The design of the mixed-use facility at One Concord Street will include a green roof, or living roof, as part of its sustainable design focus. Worcester Polytechnic Institute is already a pioneer of green roof technology in Worcester installing the city's first on the newest residence hall on campus.

A green roof is one of the latest technologies to be implemented in both new construction and existing buildings in order to reduce the environmental effects of the built environment. The concept of a green roof is to include a layer of vegetation on the top of a building. In order to install a green roof on top of a building, several specialized layers must be added to a traditional roof. These layers include the vegetation layer, a growing medium layer, drainage and root barrier layer, and a membrane protection layer. These additional layers add weight to the roof, and must be accounted for in both the roof design and the structural frame design. (Low Impact Development Center, 2007) Also, the cost to install a green roof is higher than the cost of a traditional roof. The cost considerations will be addressed in the project cost estimation portion of this project.

The benefits of a green roof are vast, and include reduction of storm water runoff and water contamination, increased insulation of the building and decreased heating and cooling costs, reduction of the heat-island effect, and creation of new bird habitats. The installation of a green roof will reduce the impervious area that would be created by a traditional roof and can contribute to localized flooding problems. Because green roofs further insulate the building, they reduce the reliance on heating and cooling systems and help to pay for their construction over time. Green roofs are also awarded points in the LEED Certification program. Therefore, the green roof will be incorporated into the LEED Certification aspect of this project, as well.

Geothermal Heating and Cooling

A ground source heat pump system, the technical term for a geothermal heating and cooling system, will be incorporated into the design of the building. The concept of a ground source heat pump is based on the relatively constant temperature beneath the Earth's surface. In the winter, heat is pumped from wells that penetrate Earth's surface. In the summer, heat from the building is pumped into these wells and back underground.

There are several options for the design of one of these systems. However, our building will incorporate the closed-loop vertical system. This design consists of wells drilled 20 feet apart and 100 to 400 feet deep. Because of the deep penetration of the wells, this design usually does not require land beyond the footprint of the building and is typically the most appropriate for large schools and commercial buildings. The pipes from underground connect to the heat pump in the building, which concentrates and disperses heat throughout the building using a traditional duct system.

The benefits associated with geothermal heating and cooling systems are immense. Geothermal heat pumps use 25-50% less electricity than traditional heating and cooling systems. Geothermal heat pumps are generally very durable and reliable, and are very effective in humid areas by maintaining an indoor humidity of 50%. The electrical costs are the only costs, besides standard installation and maintenance costs, associated with geothermal heating and cooling because they do not use heating oil or gas. The increased cost of installing one of these systems will be considered in the project cost estimation. Because these systems do not depend heavily on non-renewable resources like oil, they are awarded points in the LEED Certification program.

LEED Certification

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System is the industry standard in determining the sustainability of a building. LEED certifications are issued under various categories, including new construction, core & shell, schools, healthcare, and retail. Additionally, there are separate LEED standards for existing buildings and schools, as well as commercial and retail interiors.

In order to be certified by the LEED rating system, a building must accumulate a certain number of points under various categories of sustainability. Attaining at least 40 of a possible 100 points may certify a building. Accumulating more points will result in a higher level of certification. A silver rating requires at least 50 points, a gold rating requires at least 60 points, and a platinum rating requires at least 80 points. In addition to collecting points, buildings must meet certain performance requirements in order to qualify for a LEED certification.

Under the New Construction LEED rating system, buildings are awarded points in the following categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority. Many points are rewarded in areas that may be beyond the scope of this project. For example, water reduction points may be rewarded to a building outfitted with more efficient appliances, which will not be addressed in our project. However, many points are available in areas that are within the scope of this project, such as on-site renewable energy and maximization of open space in site development. This project will include a LEED certification review process to determine a potential point total for the building design. Both the “New Construction” and “Core & Shell” LEED rating systems will be investigated, with the goal of achieving at least a “certified” rating in either of these systems for the building design produced in this project. The LEED point review will be produced as a deliverable in this project. (U.S. Green Building Council, 2009)

Software

In order to design and analyze the sustainable elements of this project, two computer software packages were utilized. The RETScreen software developed by Natural Resources Canada and the eQUEST software developed by the U.S. Department of Energy allowed for the design and simulation of the sustainable technology incorporated into the building. The computer programs allow for the systematic estimation of the energy needs and efficiency of the proposed building so that the energy needs may be addressed through the implementation of “green” technologies. Software output provides graphical and numerical analysis that will highlight the efficiency of the building.

The eQUEST Quick Energy Simulation Tool software is a comprehensive package that allows the user to “perform detailed analysis of today’s state-of-the-art building design technologies using today’s most sophisticated building energy use simulation techniques but without requiring extensive experience in the ‘art’ of building performance modeling”. (Hirsch, 2009) The eQUEST software allows for the detailed modeling of a building, including materials and layout, and was used in this project in conjunction with Autodesk REVIT modeling. By running an eQUEST program with the proposed building, the energy consumption and efficiency of the building can be presented graphically.

The RETScreen Clean Energy Project Analysis Software is a decision support tool used to "evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies". (Natural Resources Canada, 2010) The software interface is simple and familiar because it is based on Microsoft Excel. User inputs are highlighted and color-coded, based on information that is required or optional for the software analysis. The software also includes climate, hydrology, and product databases to attain the most accurate and realistic results for a project. Case studies and templates are provided to assist the user in understanding the software capabilities.

3.0 METHODOLOGY

The design of a building is a multi-faceted process that starts with the conceptualization of an idea and continues through to the detailed final design. The design team worked through various stages of design, including initial conceptualization, site investigation, and building design and modeling. The primary elements of an actual design process utilized by the design team are described in the following sections. The primary task of the design team was to compile information from the various aspects of design and incorporate it into a project that WPI and the City of Worcester may use and build upon further.

3.1 Background Research

Performing background research is the critical first step in the design process. In this step, the requirements, restrictions, and limitations of the client and site must be identified. The design team investigated the history and future of Gateway Park in order to create a viable building concept for One Concord Street. Through this initial investigation, the design team obtained information regarding the previous occupants of the desired Brownfield site at One Concord Street and the origins of site contamination. Additionally, the Gateway Park master plan was investigated in order to understand the key elements of the redevelopment project and how the proposed building could enhance the community.

An interview with Jeff Solomon, Chief Financial Officer of WPI, was arranged so that the design team could fully understand the master plan for Gateway Park and the actions that have already been taken as part of this plan. Important information regarding recent site history was obtained from the interview, including the process by which the Brownfield site was rehabilitated.

An interview with John Kavanagh, President of Kavanagh Advisory Group of Danvers, Massachusetts, was arranged to further understand the elements of a project that become most crucial to a project design becoming a reality. The design team obtained information regarding the sustainable efforts of the next phase of redevelopment in Gateway Park, and that implementing these technologies is complex. The cost of the "green" technologies being implemented must be balanced with the desires and the budgets of the potential building occupants that would rent space.

An investigation of the condominium market in the surrounding Worcester area was performed by the design team. The results of this investigation were used in the design of condominium sizes, layouts, expected prices, and targeted tenants. By researching the condominium market in the area, the design team was able to create market-rate condominiums that would compete with similar units in the area and reduce the risk of vacant units in the proposed building.

3.2 Structural Layout and Design

Before the structural design could begin, the layout of the proposed building was established. Typical bay sizes were considered based on the proposed size and shape of the building footprint. Residential, commercial, and common areas of the building were then designated, and stairwells and elevators were incorporated into the layout. The structural design of the proposed building began with the determination of building dead loads and live loads. Use of the AISC Steel Manual, The Massachusetts Building Code, and the International Building Code helped establish the typical loading in both residential and commercial areas of the building, as well as atypical areas such as elevators and stairwells. The structural members were then designed in both steel and concrete based on the appropriate design loads.

The composite steel structural members of the proposed building were designed using the LRFD method. Both the *AISC Steel Manual* and *Steel Structures: Design and Behavior* textbook by Charles Salmon, John Johnson, and Faris Malhas were referenced in the design process of structural steel members. Additionally, tabulated values of section properties and strengths from the *AISC Steel Manual* were utilized during the design process. Excel sheets were created in order to solve repetitive calculations and streamline the design process. A sample of these spreadsheets is included in the results section, and the entire collection of design spreadsheets is included in the appendices.

3.2.1 Structural Composite Beam and Girder Design

The first step in the design process of structural members is to select materials that will be used. For beams, girders, and columns the design team selected A992 grade steel with an ultimate strength $\mathbf{F_y}$ of 50 ksi and concrete with a compression strength $\mathbf{f'_c}$ of 4 ksi. For connection angles, the design team selected A36 grade steel with an ultimate strength of 36 ksi.

Once the materials have been selected, the design loads must be determined. The dead loads considered for the beam and girder design included the weight of the steel member, weight of the concrete slab, the ceilings, partitions, steel decking, HVAC components, and the living roof unit weight when saturated. The live loads considered were occupancy loads, snow loads, and roof live loads. Once the loads have been determined, the LRFD factors and load combinations may be applied. This service load is used to determine the factored load moment $\mathbf{M_u}$. The factored load moment must be less than the design strength $\mathbf{\Phi_b M_n}$.

The factored moment load is used to determine the section size of the beam or girder. To select the section size, either the design strength or the area of steel may be used as a reference in the tables of the *AISC Steel Manual*. If the design strength is chosen as the criteria, as it was in this project, Table 3-19 (Composite W-Sections) of the manual is used as a reference. The member is assumed to exhibit full composite behavior and the plastic neutral axis is located at the top of the steel flange. Additionally, the variable ***a***, which is the thickness of the portion of slab experiencing compression forces during bending, is assumed to equal 1 inch. Using these design criteria, a section may be chosen from the table that possesses a design strength $\Phi_b M_n$ greater than the factored moment load M_u.

The next step of the design process is to compute the actual location of the plastic neutral axis and check the actual strength of the member against the factored moment load. In this step, the values that were assumed in the previous step are calculated using the properties of the section that was chosen. Determining the actual value of the effective slab width $\mathbf{b_E}$ and the variable *a* will result in the determination of the actual plastic neutral axis location and strength of the section. The effective width is the lesser value of either the beam spacing or ¼ of the span length. The value for *a* is determined using the following equations:

$$C = .85 \times f'_c \times b_E \times a \qquad \textit{Equation 1}$$

$$T = A_s \times F_y \qquad \textit{Equation 2}$$

By solving for T and setting T equal to C, the variable *a* may be solved. This value, along with the slab thickness $\mathbf{t_s}$ and the section depth **d**, is then used in the following equation to determine the actual factored nominal design strength $\Phi_b M_n$.

$$\Phi_b M_n = 0.9 \times T\left(\frac{d}{2} + t_s - \frac{a}{2}\right) \qquad \textit{Equation 3}$$

This strength is checked against the factored load moment M_u to ensure that the beam or girder can support the service load. If the strength is satisfactory, the shear stud connectors may be designed. If the strength fails to support the factored load, a larger section must be selected. (Salmon, Johnson, & Malhas, 2008)

Once a section that meets the strength requirements has been chosen, the deflection under construction and service loads must be checked. The following equation is used to determine the maximum beam deflection:

$$\Delta = \frac{5\omega L^4}{384EI} \qquad \text{Equation 4}$$

In order to determine the service deflection and construction deflection, the ω in this equation represents the factored service load and the factored construction load. The maximum beam deflection must meet the requirements of the IBC and state building codes. For this project, the beams were designed for a service deflection less than 2/3 inch and a construction deflection less than 1 inch. If the beam does not meet the deflection requirements, the equation may be rearranged to determine the minimum required moment of inertia for the beam.

The design of the shear studs is based on the strength of each stud and the compressive force in the slab that must be carried by the shear studs. If the value *a* is less than the slab thickness t_s, the entire compressive force is contained within the slab and the required shear strength V_{nh} is equal to the compressive force C. The following equation may be used to determine the number of shear connectors required for half the span:

$$N = \frac{V_{nh}}{Q_n} \qquad \text{Equation 5}$$

where Q_n is the nominal strength of one shear stud connector. This strength is based on the dimensions of the stud and the compressive strength of the concrete. The value of N is rounded up to the nearest whole number (because fractions of a stud cannot be used) and doubled to determine the number of studs required for the entire span of the beam or girder. The spacing of these studs is determined by simply dividing the length of the beam or girder by the number of required studs. The maximum spacing is given as 8 times the thickness of the slab, and the minimum spacing is given as six times the diameter of the stud. If these requirements have been met, the composite beams and girders have been fully designed.

3.2.1.1 Structural Column Design

In the design of steel columns, the same materials are used as in the composite beam and girder design. The first step in the design of the columns is to determine the loads that must be supported by the columns. Dead loads that are considered in the load determination include the steel sections for beams and girders, the concrete slab and metal decking, ceilings, partitions and HVAC components. The living roof loads were considered for the top floor. Live loads considered include the occupancy live load, roof live load, and snow load. The loads are then combined using LRFD load combination factors. The factored column service load $\mathbf{P_u}$ is determined by applying this load combination.

In order to design an appropriate section for the columns, the Euler equations of buckling are used. The following equations are the Euler equations for the critical load and stress of a column:

$$P_{cr} = \frac{\pi^2 EI}{L^2} \qquad \textit{Equation 6}$$

$$F_{cr} = \frac{P_{cr}}{A_g} = \frac{\pi^2 E}{(L/r)^2} \qquad \textit{Equation 7}$$

In these equations, E is the elastic modulus, I is the moment of inertia of the section, L is the length of the member, A_g is the gross cross-sectional area of the member, and L/r is the slenderness ratio of the column. To obtain the basic column strength, these Euler equations must be modified into the following equation:

$$P_{cr} = \frac{\pi^2 E_t}{(KL/r)^2} A_g \qquad Equat\ i\varepsilon$$

In this equation, K is the effective length factor. This value is determined by the type of connection at either end of the column and represents the length between points of inflection during column buckling. For a column with pinned connections at both ends, the K value is 1. For columns with fixed connections at both ends, the K value is about 0.5. The factored nominal column strength $\boldsymbol{\phi_c P_n}$ is then determined and compared to the factored column service load so that $\boldsymbol{\phi_c P_n < P_u}$. Table 4-1 of the AISC Steel Manual contains values of column strengths based on section size, member length, and K value that are used to determine appropriate column strengths in this project.

3.2.1.2 Structural Steel Connections

The typical beam-to-girder connections and girder-to-column connections are designed to resist the maximum shear force due to the service load. These connections were designed using typical connections tabulated in the AISC Steel Manual. Table 10-1 allows for the selection of bolted connections based on bolt size, number, and layout. Table 10-4 allows for the selection of welded connections based on weld length and material strength.

Column Base Plates

The foundation or sub-structure of a building has a number of responsibilities in reference to its superstructure. Most apparent is its physical dispersion of gravitational forces from the structure to the ground below it. The greatest forces in our Gateway building are due to the weight of the structural elements, the physical additions to the building, live loads, and dead loads. The handling of these vertical stresses is especially important. Dead and live forces that are carried by the decking are transferred to the beams, and subsequently to the girders. The girders transfer the loads to the columns, which transfer the loads to the column footings at the base of a structure or building.

Column Base Plates are designed to transfer loads from the columns to the concrete footings. To determine the column size, we calculated the maximum column loading that could be expected in our building. We arrived at a 502-kip loading that could be expected in an interior column. Since the interior footings are designed using square geometry, we chose a square shape for the base plates. Concentric loads in the columns are more evenly transferred to the footings with similarly shaped base plates. Using the yield stress and design Ω_c for A36 Steel acquired from the McCormack textbook, we calculated the nominal area required for the base plate based on the loadings, designed the plates to be square, and calculated a conservative size and thickness to arrive at the final plate dimensions.

3.2.2 Reinforced Concrete Design

To create an alternate design to a steel framed structure, the building was also designed using reinforced concrete. Reinforced concrete structures use the compressive strengths of concrete with the tensile strengths of steel to create a frame that has qualities that either a concrete or steel frame would lack by itself. The design of the structure using reinforced concrete included a floor slab design including T-beams, girder design, and column design. Figure 7 shows the layout of a typical reinforced concrete structural bay. In this figure the T-beams run from the front of the building to the back, effectively cutting the loads carried by the slab in half.

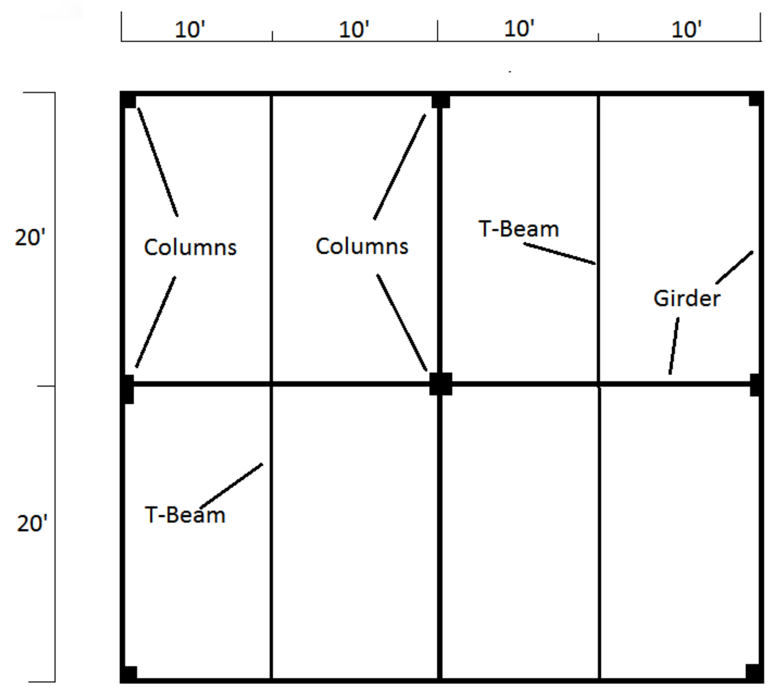

Figure 7: Typical Reinforced Concrete Structural Bay

Design was started with determining the materials to be used and the necessary loading. To help determine the necessary materials and load combinations, the text *Reinforced Concrete Design* by Wang, Salmon, and Pincheira was used as a reference. The concrete used in the design was given a dead load of 62.5 psf and 60 ksi steel was used for reinforcement. The same dead and live loads applied to the steel design were applied to the reinforced concrete design and load combinations following ASCE (American Society of Civil Engineers) code found in the previously mentioned text were used to find necessary concrete thickness and steel reinforcement.

To perform the design once the materials and loading was selected, the text was again used including applicable tables and codes it called for. To make calculations and formulas easier to compute, all work for the reinforced concrete design was completed using spreadsheets in Microsoft Excel, which are located in the appendix.

3.2.2.1 Slab Design

The concrete slab was the first part to be designed. To start the design the floor thickness is estimated and then tested for adequacy. Using the newly determined floor thickness the dead load was recalculated adding the weight of the slab to the previously used dead load. Next, to check the shear capabilities of the slab, shear reduction factors are applied the slab is tested. The last part of the slab design was the design of the reinforcement bars. A minimum area of reinforcement steel required by testing for the moments in the slab and using Table 3.9.1 from the text the type and amount of reinforcing bars were found. (Wang, Salmon, & Pincheira, 2007)

3.2.2.2 T-Beam Design

The T-beam design was completed by first estimating the weight of the stem protruding from the concrete slab based on the calculated dead and live loads. With an estimated weight found, different size stems were tested to fit the required shape of the stem and still have enough volume to carry the loads. As with the slab, once the beam is designed a new dead load was found and new factored load calculated. The next step was to find the necessary area of reinforcement bars and determine which size and amount of bars should be used. The moments acting upon the beam were then calculated, checking all calculated values.

3.2.2.3 Girder Design

The girders, the next part of the reinforced concrete design to be completed, were designed to carry the loads of the slab as well as the T-beams. The weight of the girder was estimated first and the factored moment was calculated with the dead load. The size of the girder was then determined based on moment calculations and the dead load was recalculated. The moments were then rechecked with the final dead load and once satisfactory the area of reinforcement steel was found. The necessary reinforcement steel bars were then found the same as with the slab and the T-beams.

3.2.2.4 Column Design

The columns were the last part of the reinforced concrete design and were designed to carry all loads that act upon the building. In order to make the column design easier we chose to design one column, a first floor interior column. A column in this location would be the biggest of all the columns in the building since it has a larger tributary width than exterior columns and carries the loads of all floors above it. By finding the moments acting on the column, an estimated trial size was determined as well as estimated reinforcement steel. Moments were then recalculated to check the values found and the necessary column size and reinforcement was confirmed

3.2.3 Lateral Load Resisting System

RISA

We used RISA 3D to analyze our structure and determine problem areas in the structure. RISA 3D is one of several software created by RISA Technologies, LLC, that allow users to analyze various structural components in graphical and spreadsheet form (RISA Technologies, LLC). We graphically assembled our building by defining nodes, then assigning members and fixities to the nodes. After the 400+ nodes were designated, and all members and end conditions were specified, loadings were applied. The IBC-established loading combinations for Live Loads, Dead Loads, Snow Loads, and Wind Loads were applied and the RISA software was used to generate results for joint reactions, member reactions, deflections, and more.

MASTAN2

In order to verify and double-check our hand-calculated forces and the RISA software output, we utilized another analysis software called MASTAN2 (Ziemian, & McGuire). Developed by Professor Ronald D. Ziemian of Bucknell University and Professor William McGuire of Cornell University, the program is based on a MATLAB back-end with numerical calculations based on textbook formulas. MASTAN stands for Matrix Structural Analysis and is based on a similarly titled book which the two professors took a part in writing. This software is very similar to RISA 3D with a simpler routine for element definitions and numerical output. We created a rendering of a sample portion of our building large enough to gain accurate loading for interior, exterior, and corner columns

3.3 Foundation Design

The foundation of the proposed building was designed using the LRFD method. The design team used *Foundation Design – Principles and Practices,* second edition, by Donald P. Coduto as a reference in the design process. The design team also used spreadsheets created by Coduto for use in conjunction with his textbook.

The first step of the foundation design process is the selection of the foundation type. The design process of a building foundation depends heavily on the existing site geology and the size and weight of the proposed building. The soil profile presented in the background section (see Figures 5 and 6) was prepared using the borings from the Maguire Group geotechnical report, and soil properties that were not provided in the geotechnical report were estimated based on the USCS soil classification. Soil properties can have a crucial effect on the performance of a foundation system, depending on the type of soil and foundation. Additionally, the geotechnical report recommended the use of spread footings for a similar structure that has since been constructed in Gateway Park. A shallow foundation is appropriate for the proposed building at One Concord Street because it, if designed properly, will effectively transfer the column load to the ground with little settlement. Generally, deep foundations are used for large buildings in areas with soft clays that may settle and cause overturning or sinking of a shallow foundation. In these cases, piles must be drilled to bedrock in order to provide a stable foundation for the large structure.

The spread footing dimensions were determined using the spreadsheets from Coduto. The user selects the shape, size, depth of the top of the footing from the surface, and material of the footing, and factored column service load. Additionally, the user must input several subsurface properties, such as the depth of groundwater and unit weight of the soil. Using these values, the spreadsheet automatically calculates the bearing capacity of the footing using both the Vesic and Terzaghi methods and determines if it is sufficient for the given loading. The dimensions of the footing are easily changed to accommodate repetitive calculations of footing size. Using this technique, the design team determined the dimensions for footings to support typical interior, exterior, and corner columns. Footing dimensions were determined for the proposed building with a basement and without a basement.

Once the dimensions of the footings have been determined, the structural reinforcement must be designed in order to resist shear and flexure. The shear force $\mathbf{V_{uc}}$ is determined by the following equation:

$$V_u = \left(\frac{P_u}{4} + \frac{M_u}{c+d}\right)\left(\frac{B^2 - (c+d)^2}{B^2}\right)$$

where B is the square footing width and length, P_u is the column load, c is the column base plate width and length, d is the depth from the top of the footing to the steel rebar, and M_u is the applied moment on the footing. Generally, the rebar is placed three inches from the bottom of the footing. Therefore, the value of d is equal to the total depth of the footing minus three inches and the diameter of the rebar. The factored nominal two-way shear capacity of the critical section $\mathbf{\Phi V_{nc}}$ is determined using the following equation:

$$\Phi V_{nc} = 4 b_0 d \sqrt{f'_c}$$

where b_0 is the length of the critical shear surface and f'_c is the compressive strength of concrete, in units of pounds per square inch. The value of Φ for shear is 0.85. The factored nominal two-way shear capacity must be greater than the shear force on the footing.

In order to design the rebar to resist flexure in the footing, the factored moment of the section $\mathbf{M_u}$ must less than the factored nominal moment capacity $\mathbf{\Phi M_n}$ of a flexural member made of reinforced concrete. The following equations are used to determine M_u and ΦM_n:

$$\Phi M_n = A_s f_y \left(d - \frac{a}{2} \right)$$

$$M_u = \frac{P_u l^2}{2B}, \quad where \, l = \frac{(2B - (c + cp))}{4}$$

Once the moment has been found, the area of required steel must be determined in order to obtain the necessary values for determining the moment capacity. The following equations are used to determine these necessary values:

$$A_s = \left(\frac{f'_c b}{1.176 f_y} \right) \left(d - \sqrt{d^2 - \frac{2.353 M_{uc}}{\Phi f'_c b}} \right)$$

$$a = \frac{A_s d f_y}{0.85 bd f'_c}$$

These equations are used to determine the area of required steel and the factored moment capacity of the footing with structural steel reinforcement. (Coduto, 2001)

3.4 Sustainable Design Elements

The sustainable technologies incorporated into this project ranged from simple to highly involved in their levels of design complexity. A living roof, solar panels, geothermal heating and cooling, and reusable materials were all considered in order to create a more environmentally responsible building.

A decision matrix was created in order to establish the more efficient use of roof space. The matrix considers the cost of the technology, the weight (which impacts the structural design), and value added to the building, and the value added to the community. Research of particular makes and models of the solar panels and living roof installations were researched in order to completed the decision matrix and establish a layout of the roof. The decision matrix and roof layout are presented in the forthcoming results section.

The RETScreen software described in the background sections was implemented in the design of the ground source heat pump. The heating and cooling requirements of the building were estimated and entered into the software, as well as the square footage of the building, and its location. Next, ground source heat pumps were chosen from a database based on the heating and cooling capacities. The type of system, vertical closed loop for this project, was chosen and the level of compaction was selected in order to determine the required surface area and linear footage of boring required for the ground source heat pump system. The software then allowed for the selection of an alternative source of heating and cooling in order to satisfy high peak loads so that the renewable energy system is not forced to satisfy all the energy requirements of the proposed building.

The eQUEST software described in the background sections was implemented in determining the energy demands of the building. The software takes information on the proposed building in forty different categories allowing for a very accurate representation of how the building will perform once constructed. Using the projected energy, heating, and air conditioning demands that the building will require, renewable and sustainable materials will be added to the building to help offset the demands where economically viable.

3.5 LEED Certification

During the background research of the LEED green building certification system, the design team obtained a checklist and manual for scoring a building based on the LEED point system. The checklist includes all the credits that a building may score points with, as well as the number of points that can be earned. For some credits, points are scored on a scale based on thresholds established by LEED. For example, a building may score 1 point for on-site renewable energy of at least 1% of the building's total energy cost. This point value may increase up to 7 points for 13% of the building's total energy cost.

The design team used the checklist and the accompanying manual to score the proposed building based on credits that applied, could apply, or did not apply to the building based on the level of design completed by the design team. The credits that applied to the building and the credits that may apply to the building will be outline in the results section. The credits that may apply to the building will be explained in detail in order to demonstrate how they could apply to the building in a capacity that is beyond the scope of this project. Therefore, the LEED score of the building design within the scope of the project, as well as the potential score beyond the scope of this project, will be presented in the results section.

3.6 Cost Estimation

One of the most important areas of project management lies in the calculation of material quantities and costs and the prediction of costs associated with their fabrication, delivery, and installation. Cost estimation is essential for projects of small and large proportions, especially for the owner's party. A reliably-calculated estimate aids the owner in making decisions and alterations in the materials and construction procedures based on the costs from the estimate weighed against realized capital and projected revenue from the completed structure (rented space, sales, etc.). Furthermore, an owner can use a preliminary estimate as a reference when soliciting bids from contractors, tracking costs during the construction phase, and for a variety of other applications.

We acquired data from Get-A-Quote, a company that collects data from U.S. estimating agencies and provides the information online at no cost (CD Estimator Heavy – Massachusetts).

We based our estimates on average costs generated for Massachusetts in 2009. Estimating data is presented with craft codes, which can be used to determine the number and type of workers required for supplying/installing construction, helpful for contractor scheduling. In addition, the company provides average material cost per unit. We used unit costs to determine an estimated cost for the production and delivery of the material based on our take-off quantities. Another important cost to consider is the cost of labor, which is dependent upon the craft code group required for the job. Get-A-Quote provides these estimated costs in terms of the material units to be installed, so we calculated projected costs based on our material quantities. The final cost included in our estimates was the pricing involved with special tools and supplies necessary for our construction materials. Items like rented power equipment, formwork and shoring are included in these costs. Conveniently, these costs are given in terms of unit costs, so we calculated ST&S in terms of the material quantities as well.

4.0 RESULTS

4.1 Structural Steel Results

Structural members of the proposed mixed-use facility at One Concord Street were designed using steel. Typical beams, girders, and columns were designed for the building. Atypical areas such as stairwells and elevator shafts were also designed using steel.

4.1.1 Typical Steel Members

The structural steel members designed for the proposed building were designed to be fully composite. The concrete slab to be used for the floors and roof was the first step in the design process. According to the IBC, the concrete slab with 1.5 inch steel decking must be at least 3 inches thick in order to achieve the 2-hour fire safety rating. Therefore, the concrete slab thickness is 4.5 inches. This thickness satisfies the fire safety rating and also the length of shear stud connectors that will result in composite action between the steel beam and the concrete slab. Figure 8, is a cross-section view of the concrete slab and steel decking.

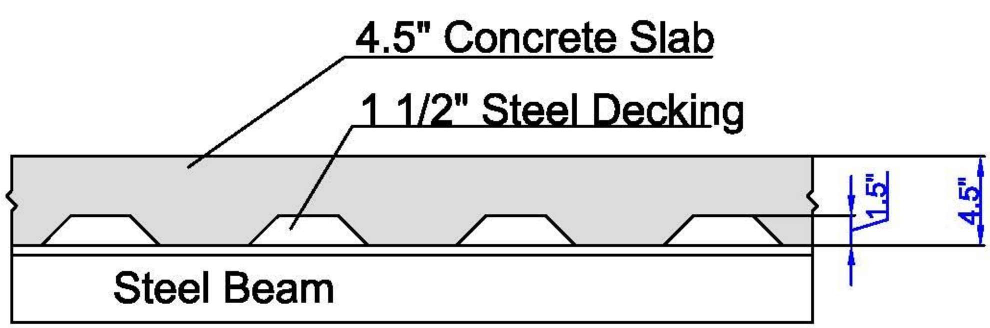

Figure 8: Composite Steel Beam and Slab Cross Section

Once the concrete slab has been designed, the steel sections may be chosen. Initially, the residential floor layout consisted of 20 foot square bays and the commercial floor layout consisted of 30 foot square bays. The larger bay size on the ground floor would allow for fewer columns and more open space in the planned retail and dining facilities. The resulting beams and girders were designed using the spreadsheet shown in Figure 9. The calculations for all beams and girders may be found in the appendices.

The larger bay size resulted in a significantly larger tributary area for interior girders. As a result, the girder section size had to be increased to a very large size in order to meet the deflection requirements. The increased cost of these sections was one of the reasons the design team decided to utilize the smaller 20-foot square bays for the commercial first floor. The change in bay size would result in the same section sizes as the residential floors.

To simplify the construction process, the typical interior girders were chosen for all girders in the building. Although exterior girders would have a smaller section size, such as W12x30, the difference is not extremely large and the use of only one girder size throughout the entire building would vastly simplify the fabrication and construction phases. All the loads considered are shown in Table 1.

Table 1: Building Loading Used in Structural Design

DEAD LOADS	LIVE LOADS
Concrete slab = 56.25 psf	Occupancy = 50 psf
Partitions = 20 psf	Snow = 55 psf
Ceilings = 1 psf	Roof LL = 20 psf
Green Roof = 25 psf	
HVAC = 5 psf	
Insulations = 1.5 psf	

Interior Composite Beam LRFD

Span (feet):	20	f'c (ksi):	4
Spacing (feet):	5	Fy (ksi):	50
Slab Thickness (inch):	4.5		

LL (psf):	50	LL (plf):	250
Partitions (psf):	20	Partitions (plf):	100
Ceiling (psf):	5	Ceiling (plf):	25
Slab (psf):	56.25	Slab (plf):	281.25
Roof (psf)	25	Roof (plf)	125
HVAC (psf):	5	HVAC (plf):	25
Insulation (psf):	1.5	Insulation (plf):	7.5
Steel (psf):	19	Steel (plf):	19

Factored DL (plf):	660.3
Factored LL (plf):	400

M_D (kip-ft):	33.015
M_L (kip-ft):	20
M_u (kip-ft)	53.015

Estimate Y2:	t_s-a/2	4

	SECTION	$\Phi_b M_n$	A_s (in^2)
option 1	W10x19	192	5.62
option 2	W		

Assuming Y1 =distance from PNA to top of steel beam=0"

	I_x (in^4)	b_f (in)	d (in)	ΣQ_n (kip)
option 1	96.3	4.02	10.2	281
option 2				

Effective Slab width b_E			
	1/4 of span (in)	60	CONTROLS
	beam spacing(in)	60	

C (kips/in)	204	a	
T (kips)	281		
a (in)	1.38	<t_s?	TRUE

Φ_bMn (kip-ft):	187.81	>Mu?	TRUE

Max p (in)	36	Qn (kip):	26.1	3/4"x3" stud
N (# of conn. per half)	10.76628352	Use	22	per span
Spacing (in):	10.91			

Deflection Δ (in):	0.52	<.67"?	TRUE

Use 46 connectors spaced every 9"
Use W16x40 section

Figure 9: Steel Girder and Beam Calculations

The resulting member sizes and shear stud connectors are summarized in Table 2.

Table 2: Steel Member Sizes

MEMBER TYPE	SECTION SIZE	SHEAR STUD	# OF STUDS
Beam	W10 x 19	¾"x3" stud	22
Girder	W16 x 31	¾"x3" stud	36

Once the beams and girders were designed, the column section sizes were chosen. In order to utilize Table 4-1 of the *AISC Steel Manual*, the column loads were determined. To determine the column loads, all loads were converted to units of pounds per square foot. Beam and girder weights were divided by tributary areas to convert from units of pounds per linear foot to pounds per square foot. Columns on lower floors carry the weight of all the floors above them, increasing the loads as the columns approach the ground. Column loads were determined for a building with a basement level and without a basement level. Column loads for the ground floor using column tributary areas were calculated using the spreadsheet shown in Figure 10.

Column Loads

Typical Interior Column (Basement Floor)		
Tributary Area	400	sq. ft.
Distributed Dead+Live Load	1309.2	psf
Column Load	523.68	kip
Typical Exterior Column (Basement Floor)		
Tributary Area	200	sq. ft.
Distributed Dead+Live Load	1309.2	psf
Column Load	261.84	kip
Typical Corner Column (Basement Floor)		
Tributary Area	100	sq. ft.
Distributed Dead+Live Load	1309.2	psf
Column Load	130.92	kip
Typical Interior Column (NO Basement Floor)		
Tributary Area	400	sq. ft.
Distributed Dead+Live Load	1255.696	psf
Column Load	502.2784	kip
Typical Exterior Column (NO Basement Floor)		
Tributary Area	200	sq. ft.
Distributed Dead+Live Load	1255.696	psf
Column Load	251.1392	kip
Typical Corner Column (NO Basement Floor)		
Tributary Area	100	sq. ft.
Distributed Dead+Live Load	1255.696	psf
Column Load	125.5696	kip

Figure 10: Spreadsheet Calculating Column Loading

The beams, girders, and columns that were designed are shown in the following figures. Figure 11 shows the layout of residential floors and Figure 12 shows the layout of the commercial ground floor.

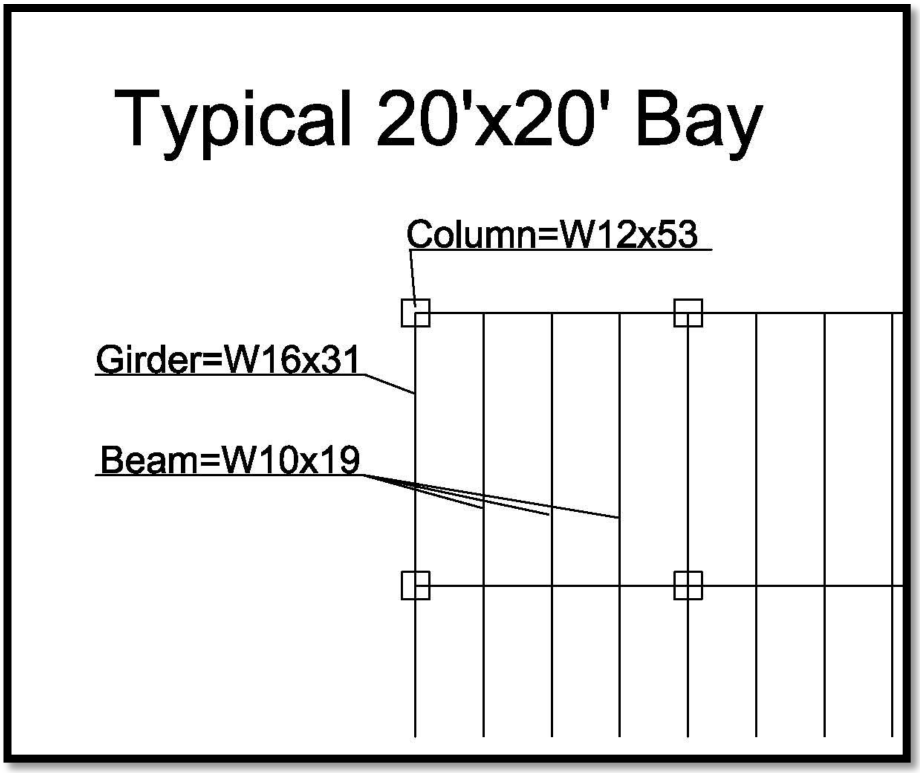

Figure 11: Residential Floors Typical Structural Bay

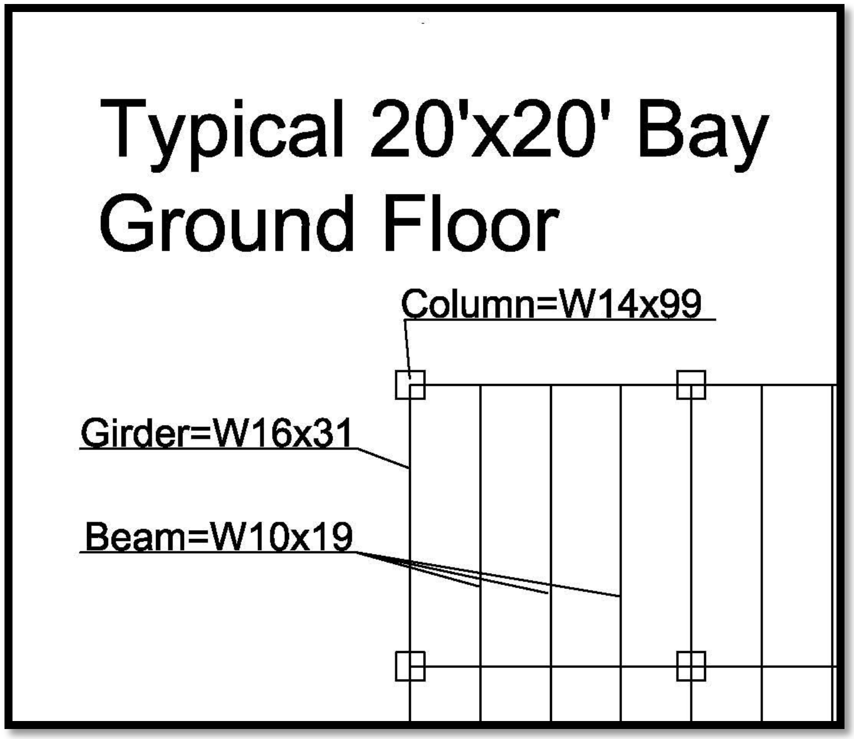

Figure 12: First Floor Typical Structural Bay

4.1.2 Typical Structural Steel Members

Areas such as stairwells and elevator shafts require special attention in the design process. These areas experience different loadings and require different sizes. The design team consulted with an expert in the elevator maintenance and installation industry to determine appropriate elevator loads and requirements. The specific elevator loads were used to design a separate frame to transfer elevator loads to the ground without being influenced by the main building frame. Generally, elevator frames are designed separately to better resist seismic events and increased loads due to the elevators.

The primary members of the elevator frame were designed using the same spreadsheets used for typical members. The elevator load was considered to be the capacity of the elevator, the weight of the elevator, and the counterweight. A factor of safety of 5 was used, as stated in the elevator appendix to the Massachusetts Building Code. The structural members of the elevator frame are shown in Table 3.

Table 3: Elevator Frame Structural Members

MEMBER	SECTION SIZE
First Floor Column	W 12 x 45
Upper Floor Column	W 12 x 45
First Floor Girder 1	W 12 x 50
Upper Floor Girder 2	W 12 x 50

The layout of the elevator frame is shown in Figure 13. This figure shows the location of the girders and columns designed for the elevator frame as well as the girders and columns designed for the main building frame. Figure 14, shows the cross-section view of the elevator frame.

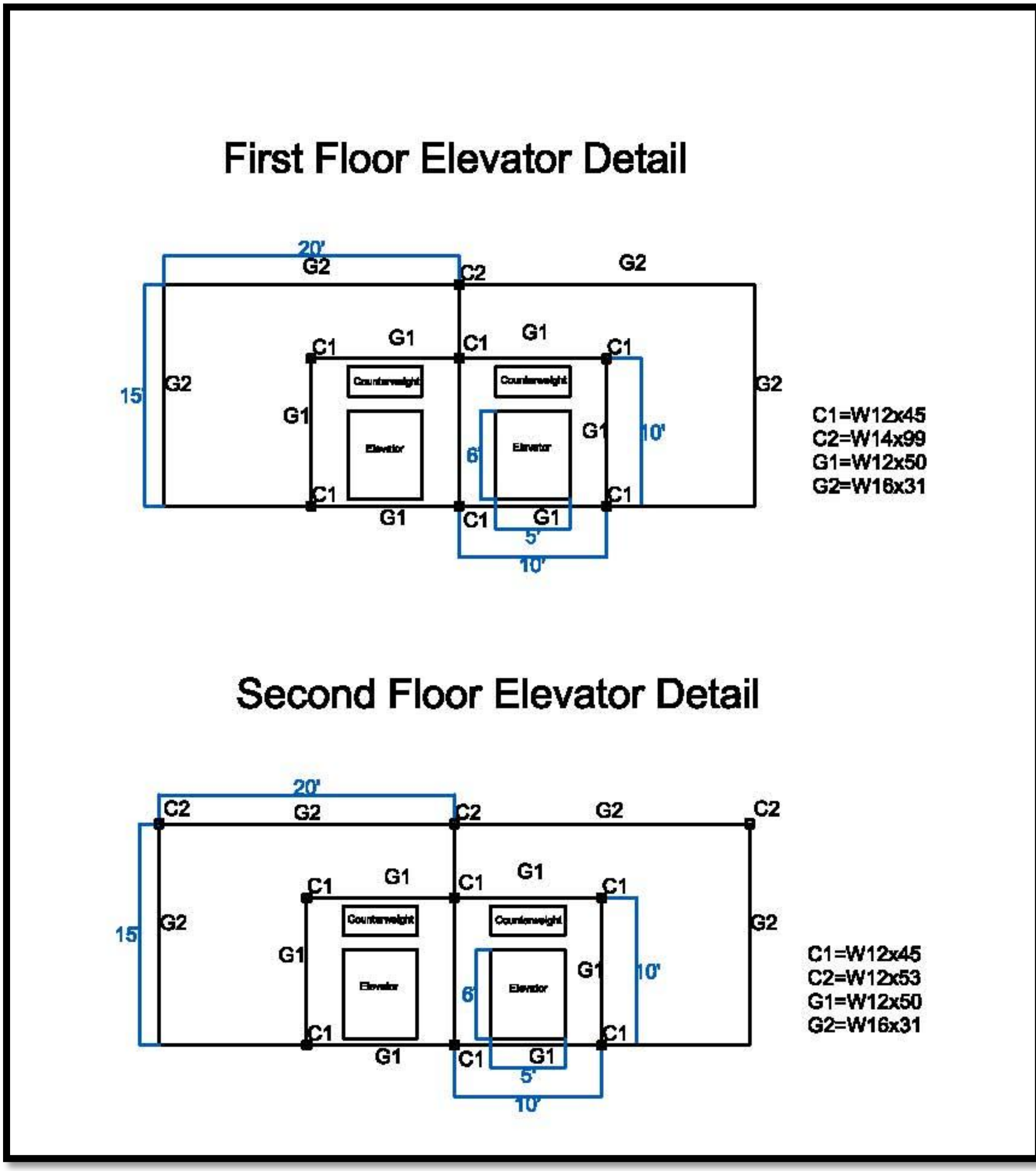

Figure 13: Elevator Shaft Layout

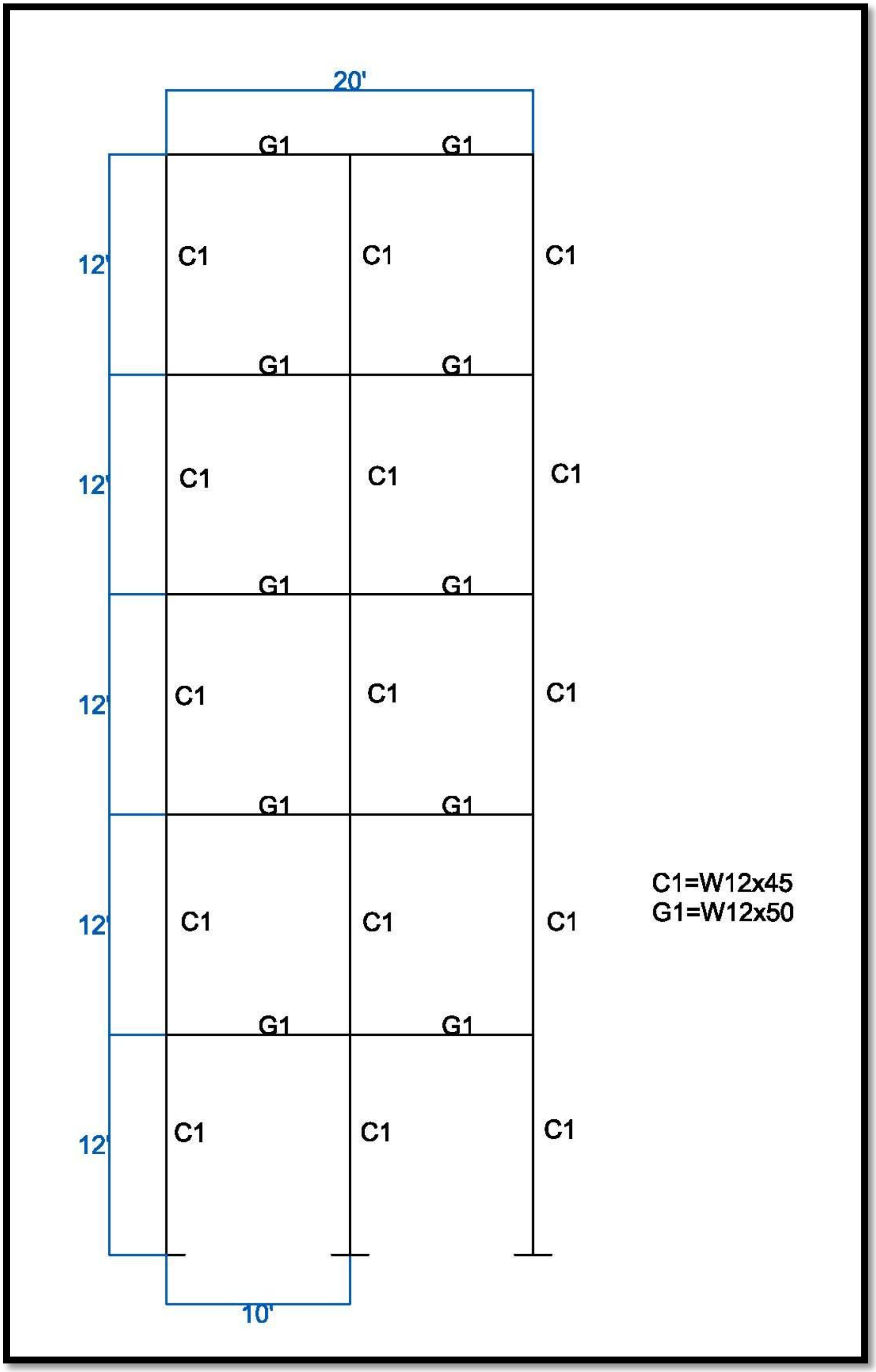

Figure 14: Elevator Shaft Cross Section

The typical stairwell design utilized a similar loading to the typical building beams and girders. The structural members of the stairwell were designed using the same design spreadsheets used for typical members. The live load used was also equal to 50 pounds per square foot. The primary difference in the design of the stairwells was the smaller member lengths required for the atypical area. The shorter length resulted in smaller bending moment and shear forces, so that smaller section sizes could be used. The selected member sizes are presented in Table 4.

Table 4: Typical Members for Stairwell

MEMBER	SECTION SIZE
First Floor Column C1	W 14 x 99
Upper Floor Column C2	W 12 x 53
First Floor Girder G1	W 16 x 31
Intermediate Stair Girder G2	W 10 x 19

Figure 15 shows the cross-section view of the stair layout and includes the location of special stairwell girders and typical building girders and columns. Figure 16 shows the overhead view of the stairwell layout and includes stairwell dimensions.

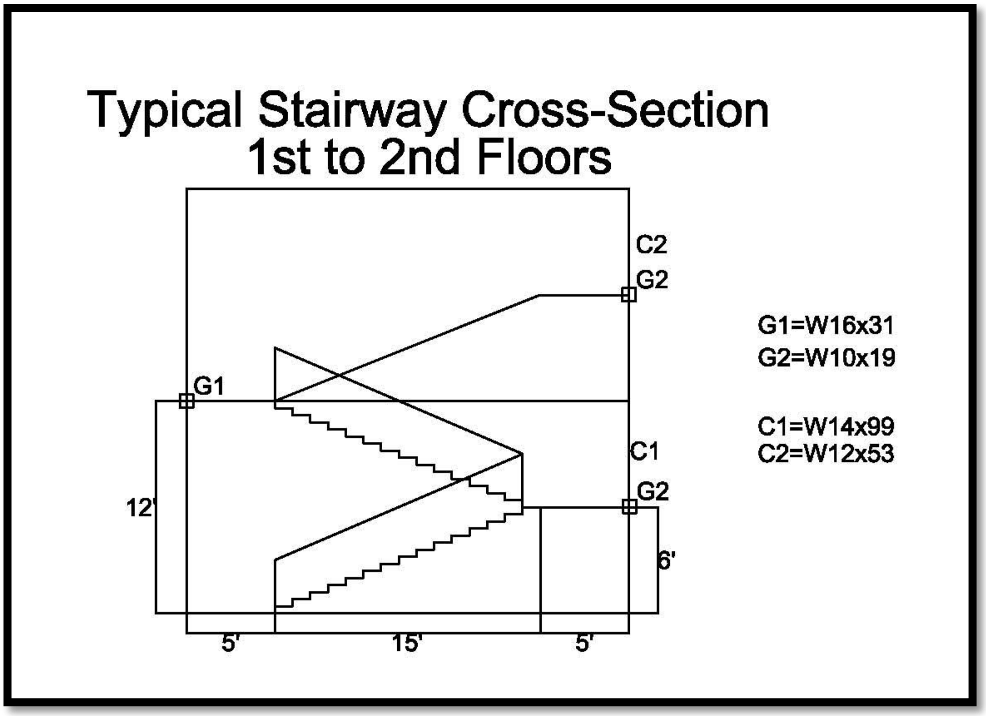

Figure 15: Stairway Cross Section

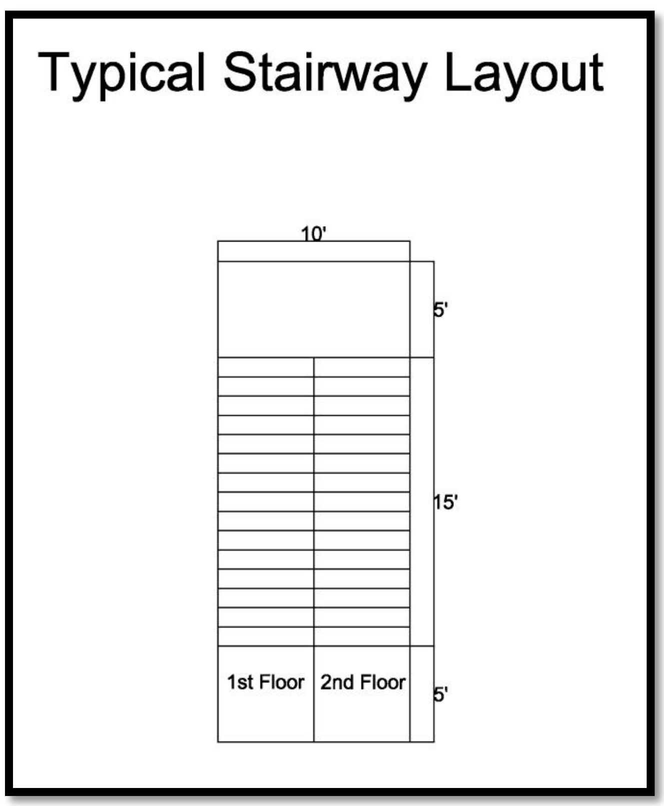

Figure 16: Stairway Layout

4.1.3 Steel Member Connections

The connections for steel members were designed using Table 7-1 of the *AISC Steel Manual*. These connections will be used to bolt beams to girders and girders to columns. The connections designed are for typical members of the building frame. The connections are either single or double angle bolted connections and were designed using the tabulated shear strength of the bolts and the shear force acting on the beams and girders.

Figure 17 is the connection detail for beam-to-girder connections throughout the building. This connection consists of a single angle with dimensions of 3 1/2” x 3 1/2” x 10”and a thickness of ½”. Three A490 bolts with 7/8” diameters will be spaced 3” on center.

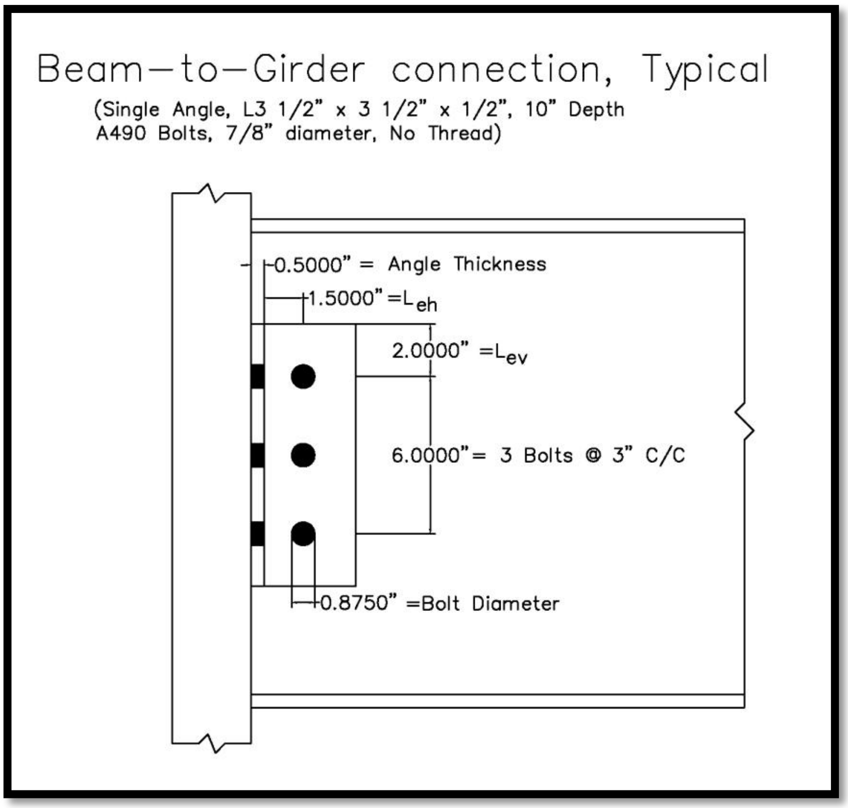

Figure 17: Typical Steel Beam to Girder Connection

Figure 18 is the connection detail for the girder-to-column connections throughout the building. This connection consists of a double angle with dimensions 3 ½" x 3 ½" x 10" and a thickness of ½". Three A490 bolts with 7/8" diameter spaced 3" will be used for each angle.

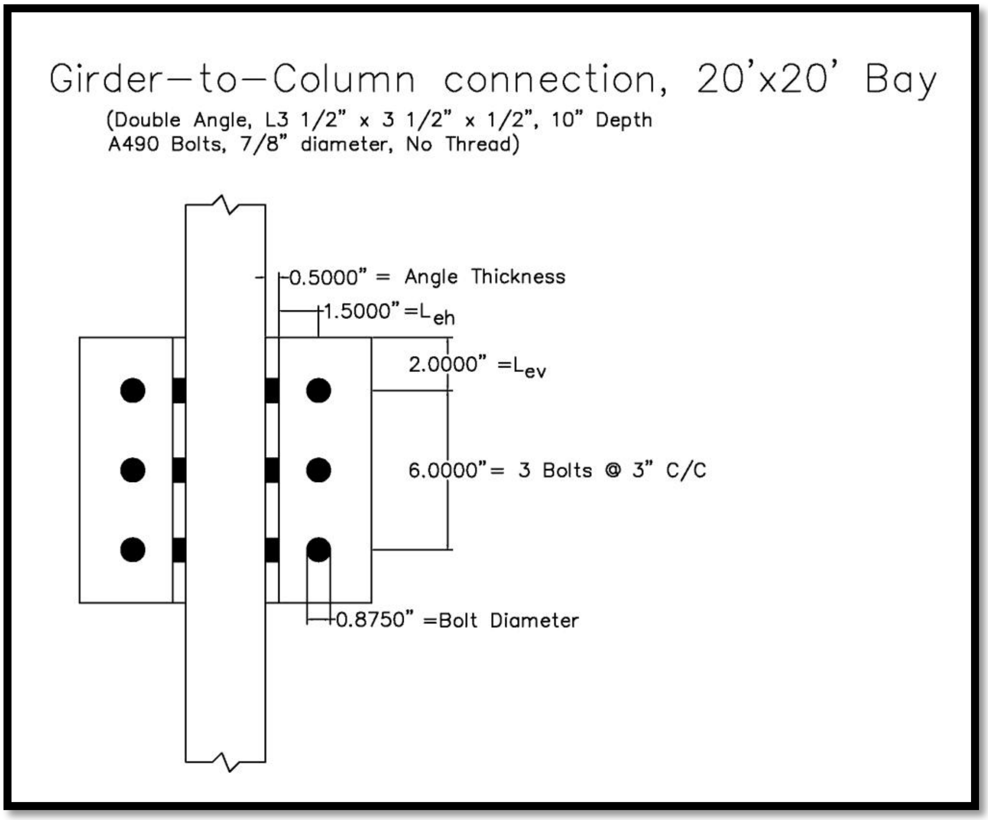

Figure 18: Typical Girder to Column Connection

These connections are not moment-resisting connections that are assumed in the analysis of the building frame. These connections simply resist the shear force that acts between beams, girders, and columns. A complete connection that resists moments would require additional plates and welding.

4.1.4 RISA – MASTAN Joint Deflections

Our analysis for the structural elements and connections was primarily completed using hand calculations, textbook formulas, and structural design Coduto Spreadsheets. By utilizing the RISA and MASTAN programs, we ultimately gained thorough sets of deflection data for our structure. Our main concerns we aimed to resolve with the use of these programs were the member loadings' affect on the sway of the structure during reasonably high wind speeds. For the Northern New England wind loadings, we consulted a Structural Engineering and Inspection site from Johannessen and Leone Associates for the local wind speeds. To calculate design wind loads, we used the 3 second wind gust speed for the Worcester area, which we interpolated to be 99 mph, since it lies in between the 90mph and 100mph wind speed zones. Using the following equation, we calculated the design wind loading for our building: Pnet = qs Kz Cnet [I Kzt]. The result was 88.5 psf. In RISA, we translated the load into forces applied laterally to our structure. As can be seen in Table 5, our deflections are very minimal (in the order of fractions of an inch).

Table 5: Vertical Joint Deflections

Node	Z	Y	X
N618	0	-0.064	0
N619	0	-0.063	0
N620	0	-0.126	0
N621	0	-0.063	0
N622	0	-0.063	0
N623	0	-0.126	0
N624	0	-0.063	0
N625	0	-0.063	0
N626	0	-0.126	0
N627	0	-0.063	0
N628	0	-0.066	0
N629	0	-0.131	0
N630	0	-0.066	0
N631	0	-0.066	0
N632	0	-0.131	0

Our joint deflections, disregarding foundation settlement, peaked at just over $1/10^{th}$ of an inch at the lowest joints in our building. The Y direction in the simulation represents elevation; X represents the East-West direction, and Z, the North-South directions. This table provides a sample of the largest deflections (in inches) calculated using the RISA software. RISA output for our sway deflections are displayed in Table 6. Deflections for our building were very small, as to be expected for a building with a 21,600 SF footprint and standing only 5 stories tall.

Node	Z	Y	X
N1082	-0.001	-0.083	0
N1083	-0.001	-0.045	0
N1084	-0.002	-0.044	0
N1085	-0.002	-0.082	0
N1086	-0.002	-0.043	0

Table 6: Sway Joint Deflections

4.2 Reinforced Concrete Results

Calculations for the reinforced concrete design were completed using spreadsheets from Microsoft Excel following load designs and formulas from the International Building Code as with the structural steel calculations. The bay sizes were the same at 20' x 20' and a live load of 40psf was used with an additional 20psf load for the green roof being added to the building.

4.2.1 One Way Slab Design

The one-way slab is designed by estimating the required thickness of the floor by using the span between columns and the loading based on occupancy. This estimated thickness was 5 inches. Then, using the loads of 40psf for live load and 5psf for HVAC with an additional 2.5psf for insulation and ceilings, and load combination equations the minimum floor thickness was calculated. The five-inch slab from the estimated thickness was found to be sufficient under the load combinations when combined with #4 reinforcing bars spaced fifteen inches apart. The slab was then checked for flexural strength, shear strength, and temperature reinforcement to be proved adequate.

4.2.2 T-Beam Design

The one-way slab was designed with a T-beam to help carry loads and ease stresses on the slab. The spans are effectively cut in half from 20' to 10' with the use of the T-beam. After using the factored loads from the slab calculations and calculating an estimated new dead load, a total required area for the T-beam was calculated. It was determined to use a depth of twenty inches and a width of twelve inches. Within the T-beam there are four #7 bars used for reinforcement. A cross-section of a typical T-beam is shown in Figure 19.

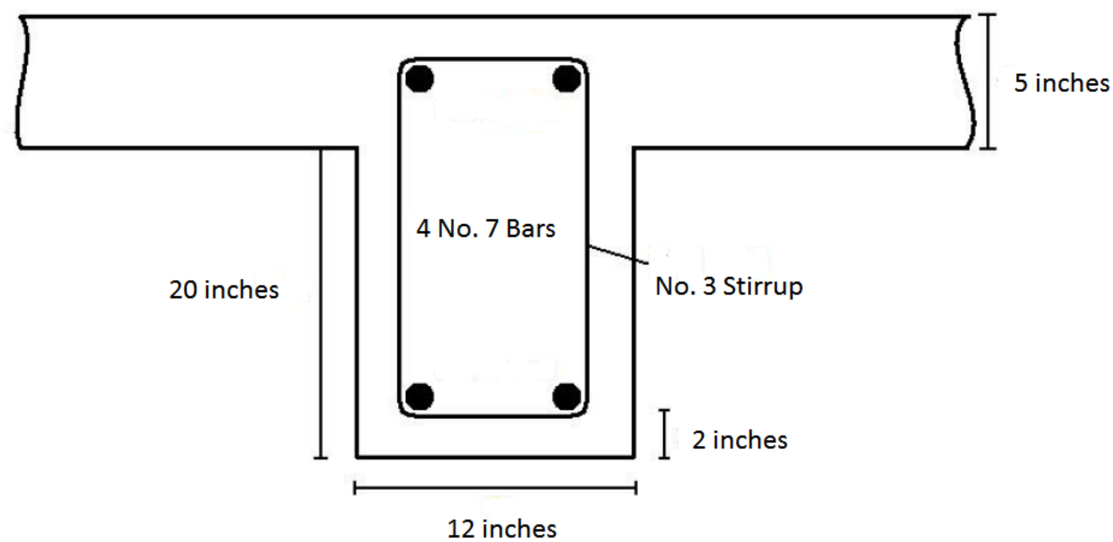

Figure 19: Typical T-Beam Cross-Section

4.2.3 Girder Design

The girders were the next part of the reinforced concrete structure to be designed. The girders were designed to be able to carry the weight of the concrete slab, the T-beam, and also any live loads that were used in the slab design calculations. Using these loads, factored moments were calculated and the required size of the girders was found. With the size of the girders thirteen inches wide and nineteen inches deep, the dead load was recalculated with the girders now included to determine the necessary reinforcing steel required. It was found that four #7 bars were sufficient reinforcements for the girders. A cross-section of a typical girder is shown in Figure 20.

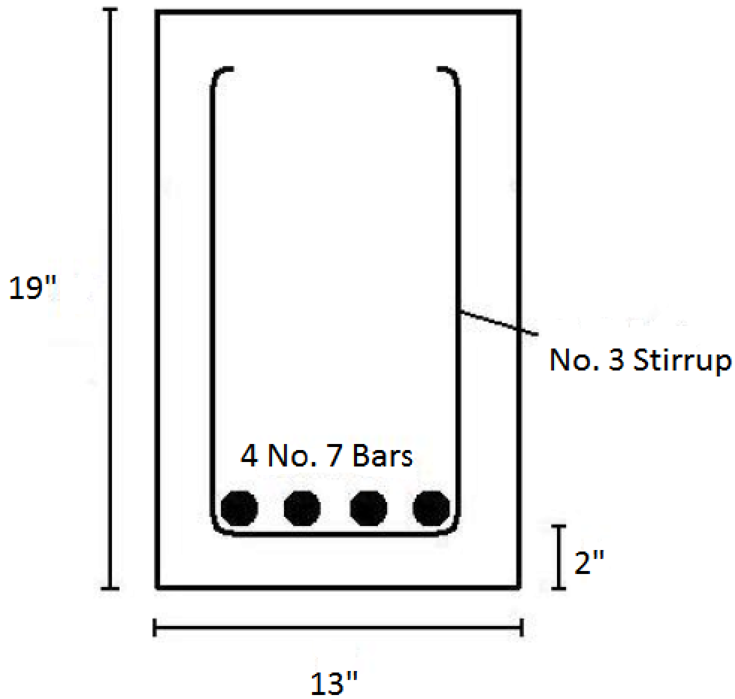

Figure 20: Typical Reinforced Concrete Girder

4.2.4 Column Design

The final structural component of the building to be designed was the columns. The columns were designed to carry the dead loads of the slab, T-beam, and the girders, as well as any live loads. The location of the column affected the loads that it carries; because of this a column was designed as an interior column of the first floor of our building. This was chosen as it has the greatest loads affecting it and has a larger tributary width than exterior columns would. To design the columns, first an estimated size is guessed with steel reinforcements. Using moment calculations, the required minimum size of the column is found by checking the values from the estimated size and making necessary adjustments. Once the size is checked the calculations for reinforcing steel and the necessary stirrups are checked. A typical first floor interior column is shown in Figure 21.

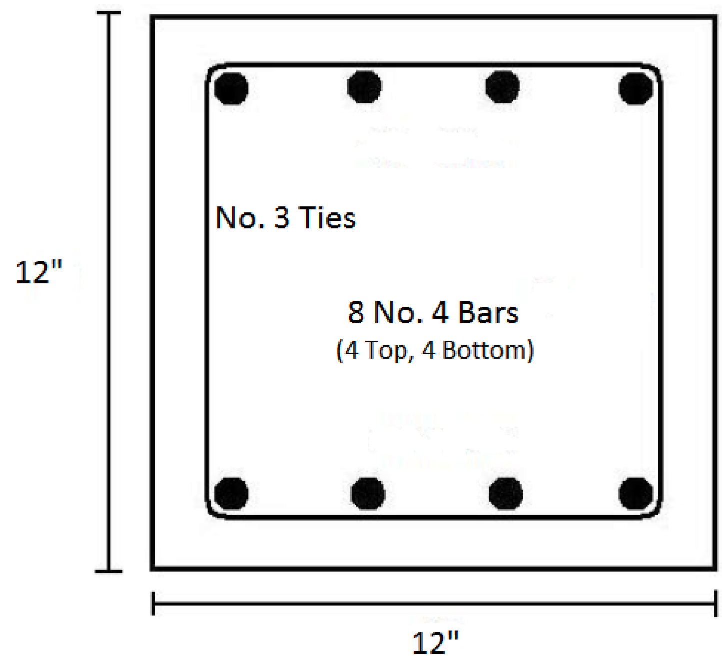

Figure 21: Typical Reinforced Concrete Column Design

4.3 Foundation Results

The foundation design required the selection of a soil profile and properties used in pertinent design equations. These properties dictate the bearing capacity of the soil and the settlement under specific loading conditions. The geotechnical report from the Maguire Group was useful in predicting several of these properties, but the lab testing portion of the subsurface investigation did not provide all the required information. Therefore, the design team estimated several properties based on the USCS classification of the soil in the area of One Concord Street. The soil profile in Figure 22 shows the typical classifications of soil in the area.

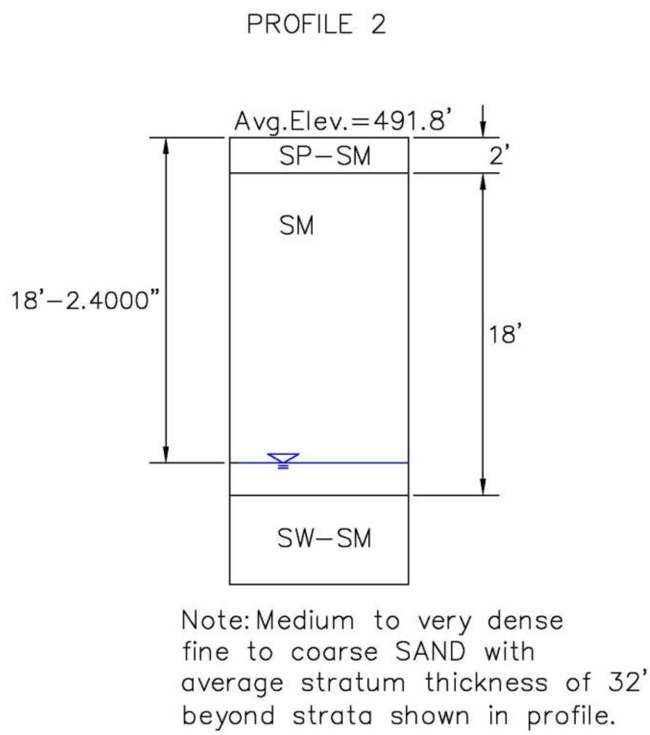

Figure 22: Typical Local Soil Classification

The soil shown in the soil profile above is granular. Therefore, the design team was able to assume that the cohesion of this soil is zero and an effective friction angle must be estimated. For medium dense sand, the effective friction angle was estimated to be 40°. The compression and recompression indices, Cc and Cr and over consolidation margin σ_m' were also estimated based on Tables 3.6 and 3.7 in Coduto's *Foundation Design – Principles and Practices*. These properties were used in the settlement analysis of the footings. The blow counts from the boring logs were used to estimate the unit weight of the soil. This unit weight was critical in determining the bearing capacity for the foundation design.

4.3.1 Footing Design

The spread footings for the shallow foundation were designed using Donald Coduto's spreadsheets, which will be included in the appendices. Using these spreadsheets eliminates the lengthy hand calculations required to determine the bearing capacity and settlement of a foundation. Figure 23, shows the set-up of the bearing capacity spreadsheet used to determine the dimensions of the footings.

BEARING CAPACITY OF SHALLOW FOUNDATIONS
Terzaghi and Vesic Methods

Date	February 18, 2010
Identification	Example 6.4

Input

Units of Measurement		
	E	SI or E
Foundation Information		
Shape	SQ	SQ, CI, CO, or RE
B =	4	ft
L =	4	ft
D =	4	ft
Soil Information		
c =	0	lb/ft^2
phi =	40	deg
gamma =	125	lb/ft^3
Dw =	18	ft
Factor of Safety		
F =	3	

Results

	Terzaghi		Vesic	
Bearing Capacity				
q ult =	64,926	lb/ft^2	88,083	lb/ft^2
q a =	21,642	lb/ft^2	29,361	lb/ft^2
Allowable Column Load				
P =	346	k	470	k

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Figure 23: Bearing Capacity Spreadsheet

Table 7 presents the footing sizes selected for interior, exterior, and corner footings for a building with a basement floor. Calculations were also performed for footings without a basement floor and will be included in the appendices.

Table 7: Footing Sizes

LOCATION	SQUARE DIMENSION	THICKNESS
Interior	5’x5’	3.5’
Exterior	4’x4’	3.5’
Corner	4’x4’	3.5’

Once the footings were designed to support the calculated column loads, the settlement was checked. The design team chose square footings with a depth of 4’ from the bottom of the basement. The settlement was limited to the lowest value possible for a footing with reasonable dimensions. For this project, footing settlement was limited to approximately 1”. The compression and recompression indices were estimated to be 0.03 and 0.006, respectively. The spreadsheet in Figure 24 was used to determine the settlement.

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS
Classical Method

Date: February 27, 2010
Identification: Interior Footing

Input

Units	E	E or SI
Shape	SQ	SQ, CI, CO, or RE
B =	5	ft
L =	5	ft
D =	4	ft
P =	523	k
Dw =	18	ft
r =	0.85	

Results

q =	21520	lb/ft^2
delta =	1.06	in

Depth to Soil Layer												
Top (ft)	Bottom (ft)	Cc/(1+e)	Cr/(1+e)	sigma m' (lb/ft^2)	gamma (lb/ft^3)	zf (ft)	sigma c' (lb/ft^2)	sigma zo' (lb/ft^2)	delta sigma (lb/ft^2)	sigma zf' (lb/ft^2)	strain (%)	delta (in)
0.0	4.0				125							
4.0	4.5	0.03	0.006	7000	125	0.25	7531	531	21004	21536	1.75	0.105
4.5	5.0	0.03	0.006	7000	125	0.75	7594	594	20639	21233	1.70	0.102
5.0	5.5	0.03	0.006	7000	125	1.25	7656	656	19546	20202	1.62	0.097
5.5	6.0	0.03	0.006	7000	125	1.75	7719	719	17814	18532	1.50	0.090
6.0	6.5	0.03	0.006	7000	125	2.25	7781	781	15772	16553	1.35	0.081
6.5	7.0	0.03	0.006	7000	125	2.75	7844	844	13719	14562	1.18	0.071
7.0	7.5	0.03	0.006	7000	125	3.25	7906	906	11830	12736	1.01	0.060
7.5	8.0	0.03	0.006	7000	125	3.75	7969	969	10177	11146	0.84	0.050
8.0	8.5	0.03	0.006	7000	125	4.25	8031	1031	8768	9800	0.68	0.041
8.5	9.0	0.03	0.006	7000	125	4.75	8094	1094	7583	8677	0.52	0.031
9.0	9.5	0.03	0.006	7000	125	5.25	8156	1156	6591	7747	0.42	0.025
9.5	10.0	0.03	0.006	7000	125	5.75	8219	1219	5761	6980	0.39	0.023
10.0	10.5	0.03	0.006	7000	125	6.25	8281	1281	5065	6346	0.35	0.021
10.5	11.0	0.03	0.006	7000	125	6.75	8344	1344	4478	5822	0.32	0.019
11.0	11.5	0.03	0.006	7000	125	7.25	8406	1406	3981	5387	0.30	0.018
11.5	12.0	0.03	0.006	7000	125	7.75	8469	1469	3558	5027	0.27	0.016
12.0	12.5	0.03	0.006	7000	125	8.25	8531	1531	3196	4727	0.25	0.015
12.5	13.0	0.03	0.006	7000	125	8.75	8594	1594	2884	4477	0.23	0.014
13.0	13.5	0.03	0.006	7000	125	9.25	8656	1656	2613	4270	0.21	0.013
13.5	14.0	0.03	0.006	7000	125	9.75	8719	1719	2378	4097	0.19	0.012
14.0	14.5	0.03	0.006	7000	125	10.25	8781	1781	2172	3954	0.18	0.011
14.5	15.0	0.03	0.006	7000	125	10.75	8844	1844	1991	3835	0.16	0.010
15.0	15.5	0.03	0.006	7000	125	11.25	8906	1906	1831	3738	0.15	0.009
15.5	16.0	0.03	0.006	7000	125	11.75	8969	1969	1690	3658	0.14	0.008
16.0	16.5	0.03	0.006	7000	125	12.25	9031	2031	1563	3595	0.13	0.008
16.5	17.0	0.03	0.006	7000	125	12.75	9094	2094	1450	3544	0.12	0.007
17.0	17.5	0.03	0.006	10100	125	13.25	12256	2156	1349	3505	0.11	0.006

Figure 24: Settlement spreadsheet created by Donald Coduto

4.3.2 Structural Reinforcement

The final step in the footing design was to add structural steel reinforcing bars to resist bending moments in the footing. The equations outlined the foundation methodology section were programmed into an excel spreadsheet to eliminate tedious hand calculations. Figure 25 shows the spreadsheet that was used to determine the design criteria for steel rebar.

FOOTING DESIGN (from Coduto Spreadsheet)			
INTERIOR WITH BASEMENT			
B=	5	ft	
L=	5	ft	
Shape	Square		
min D=	14	ft	
Allowable Load	1413	kip	Terzaghi Method
Allowable Load	2328	kip	Vesic Method
Allowable>Actual?	TRUE		
Settlement	0.9	inch	Classical Method
Vuc	174.7782	kip	
ΦVnc	318.6817	kip	
L	21.5		
Muc	4538.833	kip-in	
As	3.720202	in	
a	0.656506	in	
ΦMn	4540.747	kip-in	
min # bars	3	spaced 18"	
EXTERIOR WITH BASEMENT			
B=	4	ft	
L=	4	ft	
Shape	Square		
min D=	14	ft	
Allowable Load	888	kip	Terzaghi Method
Allowable Load	1494	kip	Vesic Method
Allowable>Actual?	TRUE		
Settlement	0.63	inch	Classical Method
Vuc	53.69766	kip	
ΦVnc	318.6817	kip	
L	15.5	in	
Muc	1474.384	kip-in	
As	1.202221	in	
a	0.265196	in	
ΦMn	1475.009	kip-in	
min # bars	3	spaced 18"	

Figure 25: Steel Reinforcement Spreadsheet

This spreadsheet shows that the service shear force is less than the factored shear strength of each footing. The service moment load is less than the factored moment capacity of each footing, but not by a significant amount. This is because the service moment load is used to calculate the required area of steel. This area is rounded up to the nearest value based on standard rebar sizes, so the moment capacity is slightly larger than the service moment load. For each footing, 3 steel bars with a diameter of 1" are required in each direction to resist bending in all directions. Figures 26 and 27 show a cross-section view of each footing with rebar and dimensions.

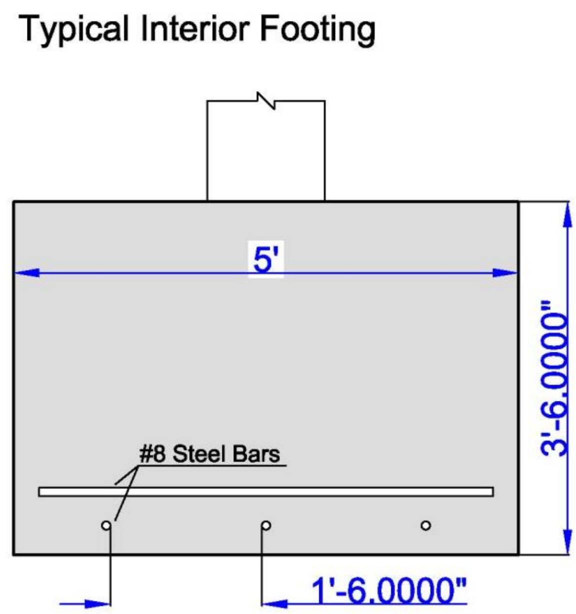

Figure 26: Typical Interior Footing

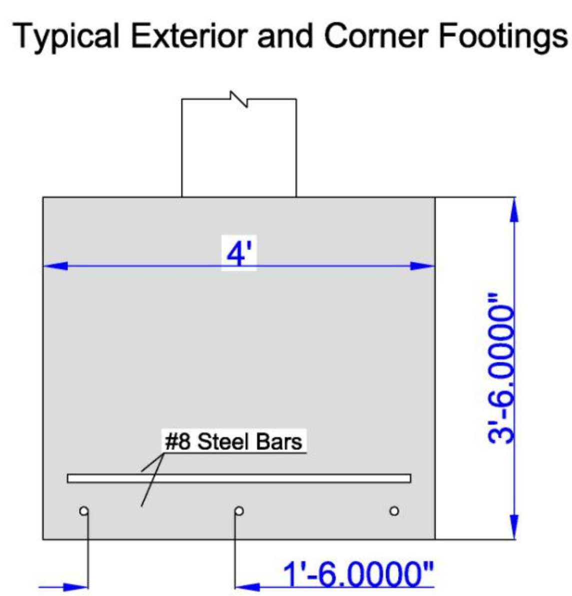

Figure 27: Typical Exterior and Corner Footings

4.4 Cost Estimation Results

The cost estimates we have created are based on get-a-quote average pricing based on 2009 prices for the State of Massachusetts. This section summarizes the estimated costs for the elements of the substructure and superstructure of our building based on our design and analysis. Additional information regarding the estimates in this section can be found in Appendix E.

4.4.1 Grading

Grading is an important operation for the preparation of our site. Grading is important for everything from placing concrete, constructing gravel roads, placing sub-base for bituminous materials, landscaping and more. Based on rental and operational costs for the mechanical equipment necessary for grading, we have calculated costs for preparing the site for general use and the structural grading necessary for placing the footings and slab, shown in Table 8.

Table 8: Grading Estimate

Grading		
	General/Structural	$ 8,592.60

4.4.2 Steel Elements

One of the first elements we priced were the steel members composing the skeleton of the building. Pricing for steel was based on per-ton costs and can be seen in Table 9.

Table 9: Steel Estimate

Structural Steel		
	Columns	$331,614.38
	Girders	$519,056.25
	Beams	$309,304.80
	Angles (for conn.)	$ 58,770.37
	Bolts/Nuts/Washers	$ 76,376.34
	Steel Decking	$255,744.00
	Column Base Plates	$ 16,438.37

First, we found quantities for each type of structural member, then calculated weights based on given weights and the linear feet needed for construction. We calculated angles and connecting pieces based on the number of member connections in our structural. We calculated angles (3"x#.5"x10" @ .5" thick) based on weight and the connecting pieces (7/8" and 1" bolts, washers, and nuts) and base plates based on the number of connections involved.

Table 10: Rebar Estimate

Rebar			
	Footing Reinforcement		$ 10,486.51

In addition to structural steel, we estimated prices for the #8 bars we used in our column footings based on bar weights as can be seen in Table 10. In addition to these structural metals, we considered metal stairs for connecting each floor. Table 11 shows the pricing for fabrication and installation for the 4 sets of metal stairs and the installation of the two automatic elevators we accounted for in our design.

Metal Stairs		
	4 Sets of Stairs	$ 44,868.00
Conveyors		
	2 Conveyors - 5 Floors	$ 1,990.00

Table 11: Stairs - Conveyor Estimate

4.4.3 Concrete Placement

Pricing for concrete depends on the structural properties and the placing conditions. Pricing for the slab on grade was cheaper per cubic yard than for elevated slabs, due to the ease of access for workers constructing formwork and placing the concrete. Table 12 shows concrete pricing for the column footings and the 4.5" slabs.

Concrete		
	Footings	$ 96,349.63
	Slabs	$158,954.67

Table 12: Concrete Estimate

Formwork accounts for a large portion of the cost of concrete elements, as can be seen in Table 13. Curing is also shown in this table, assuming the need for protection from nature during the concrete curing process. Formwork is estimated with multiple uses in mind. That is, when considering the formwork required for our job, we plan to reuse some of the formwork to save on labor and material costs. Using this approach, we rounded quantities conservatively to account for partial loss of formwork materials during construction.

Table 13: Formwork - Curing Estimate

Formwork		
	Footings	$ 61,662.98
	Slabs	$ 18,201.60
Curing		
	Footings	$ 404.60
	Slabs	$ 10,157.40

4.4.4 Masonry

For the building's outer shell, we have priced a standard outer cavity wall. Pricing was based on square footage, and we calculated for complete building coverage as shown in Table14.

Table 14: Brick Estimate

Brick		
	Building Exterior	$714,672.00
	Scaffolding (3 Months)	$194,911.92

4.5 Sustainable Design Results

One of the primary goals of this project is to incorporate sustainable technology into the design of the proposed building at One Concord Street. As an extension of WPI, the new Gateway Park redevelopment efforts should implement and showcase some of the latest green technologies in the industry. WPI has also mandated that all new buildings on campus attain

LEED certification. This project will adhere to the new WPI initiative and implement some of the newest and most unique element of sustainable design.

4.5.1 Living Roof

The design team utilized a decision matrix in order to determine the use of the roof space for the proposed building. The decision matrix, shown in Figure 28, includes four categories to place a numerical value on the worth of both green roof and solar panel technologies. Each technology begins with an initial score of 100. The weight and cost per square foot are then subtracted from each initial score. The specific value added to the building and to the community is assigned a rating from 1-10, based on the impact it is likely to have and the sustainability it will provide the building and the community. These numbers are somewhat subjective, but are based on background information collected on each particular technology. These ratings are then added to the score, with the highest final score representing the most logical choice for use of roof space. The final sum, highlighted in yellow, represents a numerical basis for the decision on how to use the available roof space.

	Cost	Weight	Value to Building (1)	Value to Building (2)	Value to Community (1)	Value to Community (2)	Total
Green Roof	In $/s.f.	In psf	Insulation	Aesthetics, landscape	Stormwater Runoff reduction	Habitat for local bird population	
	$6.50	25	7	1	6	2	84.50
Solar Panels	In $/s.f.	In psf	Reduction of gas/oil use	N/A	N/A	N/A	
	$56	5	9	0	0	0	48.00

Figure 28: Roof Usage Decision Matrix

While both the green roof and solar panel systems benefit the environment and the community, the specific features and benefits of each are very different. The green roof is less costly, but is also significantly heavier than the solar panels and could result in larger beam and girder sections to support the roof. The green roof also offers more value to both the building and the community. The green roof provides insulation to the building and creates a natural environment that is aesthetically pleasing to those with roof access or views. The solar panels only offer an alternative source of electricity and a reduction of nonrenewable resources consumed by the building. No immediate benefits are offered to the surrounding community by the solar panel system. The green roof, however, reduces storm-water runoff that can cause localized flooding and provides a habitat for local bird populations that are being forced from increasingly urbanized areas.

The decision matrix shows that a living roof is the more logical choice for use of the available roof space of the proposed building. The GreenGrid green roof system, currently present atop the new East Hall residence hall at WPI, will be incorporated into the design of the proposed building. The GreenGrid system consists of pre-planted modules that may be easily installed atop a building. The design team chose the standard extensive module for inclusion in this project. These units typically weigh between 18 and 22 psf when wet and grow mostly sedum and some native vegetation. These modular units generally add less weight to the roof than a traditional built-in-place system, positively impacting the structural design of the building by reducing the required area of structural member sections. Additionally, these modules consist of recycled plastic materials that contribute to LEED certification credits. The GreenGrid system is the more economical and environmentally responsible use of roof space. (GreenGrid, 2008)

The roof layout is such that the living roof area will be maximized to obtain the greatest results from the green technology. Approximately 14,500 square feet will be covered with the GreenGrid modules. This area represents about two thirds of the total roof area. The layout of the roof is shown in Figure 29.

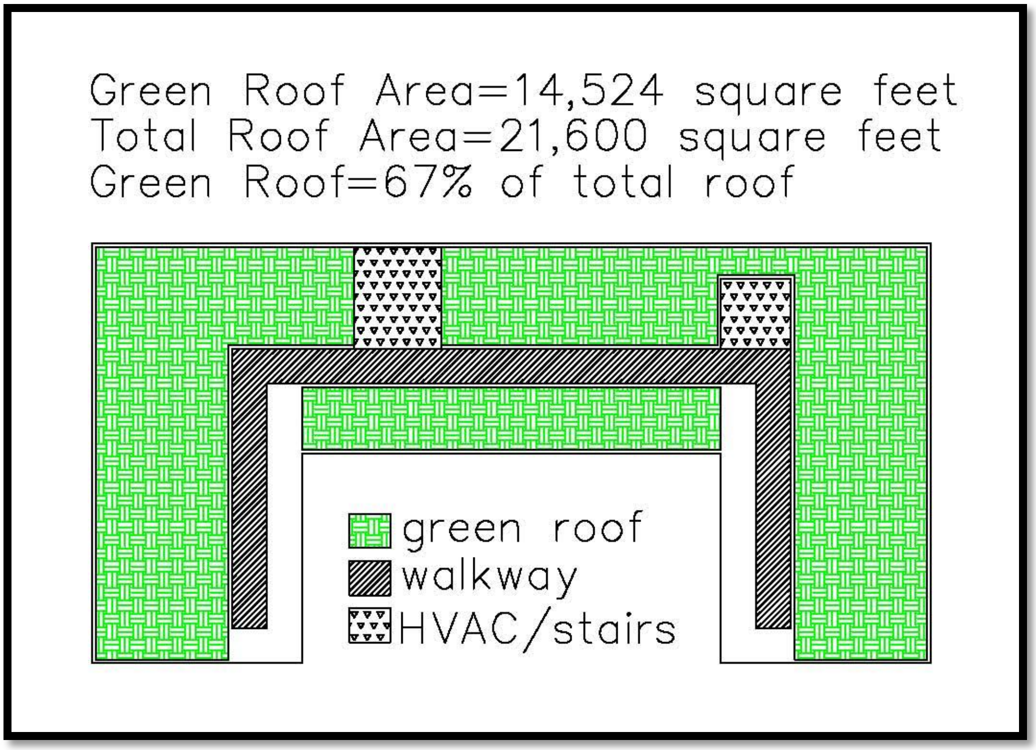

Figure 29: Proposed Green Roof Layout

4.5.2 Geothermal Heating and Cooling System

The geothermal heating and cooling system was designed using the RETScreen software described in the methodology section. The software allowed for the input of the square foot area of the proposed building and its heating and cooling demands. Using an online database, the software allowed for the selection of various makes and models of ground source heat pumps with specific heating and cooling capacities to meet the normal and peak loading. Figure 30 shows the estimated heating and cooling loads for the building for each month. Because the peak loading for heating and cooling were both high, secondary heating and cooling systems were designed using more traditional technologies in order to meet maximum loads.

Month	Cooling average load kW	Heating average load kW
January	0	352
February	0	293
March	0	214
April	0	141
May	82	81
June	205	37
July	282	37
August	254	37
September	144	59
October	0	112
November	0	172
December	0	269
Peak load - annual	465	465

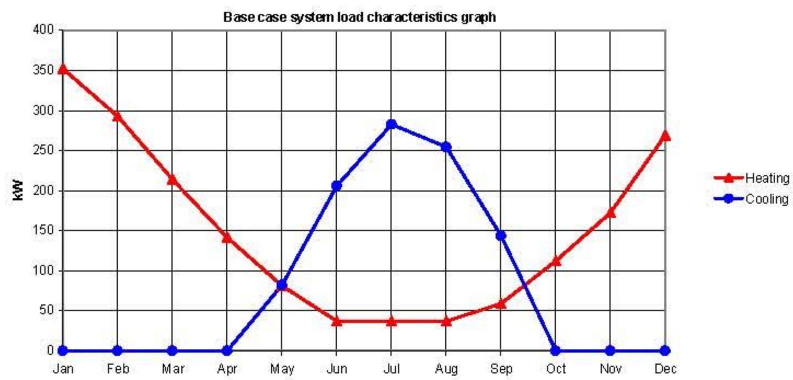

Figure 30: Estimated Heating and Cooling Loads

The ground source heat pump chosen by the design team was a Bard GSVS301-A unit. The heating capacity of one GSVS301-A unit is 0.3 million BTU/h, and the cooling capacity is 39 refrigerant tons (RT). One pump will be used for each floor, resulting in a total of five units. The subsurface layout of the geothermal system will consist of a vertical closed loop system that will require 4,400 square meters of surface area. This type of system is generally used in urban areas because the subsurface piping extends deeper over a more compact area to fit into the compacted layout of a city. The lot size of the proposed building site, which was approximated by the design team to be 90,000 square feet, easily accommodates the required surface area of the vertical closed loop system.

The secondary heating system consists of a natural gas powered boiler from A.O. Smith. The secondary cooling system consists of an electric compressor from York International. Figure 31 demonstrates the percent of peak loading that each type of technology can meet. The ground source heat pump is represented on the graph by the darker shades. The blue bars represent cooling requirements and the red bars represent heating requirements.

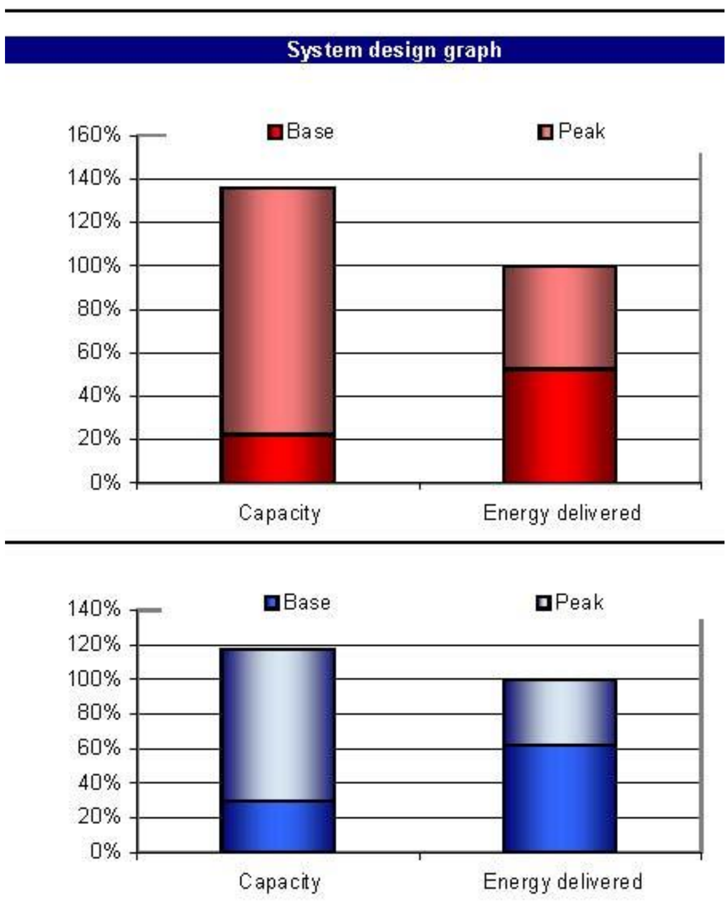

Figure 31: Peak Loading Capability of Gas Powered Boiler

The RetScreen software analyzes the reduction of carbon dioxide emissions that result from the implementation of the ground source heat pump, and converts the average amount into an interesting figure. According to the software, by implementing this geothermal heating and cooling system, enough carbon dioxide emissions will be avoided that it would equal the removal of 334 cars and light trucks from roadways. The software does not specify whether this reduction is based on yearly figures or lifetime figures of the vehicles and the heat pump. It does, however, highlight the environmental benefits that this type of system can produce.

4.5.3 LEED Certification Results

A LEED Green Building certification review was applied to the proposed building at One Concord Street in order to determine whether the score of the design aspects of building within the scope of this project would merit a baseline LEED certification. The LEED scoring system ranges from 0 to 100, with the baseline certification threshold at 40 points, the silver threshold at 50 points, the gold threshold at 60 points, and the platinum rating achieved at 80 points. (U.S. Green Building Council, 2009)

LEED Item	Prerequisite	Points
SUSTAINABLE SITES		
Construction Activity Pollution Prevention	Y	---
Site Selection	N	1
Development Density and Community Conenctivity	N	5
Brownfield Redevelopment	N	1
Alternative Transportation - Public Transportation Access	N	6
Alternative Transportation - Bicycle Storage and Changing Rooms	N	1
Alternative Transportation - Low Emitting and Fuel Efficient Vehicles	N	3
Site Development - Protect or Restore Habitat	N	1
Site Development - Optimize Open Space	N	1
Heat Island Effect - Nonroof	N	1
Heat Island Effect - Roof	N	1
WATER EFFICIENCY		
Water Use Reduction - 20% Reduction	Y	---
ENERGY AND ATMOSPHERE		
Fundamental Commissioning of Building Energy Systems	Y	---
Minimum Energy Performance	Y	---
Fundamental Refrigerant Management	Y	---
Optimize Energy Performance	N	3
On-Site Renewable Energy	N	7
MATERIALS AND RESOURCES		
Storage and Collection of Recyclables	Y	---
Recycled Content - 20% of Content	N	2
INDOOR ENVIRONMENTAL QUALITY		
Minimum Indoor Air Quality Performance	Y	---
Environmental Tobacco Smoke (ETS) Control	Y	---
Daylight and Views - Views	N	1
REGIONAL PRIORITY CREDITS		
Regional Priority - Brownfield Redevelopment	N	1
Regional Priority - Heat Island Effect - Roof	N	1
Regional Priority - On-Site Renewable Energy (1%)	N	1
TOTAL DEFINITE POINTS		**37**

Figure 32: LEED Certification Point Breakdown

The results of the LEED certification review for the building within the scope of this project, obtained with the aid of eQUEST and RETScreen software results, are displayed in Figure 32. The LEED checklist obtained from the United States Green Building Council website and was used in this certification review can be found in the appendices.

4.5.3.1 Sustainable Sites

The proposed building earned 16 points from the "sustainable sites" category of LEED credits. One point was earned from the first credit, "site selection", because it met the following requirements:

- Must not be prime farmland, as defined by U.S. Department of Agriculture
- Must not be previously undeveloped land with an elevation less than 5 feet above the elevation of the 100-year flood as defined by FEMA
- Must not be a habitat for any species on the federal or state threatened or endangered lists
- Must not be within 100 feet of any wetlands or within setback distances of wetlands identified in state regulations.
- Must not be previously undeveloped land within 50 feet of seas, lakes, rivers, streams, and tributaries that could or do support fish, recreational use, or industrial use.
- Must not be land that was previously public parkland, unless that parkland is replaced.

Five points were earned from the second credit, "development density and community connectivity", because the proposed building is located on a previously developed site in a community with a minimum density of 60,000 square feet per acre net. Additionally, the site is located within one half mile from a community with a minimum density of 10 units per acre net and one half mile from at least 8 operational basic services, such as Laundromats, places of worship, and grocery convenience stores. (U.S. Green Building Council, 2009)

One point was earned from the "Brownfield redevelopment" credit because the proposed building is located on a site that has been designated a Brownfield by a state agency. The site also has been documented as contaminated.

Six points were earned from the "alternative transportation – public transportation access" credit. These points were earned because the proposed building is within ¼ mile from at least one bus stop for multiple bus lines accessible to the buildings residents and visitors. The WRTA bus line and the WPI Gateway shuttle are both bus lines accessible to residents and visitors of the proposed building.

One point was earned from the fifth credit, which is "bicycle storage and changing rooms". Bicycle storage and changing rooms for bicycle users have been incorporated into to the design of the proposed building. Changing rooms are located on the ground floor of the building, and bicycle storage will be accommodated outside the entrances of the building.

Worcester Polytechnic Institute has already implemented a program on campus to share fuel efficient vehicles among members of the community. The "Zipcar" program will be extended to include the proposed mixed use facility at One Concord Street in order to serve residents of this building and employees within the Gateway Park community. By implementing this program under a 2 year contract and supplying cars for at least 3% of the full time residents, the requirements of the "alternative transportation – low-emitting and fuel efficient vehicles" credit will be met and three points will be earned.

The proposed building earned one point under the "site development – restore or protect habitat" credit. The point was earned because 50% of the site excluding the building footprint or 20% of the site including the building footprint will be restored with native vegetation. Because the building earned the “development density and community connectivity” credit, its vegetated roof area may be counted in the total area of restored vegetation.

Under the “site development – optimize open space” credit, one point was earned by the proposed building. This credit stipulates that, for areas with zoning ordinances without open space requirements, 20% of the site be maintained as vegetated open space. The design of the proposed building includes a great deal of open space between the front entrance and Concord Street that will satisfy this requirement.

In order to reduce the heat island effect of the building, landscaping will consist of weathered concrete that has solar reflectance index less than 29. Because at least 50% of the landscaping will consist of this material, the requirements of the “heat island effect – non-roof” credit are met and one additional point is earned.

One point was earned by the building for the “heat island effect – roof” credit due to the vegetated roof. The living roof incorporated into the design of the building covers 67% of the roof, satisfying the 50% LEED requirement.

4.5.3.2 Energy and Atmosphere

Using the eQUEST software results that estimate the building energy performance, the design team determined the proposed building should earn 3 points from the “optimize energy performance” credit. The scoring system for this credit is staggered based on a series of percentage thresholds based on the baseline energy performance comparison. The percentage is based on the cost reduction in energy for the entire building. The proposed building about is 16% more energy efficient than this baseline.

Using the RETScreen software results of the ground source heat pump design, the design team determined the proposed building should earn 7 points from the "on-site renewable energy" credit. The ground source heat pump system was designed to provide heating and cooling for normal loading to the building, with traditional heating and cooling systems serving as backup for peak loading scenarios. Therefore, the geothermal renewable energy source is capable of producing the 13% on-site renewable energy required by this credit.

4.5.3.3 Materials and Resources

The design team investigated both composite steel and reinforced concrete as materials for the structural members of the building. Ultimately, the composite steel design was chosen for the final design of the building. One factor that was considered by the design team is the recycled content of structural steel. Because almost all structural steel is recycled at some point in its lifetime, the structural members of the proposed building will satisfy the 20% recycled content requirement of the "recycled content" credit and earn two points for the proposed building. The percentage is based on total value of materials in the building.

4.5.3.4 Indoor Environmental Quality

The proposed building earns one point from the "daylight and views – views" credit because 90% of regularly occupied spaces in the building achieve a direct line of sight to the outdoor environment. The condominium layouts were designed to be open and maximize natural light through the abundance of windows.

4.5.3.5 Regional Priority Credits

The proposed building earned three out of a possible four points from the regional priority credits. Regional priority credits are credits from the regular LEED categories that are deemed especially important to a specific region. If a project meets the requirements of a credit that is also deemed a regional priority, the project earns one additional point for that credit. A spreadsheet of these credits is available through the USGBC website. This spreadsheet was obtained so that the local regional priority credits could be determined for the proposed building.

One point was earned for the first regional priority, "Brownfield redevelopment", because the project met the requirements of this credit. Another point was earned for the second regional priority, "heat island effect – roof", because the living roof satisfied the requirements of this credit. One final point was earned from regional priorities because the proposed building met the requirements of the "on-site renewable energy" credit.

In total, 37 LEED points will be accumulated within the scope of this project. While this number falls short of the ultimate goal of 40 points and baseline certification set forth by the design team, the building stands an excellent chance of attaining LEED certification. The scope of this project is such that, due to the comprehensive nature of the LEED rating system, not all credits are applicable to the work that has been prepared by the design team. However, many of the requirements to these credits are not unreasonable and could easily be incorporated into the remaining design and outfitting of the building. The potential LEED credits that could be included, and strategies for meeting their requirements, will be discussed in the following section.

4.5.3.6 Potential Points Beyond Project Scope

Despite the advantage of the living roof in reducing storm-water runoff, a storm-water runoff system was not designed and no analysis was performed to calculate the runoff figures. By designing a storm-water runoff system and performing an analysis to calculate the reduction that may be attributed to the living roof, LEED points may be earn in both the "storm-water design – quantity control" and "storm-water design – quality control" credits. From these two credits, an additional three points may be earned; two from the credits and one from regional priority credits. (Note that only one point is earned from the regional priority credit because a maximum of four is allowed. Three regional priority credits have already been earned.)

Lighting was not a primary concern in this project. As a result, the "light pollution" credit was not investigated. By installing automated devices to shield openings in the building between 11:00pm and 5:00am and designing exterior lighting to reduce excess ambient light, one additional point may be earned.

Landscaping was beyond the scope of this project, and irrigation systems were not considered in the design of the building at One Concord Street. The "water efficient landscaping credit" primarily concentrates on the conservation of water used for the landscape. The design of the landscape to use no permanent irrigation system would earn four points, or the reduction of potable water use for irrigation by 50% would earn an additional two points.

The outfitting of the building will have a profound effect on the satisfaction of requirements for the "water use reduction" credit. Many appliances, such as toilets and washing machines, affect the water use of a building. By selecting more efficient models of these items, water use may be reduced by 30-40%, earning up to four additional points for the building.

Because the ground source heat pump system was designed to handle normal cooling loads but not peak loads, a backup cooling system was designed to meet these peak loads. This alternative system includes the use of refrigerant, but other models are available. By reducing the use of refrigerant, or eliminating it entirely, the requirements of "enhanced refrigerant management" credit will be satisfied and two additional points may be earned. Due to the incorporation of the ground source heat pump system, the reduction of refrigerant may already be reduced to satisfactory levels. However, the design team performed no refrigerant level calculations, so these points have been considered potentially attainable.

The "green power" credit of the LEED rating system is particularly attainable. The requirements of this credit are to engage in, at the minimum, a two-year contract to supply at least 35% of the building's electricity from renewable sources. The primary decision involved in satisfying this requirement would be balancing the increased cost in electricity from green sources with the value of the additional LEED points and the added benefit to the environment. Two points may be earned from this credit.

The design team performed a cost analysis of the materials used in this project, but selecting a manufacturer for these materials was not considered in this project. However, the "regional materials" credit awards one point for 10% of materials that have been extracted, harvested, and manufactured within 500 miles of the site, and two points for 20% of materials meeting this description. By selecting a local steel manufacturer to supply the structural steel for the building, up to two additional points may be earned.

The design team considered the design of the HVAC system to be beyond the scope of this project. However, by including a more efficient mechanical ventilation system that increases outdoor air ventilation rates in occupied spaces by 30%, an additional point may be earned. As with many aspects of green design, the cost of the more efficient system must be weighed against the benefits to the environment and the LEED score of the building.

The LEED rating system includes four credits concentrated on low-emitting materials. By choosing low-emitting adhesives and sealants, paints and coatings, composite woods and agrifiber products, and flooring systems, four additional points may be earned.

As mentioned in the explanation of the ventilation credit, the design team considered the design of the HVAC system to be beyond the scope of this project. However, by designing a system that maximizes user controllability, two additional points may be earned. The requirement of the “controllability of systems – lighting” credit is to provide controls for a minimum of 90% of building occupants to enable lighting adjustments. The requirement of the “controllability of systems – thermal comfort” credit is to provide individual control to 50% of building occupants to enable adjustments to thermal systems. One point is awarded for each credit, and inclusion of these systems is likely for residential condominiums and retail stores.

One credit that is very similar to a credit that has already been met in this project is “daylight and views – daylight”. As with the “views” credit, this credit concentrates on maximizing the openness of the occupied spaces to increase natural lighting. However, no calculations were performed to demonstrate the satisfaction of this credit’s requirement. To earn one additional point, at least 75% of regularly occupied spaces must achieve day lighting. The percentage must be demonstrated through the use of a simulation or formula that requires measurements and calculation.

Finally, one additional point may be earned by incorporating at least one LEED accredited professional into the project team to play an active role.

Overall, the design team has determined that 20 to 23 additional points may be earned in the later stages of design and planning. As a result, the building could potentially earn LEED gold certification. Although the design team did not achieve its goal of earning a baseline LEED certification within the scope of this project, the proposed building incorporates a great deal of green design and environmentally responsible engineering techniques that are recognized by LEED.

5.0 CONCLUSION

Gateway Park is one of the most prominent new developments in Worcester, and the addition of the proposed building of this design project would further diversify the area. The condominiums would serve to house many of the new employees of Gateway Park's various biotechnology firms, and the commercial space on the ground floor would provide valuable services to these employees and residents on a daily basis.

From conceptualization to detailed structural specifications, the project team strived to design a feasible mixed-use facility that would be beneficial to the neighborhood and the environment. The structural design performed for this building is necessary for all structures; the building must be able to support the various loads that will or possibly act on it. Similarly, the foundation is a necessary part of all building designs. Although foundations are rarely seen or discussed outside of the engineering and construction industries, many of the tallest and most complex buildings around the world are still standing because of a properly designed foundation. One of the more recent additions to the design process is the LEED certification system that determines the energy efficiency and environmental impact of a new building. Through the LEED certification system and the utilization of green design technologies, the design team addressed the energy requirements and environmental impact of the proposed mixed-use facility. In order to ensure that the concepts and designs of this project remained feasible, a cost analysis was performed.

The final product is a mixed-use facility that will serve the community, strengthen the Gateway Park redevelopment project, and promote sustainability and environmentally responsible design and construction.

The completion of this project demonstrates the ability of the design team to apply knowledge and theory from the WPI curriculum to a real world application. Although it is unlikely this project will ever come to fruition, it served as valuable experience and illustrated the importance of communication and cooperation in the design process.

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Appendices

Appendix A - The Proposal

INTRODUCTION

Gateway Park is a joint venture of WPI and the Worcester Business Development Corporation, consisting of 12 acres of land near Interstates I-190 and I-290. Gateway Park is comprised of former Brownfield sites that have now been designated for mixed-use development. This development includes the newly constructed Life Sciences and Bioengineering Center, completed in September 2007, and an 880 car parking structure. However, this 12 acre site is only a small part of a larger redevelopment endeavor. The Gateway Park redevelopment plan includes 55 acres, beginning at the Northworks building in the north, and stretching south to Lincoln Square. Included in this plan are proposed luxury condominium renovations at the former vocational school, construction of several mixed-use buildings, including space for WPI graduate housing, and construction of three new buildings for commercial space. In addition to this redevelopment plan, Gateway Park is part of the newly established Innovation Square Growth District, one of 16 sites across the state designed to spur economic growth. The task of our project group will be to use the land located at 2 Lexington Street and develop a plan for the construction of a roughly 100,000 square foot mix use building.

This project not only will require a proof of the understanding of concepts learned through our group's completed studies but also will aid the WPI community by providing a possible design for a future building at Gateway Park. Our project will show our proficiency in the construction process from the original designs for our building to the cost estimating and structural design. To start off our project we will create a design of our building including general floor plans and a design for the exterior. We will carry out design work by following established rules and regulations, zoning laws, and the general designs of the Gateway Park community which will be found while completing our literature review. Next will be a section including the required design components of the building including beam and girder design, connection design, and foundation design. In this section the possibility of creating an underground parking structure will be shown as well. This section will be followed by the cost estimating and scheduling of the building's construction. The cost estimating and scheduling will be based on the designs already created and will give an idea to the timeline of actual construction, expected costs, and highlight any possible issues that could arise in the construction process. The last section of our building design will be the LEED certification. While making steps to becoming LEED Certified will be accounted for in all designs of our building, a section of what could be done with the outfitting of the building to become more “green” will be included after the cost estimation.

BACKGROUND

GATEWAY PARK

Gateway Park is a joint venture of WPI and the Worcester Business Development Corporation, consisting of 12 acres of land near Interstates I-190 and I-290. Gateway Park is comprised of former Brownfield sites that have now been designated for mixed-use development. The master Gateway plan consists of 5 life science buildings creating 500,000 square feet of lab space, 241,000 square feet of condominiums, and several buildings providing retail space. Figure 1, below, shows the various stages of the Gateway Park development project.

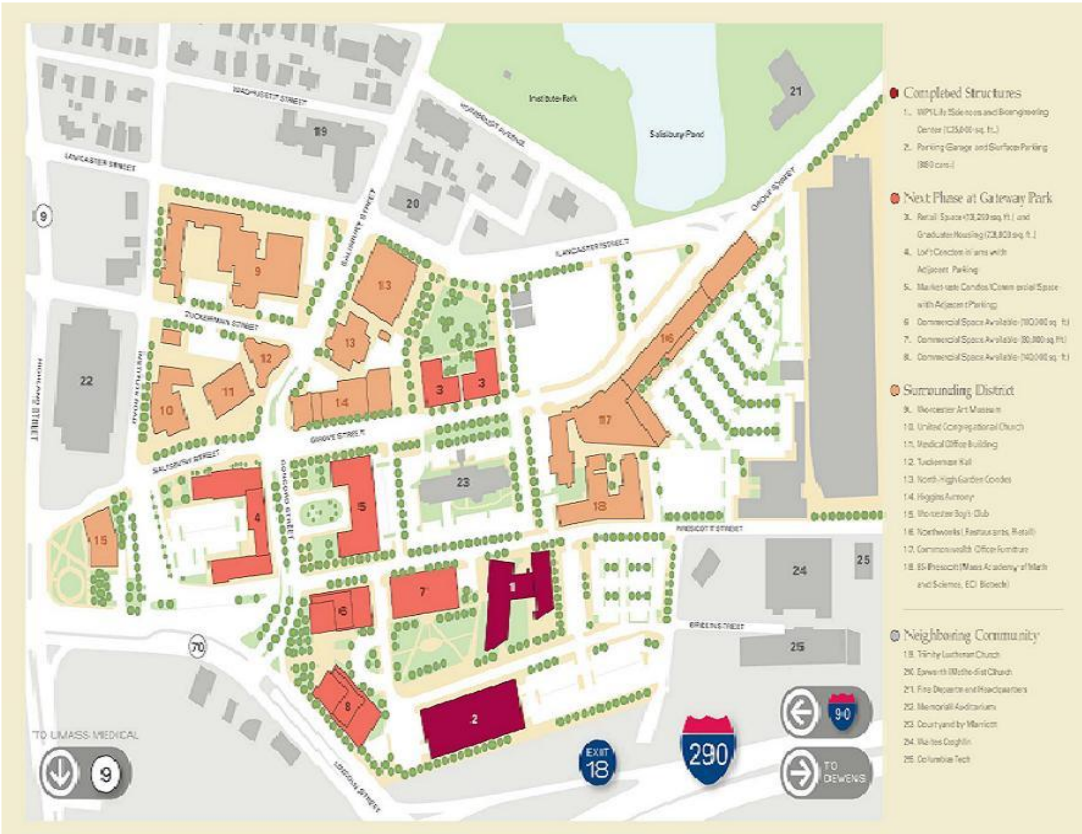

Figure 33. Map of the planned Gateway Park development stages

This development includes the newly constructed Life Sciences and Bioengineering Center, consisting of four stories and 124,600 square feet, was completed in September 2007. WPI invested $43 million and is home to the Biology and Biotechnology, Biomedical Engineering, Chemistry and Biochemistry, and Chemical Engineering departments. The Life Sciences and Bioengineering Center is also home to several pharmaceutical companies. Tsoi/Kobus & Associates served as the architect for the building, and Consigli Construction Company, Inc served as the contractor. In 2007, RXi Pharmaceuticals signed a 20-month lease for space in the Life Sciences and Bioengineering Center, with the option to become the lead tenant in the future lab facility in Gateway Park. RXi Pharmaceuticals was founded by Dr. Craig Mello, a 2006 Nobel Laureate. Also constructed in the last year is the 880 car parking structure that will serves the current LSABC building and future Gateway Park buildings.

Kavanagh Advisory Group will develop future phases of Gateway Park, and has been given the opportunity to develop up to four new buildings in Gateway Park. It is currently in the design process for its first building, an 80,000 square feet state-of-the-art wet lab facility. KAG is also working toward securing funding for construction and negotiating with potential tenants for the new building. KAG hopes to break ground on a new building this year.

In 2007, Gateway Park received the Phoenix Award for its Brownfield revitalization in downtown Worcester. The Gateway Park properties formerly consisted of blighted and abandoned industrial buildings. The award is given to individuals and groups that transform Brownfield properties into productive new uses. (Gateway Park Development Receives 2007 Phoenix Award, 2009)

This 12 acre site is only a small part of a larger redevelopment endeavor. The Gateway Park redevelopment plan includes 55 acres, beginning at the Northworks building in the north, and stretching south to Lincoln Square. Included in this plan are proposed luxury condominium renovations at the former vocational school, construction of several mixed-use buildings, including space for WPI graduate housing, and construction of three new buildings for commercial space. The Gateway Park redevelopment district also includes the newly constructed Courtyard by Marriott Hotel. In addition to this redevelopment plan, Gateway Park is part of the newly established Innovation Square Growth District, one of 16 sites across the state designed to spur economic growth. (Gateway Park Anchors First New State Growth District, 2009)

1 CONCORD STREET

The Gateway Park redevelopment complex is located at the junction of Route 190 and Route 290 and is most easily accessible from just off exit 18 of Route 290. The site is completely contained by surrounding streets with Concord Street to the south, Lexington Street to the north, Prescott Street to the east, and Grove Street to the west. The site was purchased by Gateway Park LLC in 2007 for a price of about $1.1 million dollars. Previously the site had been home to the machine shops of Worcester Vocational High School whose main building was located across Concord Street. Since the site has already been developed it is expected that all major utilities have existing connections on or near the site making it easier to connect into the building.

Since acquiring the property, Gateway Park LLC has already transformed it into something completely different. The 55,000 square foot building that stood on the property was taken down and the site leveled. Also, Lexington Street, the road that bordered the north edge of the site and separated it from the Marriot Hotel is being removed. Lexington Street served as a cut-through from Grove Street to Prescott Street and it has been proposed by the city of

Worcester to reopen Faraday Street, on the north side of the Marriot Hotel, to serve the purpose that Lexington Street had fulfilled.

When Gateway Park LLC purchased the property, it was designated as a Brownfield site. A Brownfield site is a property that is expected to be contaminated by pollutants caused by previous site use, nearby industrial areas, or a high number of natural pollutants in the soil. It was found that the site was contaminated by asbestos, lead paints, and solvents from the building that made their way into the soil. Although it is required that the site be cleaned before it can further developed, Gateway Park LLC received $615,486 in funding to help with the costs to remediate the site. Currently, the site consists of a large pit covering most of the lot. This pit is shown in figure 3, below. This is because much of the contaminated soil that required removal was moved to a new construction site in the Worcester area. Contaminated soils may be moved to new locations if the soil that is being moved is less contaminated than the soil at the new location.

Figure 34: 1 Concord Street Located within Green

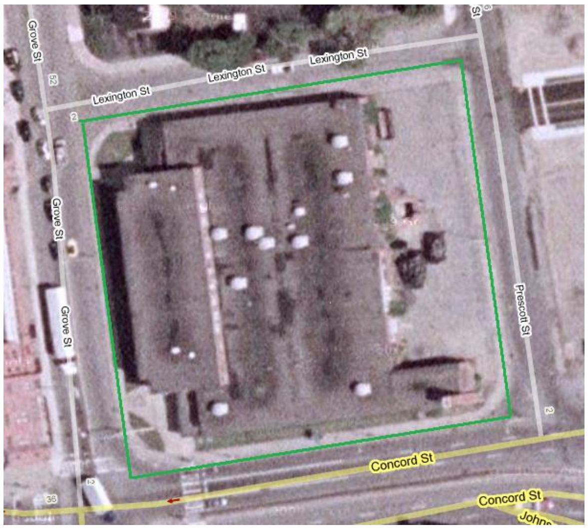

Figure 35: Pit at the 1 Concord Street site

This site was chosen for the project because we felt it left the most opportunity, of the planned sites in Gateway Park, to be open for our individual design and input while still directly benefiting the WPI student body. While all buildings in Gateway Park are currently filled with lab space and technology companies, with the design of our building we will offer a commercial outlet for students that is not currently offered within reasonable walking distance of campus. This site will also offer new housing which not common in to the section of Worcester and we feel will appeal to companies who wish to move to Gateway Park.

ZONING

The City of Worcester Zoning Ordinance was ordained in 1991 to establish a set of rules and guidelines for development within the city. The document has been regularly amended since its creation and was most recently updated in November of 2008. Covered in the 182 pages are comprehensive descriptions and rules regarding specialty building permits, land use regulations, zoning districts, water resource protection, retirement centers, parking stipulations, mixed-use development, and much more. Permits, zoning, and mixed-use development are among the most important topics to those in charge of the expansion efforts at Worcester's Gateway Park.

The purpose of the Zoning Ordinance is designed to encourage the six following aspects of city development: Fulfilling social/economical needs of the future, to secure necessary public requirements including schools and parks, developing and maintaining housing suitable for the present and future, preventing congestion of residents and traffic to promote fire and natural disaster safety, enhance the aesthetics of the city while preserving natural resources, and preserving land significant in historical or architectural nature.

Social and Economical Needs

The vision of the Gateway Park project targets revitalization within the immediate area and proposes a strong turnaround for an area rich in art and music; within just a quarter mile are Tuckerman Hall, Mechanics Hall, and the Worcester Art Museum. Furthermore, the estate will be home to not only the WBDC and student life, but also restaurants, retail units, and other residential buildings.

Public Requirements

Worcester Polytechnic Institute is a leader in technology and education, which is a major division of the public requirements as defined in the Zoning Ordinance. Furthermore, parking demand is squelched by the nearby GP parking garage and the proposed open space will serve to decongest the formerly "bricked-off" warehouse complex.

Suitable Housing

Our proposed residence units will be between 1,200 and 3,000 square feet with maximized exposure to the face of the building for increased sunlight, exceptional aesthetic characteristics, and overall comfort of living.

Traffic and Residence Congestion

The corner of Prescott and Concord generates a large volume of traffic and it is therefore important that line of sight is preserved, street-side parking does not obstruct traffic flow, and pedestrian flow is maintained. With the recently constructed, 660-space parking garage just a few hundred feet away and our proposed two-story, sub-surface parking garage at 1 Concord, parking space will be abundant and allow for the preservation of the existing traffic and pedestrian patterns.

Resources and Aesthetics

During the course of construction at Gateway, the old Vocational School structure was demolished and the site was remediated. Aesthetically speaking, the site at 1 Concord has already been improved through the demolition processes carried out. The new mixed-use facility and associated green space will serve to enhance the immediate area's visual diversity.

Land Preservation

The land, which was previously occupied by abandoned and unappealing warehouses and brick buildings, has been reclaimed through the efforts of the Gateway Park Business Development.

BUILDING USES

The mixed-use facility that will be designed in this project is envisioned as an important part of the growth of Gateway Park and the sense of community with the main WPI campus. The commercial space is envisioned as a retail space that would appeal to college students and young professionals. This retail store would provide a place for students to work and shop in their free time, and would provide more incentive for students living on or around the main WPI campus to travel to Gateway Park.

The market-rate condos would appeal to young professionals working in the various life science companies that are tenants in the existing Life Sciences and Bioengineering Center. The condos also would provide housing for tenants of the future life science facilities that are in development for Gateway Park. Our proposed building would further the development of Gateway Park and help create a greater sense of community in the area.

SCOPE OF WORK

OVERVIEW

This project will require work in various civil engineering disciplines. The design of the structural system will require knowledge of the engineering of steel and reinforced concrete structures. The foundation design requires knowledge of geotechnical and structural engineering for footings and bearing stresses. The construction schedule and cost estimation are aspects of project management that will be necessary in this project. Sustainable design is a growing field of civil engineering, and various aspects of sustainability will be incorporated into the final design. An outline of the scope of work is presented in the following sections.

BUILDING LAYOUT

Our proposed layout for the building incorporates multiple aspects of sustainable and economical design. We have incorporated retail space in the first floor of the building and residential areas in the four floors above it. The preliminary design is based upon our background in column design, steel and concrete structures, and LEED suggestions. Residences are planned to maximize floor space usability and access to exits, while simultaneously dispersing exterior faces along walls as much as possible. Utilizing this exposure can provide substantial heating and cooling advantages as well as provide a basis for superior aesthetics and apartment sale-ability.

The bay areas are rather standard, sized in 30-foot squares, and floors are planned to be 12 feet in height. Apartments are designed in two ways: maximum single-floor square-footage and two-story puzzle-piece style apartments. As displayed in Figure 4, some of the 3rd floor additions to the 2nd floor apartments are positioned partially above other apartments to, again, maximize exterior wall exposure. The ideology and floor plan of the 2nd and 3rd floors is repeated again on the 4th and 5th floors, respectively so that 2nd and 3rd floors share apartment living areas and the 4th and 5th floors share apartment living areas.

Site layout is planned so that the largest portion of green space and the entrance to the building are positioned adjacent to the most frequently traveled right of way bordering the building: The Concord - Salisbury St intersection. By planning this space as such, not only are the aesthetics of the complex improved and available to the most passersby possible, the intersection of Concord, Grove, and Salisbury Streets remains mostly open with a clear line of sight for motor vehicle operators.

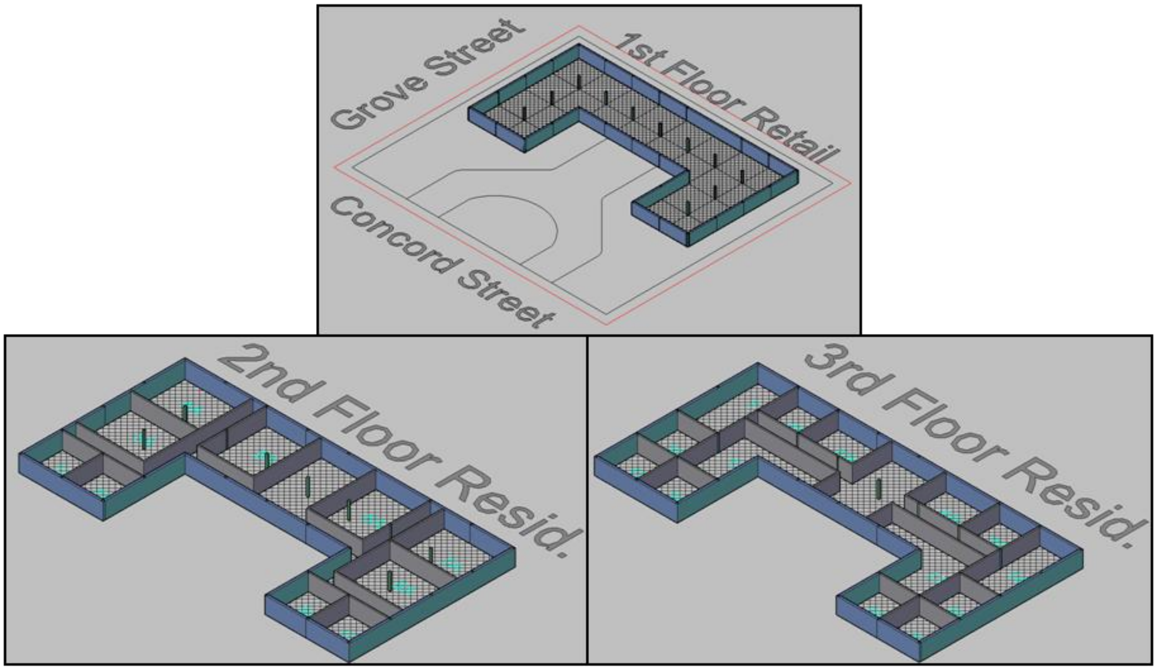

Figure 36. Building Layout and Floor Plan

STRUCTURAL DESIGN

This project requires the design of a structural system for the mixed-use facility at 1 Concord Street. The structural system will be comprised of uniform structural bays that will be laid out in a grid. The bay layout will be considered in the design of the building layout to ensure that the building layout fits within the structural system of the building. The commercial area of the mixed-use facility may require special attention to accommodate necessary the open space necessary for a retail business.

The structural system design process will include the selection of bay sizes, structural member sizes, and loads. This project will include the design of one structural steel frame and one reinforced concrete frame. A comparison of the two frames will be performed, and will be based on both cost and structural performance. Based on this comparison, one frame will be chosen for the final design of the building. Lateral loadings will be considered in the final frame design, and any necessary adjustments will be made to accommodate these loadings. Structural connections will also be considered in the final frame design.

Design calculations and drawings will be produced as a deliverable for this project.

FOUNDATION DESIGN

After the structural design of the building frame has been finalized, a foundation design can be developed in order to transfer the building loads to the ground. Foundations may be either deep or shallow; for this building, a shallow foundation will be designed, consisting of column footings, wall footings, foundation walls, and the slab-on-grade. The design of the underground parking structure may also require special foundation elements that will be addressed in the foundation design process.

In order to design a foundation, existing soil conditions must be examined. A soil profile will be created using the boring data from the Gateway Park Geotechnical Report, preformed in 2005 by the Maguire Group. From this soil profile, the bearing capacity may be investigated for the existing soil strata. The foundation calculations and designs will be produced as a deliverable for this project.

SUSTAINABLE DESIGN

Sustainability will be a strong focus in the design of the mixed-use facility at 1 Concord Street. In the United States, buildings account for 72% of electricity use, 39% of overall energy consumption, and 38% of carbon dioxide emissions. The advantages of sustainable design and green technology benefit the owner, the environment, and the community. Sustainable design places a greater emphasis on efficiency and better management of resources, including land, building materials, and energy.

By reducing the building's reliance on electricity, oil, and gas, green technologies can help pay for themselves over time. Living roofs and geothermal heating and cooling systems, which will both be discussed in greater detail in the following pages, help to lower the costs associated with building climate control by providing efficient insulation and alternative energy sources. Our project will explore some of these green technologies, including living roofs, geothermal heating, solar hot water, and cooling, and recycled and reclaimed building materials.

One method of implementing more sustainable building design is through the LEED Green Buildings Rating System. LEED (Leadership in Energy and Environmental Design) certification verifies a building is "environmentally responsible, profitable, and a healthy place to live and work" (USGBC: LEED) and will be discussed in greater detail in the following pages. This project will perform an initial LEED Green Buildings Rating review with the goal of attaining at least LEED certified for the final designs produced in this project.

GEOTHERMAL ENERGY

A geothermal heating and cooling system will be incorporated into the design of the building. The concept of geothermal heating and cooling, often called geothermal heat pumps, is based on the relatively constant temperature beneath the Earth's surface. In the winter, heat is pumped from wells that penetrate Earth's surface. In the summer, heat from the building is pumped into these wells and back underground.

There are several options for the design of one of these systems. However, our building will likely incorporate the closed-loop vertical system. This design consists of wells drilled 20 feet apart and 100 to 400 feet deep. Because of the deep penetration of the wells, this design usually does not require land beyond the footprint of the building and is typically the most appropriate for large schools and commercial buildings. The pipes from underground connect to the heat pump in the building, which concentrates and disperses heat throughout the building using a traditional duct system.

The benefits associated with geothermal heating and cooling systems are immense. Geothermal heat pumps use 25-50% less electricity than traditional heating and cooling systems. Geothermal heat pumps are generally very durable and reliable, and are very effective in humid areas by maintaining an indoor humidity of 50%. The electrical costs are the only costs, besides standard installation and maintenance costs, associated with geothermal heating and cooling because they do not use heating oil or gas. The increased cost of installing one of these systems will be considered in the project cost estimation. Because these systems do not depend heavily on non-renewable resources like oil, they are awarded points in the LEED Certification program.

LIVING ROOF

The design of the mixed-use facility at 1 Concord Street will include a green roof, or living roof, as part of its sustainable design focus. Worcester Polytechnic Institute is already a pioneer of green roof technology in Worcester, installing the city's first on the newest residence hall on campus.

A green roof is one of the latest technologies to be implemented in both new construction and existing buildings in order to reduce the environmental effects of the built environment. The concept of a green roof is to include a layer of vegetation on the top of a building. In order to install a green roof on top of a building, several specialized layers must be added to a traditional roof. These layers include the vegetation layer, a growing medium layer, drainage and root barrier layer, and a membrane protection layer. These additional layers add weight to the roof, and must be accounted for in both the roof design and the structural frame design. (Urban Design Tools, 2009) Also, the cost to install a green roof is higher than the cost of a traditional roof. The cost considerations will be addressed in the project cost estimation portion of this project.

The benefits of a green roof are vast, and include reduction of storm water runoff and water contamination, increased insulation of the building and decreased heating and cooling costs, reduction of the heat-island effect, and creation of new bird habitats. The installation of a green roof will reduce the impervious area that would be created by a traditional roof and can contribute to localized flooding problems. Because green roofs further insulate the building, they reduce the reliance on heating and cooling systems and help to pay for themselves over time. Green roofs are also awarded points in the LEED Certification program. Therefore, the green roof will be incorporated into the LEED Certification aspect of this project, as well.

LEED GREEN BUILDING RATING SYSTEM

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System is the industry standard in determining the sustainability of a building. LEED certifications are issued under various categories, including new construction, core & shell, schools, healthcare, and retail. Additionally, there are separate LEED standards for existing buildings and schools, as well as commercial and retail interiors.

In order to be certified by the LEED rating system, a building must accumulate a certain number of points under various categories of sustainability. Attaining at least 40 of a possible 100 points may certify a building. Accumulating more points results in a higher level of certification. A silver rating requires at least 50 points, a gold rating requires at least 60 points, and a platinum rating requires at least 80 points. In addition to collecting points, buildings must meet certain performance requirements in order to qualify for a LEED certification.

Under the New Construction LEED rating system, buildings are awarded points in the following categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority. Many points are rewarded in areas that may be beyond the scope of this project. For example, water reduction points may be rewarded to a building outfitted with more efficient appliances, which will not be addressed in our project. However, many points are available in areas that are within the scope of this project, such as on-site renewable energy and maximization of open space in site development. This project will include a LEED certification review process to determine a potential point total for the building design. Both the “New Construction” and “Core & Shell” LEED rating systems will be investigated, with the goal of achieving at least a “certified” rating in either of these systems for the building design produced in this project. The LEED point review will be produced as a deliverable in this project. (U.S. Green Building Council, 2009)

COST ESTIMATE

For any developer, accurately estimating the cost of construction is important for many reasons. Obtaining an approximate number for expenditures expected from a General Contractor or Project Manager is very helpful during the proposal/bid process, because it can help to guide bidders to the cost that you feel is appropriate for the project.

The building at 1 Concord Street will be no exception to the general guidelines for project cost estimation. It will be advantageous for WPI and the WBDC to have approximate figures for construction to weigh against benefits from leasing apartments and retail space to estimate profit margins, readdress building use, and steer the development of future construction at Gateway Park. Therefore, we will provide a qualitative estimation for permanent materials, supplies, tools, and man-hours necessary for erection of the building’s skeleton and preliminary structural members. Some materials that will be considered for estimation will be excavation (cut and fill) and placement of backfill, stone, and topsoil, structural and asphaltic concrete and miscellaneous metals, specialty materials, finishes, and maintenance of traffic.

The calculations and summaries for cost estimation for this project will be provided in the appendices at the end of this report.

CONSTRUCTION SCHEDULE

Scheduling for the proposed building will be based upon a work breakdown schedule, which will make it easier to keep different project parameters organized. By keeping the schedule as explicit at possible, we will determine where different firms and contractors will be needed and the phasing of their work with others. Furthermore, it will be easier to locate possible problem areas throughout the course of construction and to schedule in order to allow for discrepancies without affecting the critical path for completion.

Once all items are determined and all sub-projects identified, we will develop a schematic of the network diagram that will portray the order in which construction will need to be carried out. We will use this diagram in correlation with determining time, cost, and the resources necessary to complete each part of the construction process.

The deliverable that will come from our efforts in project scheduling will be time schedules broken out into individual tasks, a cost schedule, and a resource schedule. The time schedule in construction of this project will theoretically serve as a basis for deadlines and milestones for which a contractor must abide by for a timely completion. The cost schedule will map net worth and expenditures for the project as time progresses, which is necessary to track costs and continuously estimate the final cost. The resources map is especially important for the management of deliveries and stockpiling on the project site. When developing on a small project site, this becomes extremely important for trucking and leasing agreements which, when violated, become expensive to correct.

ALTERNATIVE UNDERGROUND PARKING

One concern with urban development is the availability of accessible parking. With such a small footprint for the site, an underground parking structure will be designed to fulfill parking needs. The garage will be used not only for the permanent residences in the building but for employees and consumers who visit the commercial area located on the first floor of the building. The amount of spaces and levels of the garage will be determined by the limiting regulatory factors which will include the use of the building and the location. Since the only other parking area currently in Gateway Park is the existing parking garage, it is possible to expand the proposed underground garage past the needs of the proposed building to act as a supplement to the rest of the Gateway facility, assuming it stays within regulations.

Another limiting factor of the underground parking structure is the cost. The cost of the garage will be included with the rest of the design costs. Along with providing cost analysis in the report on the garage, there will also be structural design component and layout drawings showing the location of the garage in relation to the proposed building and site boundaries.

PROJECT SCHEDULE

The project will follow as closely as possible the schedule presented in the Project Schedule Table, shown below. It may be necessary to change some aspects of the schedule as the project progresses. This is an approximate timeline and will serve as a tool for keeping the project on pace for its completion in C-term.

Week 7 (10/12-10/16) Fall Break	Finalize building layout using IBC standards. Design generic exterior walls. Begin structural system design process by determining gravity loads of roof, floors, and exterior walls. Consider increased roof load due to living roof and photo-voltaic panels. Create schematics of living roof layers (cross-section) and layout.
Week 8 (10/26-10/30)	Begin design of structural frame in both steel and reinforced concrete. Beams, girders, columns, and floor systems will be designed first based on gravity loads. Research building codes and standards relating to structural frames.
Week 9 (11/2-11/6)	Design structural member sizes and shapes. Begin cost estimation based on member sizes and material costs. Work on member structural drawings. Based on structural performance.
Week 10 (11/9-11/13)	Redesign frame based on lateral loading, if necessary. Make any necessary member size changes based on lateral designs. Finalize structural drawings and calculations.
Week 11 (11/16-11/20)	Begin construction project schedule. Include major milestones Consider installation time, labor rates, and other variables. Finish any incomplete structural design work. Begin writing the section of the report for the construction

	schedule.
Week 12 (11/23-11/27)	Begin design of foundation. Research building codes and standards relating to foundation design. Necessary design elements are column footings, foundation walls, and foundation wall footings. Create (or obtain existing) soil profile based on Gateway Park geotechnical report. Begin writing the section of the report for foundation design.
Week 13 (11/30-12/4)	Complete foundation design. Research incorporation of geothermal energy wells. Include in final foundation design drawings. Begin creating a 3D rendering of the building using REVIT.
Week 14 (12/7-12/11)	Conduct LEED Green Building Rating system review. Write section of final MQP report for LEED topic. Complete construction project schedule and cost estimate. Begin writing section of the final report for LEED rating review.
Week 15 (12/14-12/18) Winter Break	Design alternate underground parking levels and update cost estimate and construction schedule. Complete any unfinished elements of the building design.
Week 16 (1/18-1/22)	Begin writing major sections of the final MQP report, including introduction, background, and methodology sections. Continue finalizing all elements of the building design, including CAD drawings, 3D renderings, and calculations.
Week 17 (1/25-1/29)	Continue writing major sections of the final report,

	including design and conclusion sections. Writing the design section requires writing individual sections for the various design aspects.
Week 18 (2/1-2/5)	Finish writing individual sections of the design. Edit and organize all information, including calculations, figures, and tables.
Week 19 (2/8-2/12)	Begin to assemble major pieces of the final report, including the introduction, background, methodology, design, and conclusion sections.
Week 20 (2/15-2/19)	Continue to assemble all pieces of the final report, including drawings, calculations, and appendices.
Week 21 (2/22-2/26)	Complete any necessary revisions to all sections of final MQP report.
Week 22 (3/1-3/5)	Submit final MQP report to advisor for final approval. Submit eCDR form online to Registrar's office.

Table 15: Project Schedule Table

CAPSTONE CRITERIA

The American Board of Engineering and Technology (ABET) require that upon graduation from an ABET accredited institution that a capstone design project be completed exhibiting the students understanding of material studied and ability to apply it to real world problems. To prove this satisfactory, ABET determined eight criteria that a capstone design project must touch upon for acceptance. These eight criteria are economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. (ABET General Criterion, 2009)

The economic considerations for the project will be covered in making the project economically feasible for it to be completed. This will be done through a close evaluation of a project budget and cost estimation. In order to make the project as economically feasible as possible it is necessary to look at the project's efficiency and cut out unnecessary expenses from the design process to construction. Major factors in the economics of the project include materials used, exterior site design, and the use of the building.

Considerations for the environmental impact, sustainability, and the manufacturability all hinge on the use and construction of the site. The environmental impact of the project will be considered by ensuring the previous contamination of the site will not cause problems with runoff. Sustainability, which closely effects environmental impact, will be addressed in the "green design" of the project. The sustainability of the project will be looked at in regards to LEED certification as well as other areas of environmentally friendly design and construction. Thirdly, the manufacturability of the site will rely on the design of the building and the choices of materials. This will be shows through structural design of the building.

The next set of considerations from ABET are ethical and health and safety considerations. The ethical considerations of the project pertain to the construction of the building as well as its use. For the construction, safe practices should be followed and all regulations and the safety of the public should be considered during the process. Also, the intended use of the building should fit within ethical and social strategy of both WPI and the WBDC. Coinciding with the ethical issues through construction are health and safety issues. By outlining ethical practices during construction, the project will ensure the safety of workers. Regarding the safety of patrons and tenants of the proposed building, safety precautions will be made in the design of the building including proper structural design and the use of correct rules and regulations on fire codes, building codes, and occupancy laws.

The social and political considerations of the project affect the design, construction, and use of the proposed building. These considerations include following the social plan developed by WPI and the WBDC. Also, the use of the building has to coincide with what is socially acceptable and relevant for the area. This is somewhat determined by the zoning laws and codes that limit what the buildings can be used for.

In following the eight criteria set forth by ABET, the project will be of relevant influence to real world scenarios by relating the economic, political, and social aspects of design and construction into one. The successful completion of this project not only exhibits the education gained through undergraduate study at WPI, but also opens a door for further connection between WPI and the city of Worcester.

CONCLUSION

In conclusion, our group proposes to design a mixed-use facility for the empty lot at 1 Concord Street in Gateway Park. This design will include the structural system using steel and reinforced concrete, the foundation, various sustainable elements, and an alternate underground parking system. Additionally, cost estimation will be performed considering both steel and reinforced concrete designs. A construction schedule and a LEED accreditation review will also be performed. The project design will serve as a potential future project for Worcester Polytechnic Institute.

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Figures:

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2. Image from Google Maps, accessed 9/28/09

Appendix B - Structural Steel Design Spreadsheets

Interior Composite Beam LRFD				
Span (feet):	20	f'c (ksi):	4	
Spacing (feet):	5	Fy (ksi):	50	
Slab Thickness (inch):	4.5			
LL (psf):	50	LL (plf):	250	
Partitions (psf):	20	Partitions (plf):	100	
Ceiling (psf):	5	Ceiling (plf):	25	
Slab (psf):	56.25	Slab (plf):	281.25	
Roof (psf)	25	Roof (plf)	125	
HVAC (psf):	5	HVAC (plf):	25	
Insulation (psf):	1.5	Insulation (plf):	7.5	
Steel (psf):	19	Steel (plf):	19	
Factored DL (plf):	660.3			
Factored LL (plf):	400			
M_D (kip-ft):	33.015			
M_L (kip-ft):	20			
M_u (kip-ft)	53.015			
Estimate Y2:	t_s-a/2	4		
		SECTION	$\Phi_b M_n$	A_s (in^2)
	option 1	W10x19	192	5.62
	option 2	W		
	Assuming Y1 =distance from PNA to top of steel beam=0"			
	I_x (in^4)	b_f (in)	d (in)	ΣQ_n (kip)
option 1	96.3	4.02	10.2	281
option 2				
Effective Slab width b	1/4 of span (in)	60	CONTROLS	
	beam spacing(in)	60		
C (kips/in)	204	a		
T (kips)	281			
a (in)	1.38	<t_s?	TRUE	
Φ_bMn (kip-ft):	187.81	>Mu?	TRUE	
Max p (in)	36	Qn (kip):	26.1	3/4"x3" stud
N (# of conn. per half	10.76628352	Use	22	per span
Spacing (in):	10.91			
Deflection Δ (in):	0.52	<.67"?	TRUE	
	Use 46 connectors spaced every 9"			
	Use W16x40 section			

The spreadsheet above was used to design the composite beams for 20’x20’ bays.

Interior Composite Beam LRFD				
Span (feet):	30	f'c (ksi):	4	
Spacing (feet):	6	Fy (ksi):	50	
Slab Thickness (inch):	4.5			
LL (psf):	50	LL (plf):	300	
Partitions (psf):	20	Partitions (plf):	120	
Ceiling (psf):	5	Ceiling (plf):	30	
Slab (psf):	56.25	Slab (plf):	337.5	
HVAC (psf):	5	HVAC (plf):	150	
Insulation (psf):	1.5	Insulation (plf):	45	
Roof (psf)	25	Roof (plf)	150	
Steel (psf):	19	Steel (plf):	19	
Factored DL (plf):	1021.8			
Factored LL (plf):	480			
M_D (kip-ft):	114.9525			
M_L (kip-ft):	54			
M_u (kip-ft)	168.9525			
Estimate Y2:	t_s-a/2	4		A_s (in^2)
				11.8
		SECTION	$\Phi_b M_n$	
	option 1	W16x40	530	
	option 2	W		
	Assuming Y1 =distance from PNA to top of stee			ΣQ_n (kip)
				589
	I_x (in^4)	b_f (in)	d (in)	
option 1	518	7	16	
option 2				
Effective Slab width b	1/4 of span (in)	90	CONTROLS	
	beam spacing(in)	72		
C (kips/in)	306	a		
T (kips)	590			
a (in)	1.93	$<t_s$?	TRUE	
Φ_bMn (kip-ft):	510.47	>Mu?	TRUE	3/4"x3" stud
				per span
Max p (in)	36	Qn (kip):	26.1	
N (# of conn. per half	22.56704981	Use	46	
Spacing (in):	7.83			
Deflection Δ (in):	0.58	<.67"?	TRUE	
	Use 46 connectors spaced every 8"			
	Use W16x40 section			

The spreadsheet above was used to design the composite beams for 30’x30’ bays.

Interior Composite girder LRFD				
Span (feet):	20	f'c (ksi):	4	
Spacing (feet):	20	Fy (ksi):	50	
Slab Thickness (inch):	4.5			
LL (psf):	50	LL (plf):	1000	
Partitions (psf):	20	Partitions (plf):	400	
Ceiling (psf):	5	Ceiling (plf):	100	
Slab (psf):	56.25	Slab (plf):	1125	
HVAC (psf):	5	HVAC (plf):	100	
Insulation (psf):	1.5	Insulation (plf):	30	
Roof (psf)	25	Roof (plf)	500	
Steel (psf):	19	Steel (plf):	19	
Factored DL (plf):	2728.8			
Factored LL (plf):	1600			
M_D (kip-ft):	136.44			
M_L (kip-ft):	80			
M_u (kip-ft)	216.44			
Estimate Y2:	t_s-a/2	4		A_s (in^2)
				9.13
		SECTION	$\Phi_b M_n$	
	option 1	W16x31	409	
	option 2	W		
	Assuming Y1 =distance from PNA to top of stee			ΣQ_n (kip)
				456
	I_x (in^4)	b_f (in)	d (in)	
option 1	375	5.53	15.9	
option 2				
Effective Slab width b	1/4 of span (in)	60	CONTROLS	
	beam spacing(in)	240		
C (kips/in)	204	a		
T (kips)	456.5			
a (in)	2.24	$<t_s$?	TRUE	
Φ_bMn (kip-ft):	387.95	>Mu?	TRUE	3/4"x3" stud
				per span
Max p (in)	36	Qn (kip):	26.1	
N (# of conn. per half	17.47126437	Use	36	
Spacing (in):	6.67			
Deflection Δ (in):	0.53	<.67"?	TRUE	
	Use 36 connectors spaced every 6.67"			
	Use W16x31 section			

The spreadsheet above was used to design composite girders for 20’x20’ bays.

Interior Composite Girder LRFD				
Span (feet):	30	f'c (ksi):	4	
Spacing (feet):	30	Fy (ksi):	50	
Slab Thickness (inch):	4.5			
LL (psf):	50	LL (plf):	1500	
Partitions (psf):	20	Partitions (plf):	600	
Ceiling (psf):	5	Ceiling (plf):	150	
Slab (psf):	56.25	Slab (plf):	1687.5	
HVAC (psf):	5	HVAC (plf):	150	
Insulation (psf):	1.5	Insulation (plf):	45	
Roof (psf)	25	Roof (plf)	750	
Steel (psf):	19	Steel (plf):	19	
Factored DL (plf):	4081.8			
Factored LL (plf):	2400			
M_D (kip-ft):	459.2025			
M_L (kip-ft):	270			
M_u (kip-ft)	729.2025			
Estimate Y2:	t_s-a/2	4		A_s (in^2)
				24.8
		SECTION	$\Phi_b M_n$	
	option 1	W27x84	1610	
	option 2	W		
	Assuming Y1 =distance from PNA to top of stee			ΣQ_n (kip)
				1240
	I_x (in^4)	b_f (in)	d (in)	
option 1	2850	10	26.7	
option 2				
Effective Slab width b	1/4 of span (in)	90	CONTROLS	
	beam spacing(in)	360		
C (kips/in)	306	a		
T (kips)	1240			
a (in)	4.05	<t_s?	TRUE	
Φ_bMn (kip-ft):	1471.62	>Mu?	TRUE	3/4"x3" stud
				per span
Max p (in)	36	Qn (kip):	26.1	
N (# of conn. per half	47.50957854	Use	96	
Spacing (in):	3.75			
Deflection Δ (in):	0.53	<.67"?	TRUE	
	Use 96 connectors spaced every 4"			
	Use W27x84 section			

The spreadsheet above was used to design composite girders for 30'x30' bays

Column Loads

Typical Interior Column (Basement Floor)		
Tributary Area	400	sq. ft.
Distributed Dead+Live Load	1309.2	psf
Column Load	523.68	kip
Typical Exterior Column (Basement Floor)		
Tributary Area	200	sq. ft.
Distributed Dead+Live Load	1309.2	psf
Column Load	261.84	kip
Typical Corner Column (Basement Floor)		
Tributary Area	100	sq. ft.
Distributed Dead+Live Load	1309.2	psf
Column Load	130.92	kip
Typical Interior Column (NO Basement Floor)		
Tributary Area	400	sq. ft.
Distributed Dead+Live Load	1255.696	psf
Column Load	502.2784	kip
Typical Exterior Column (NO Basement Floor)		
Tributary Area	200	sq. ft.
Distributed Dead+Live Load	1255.696	psf
Column Load	251.1392	kip
Typical Corner Column (NO Basement Floor)		
Tributary Area	100	sq. ft.
Distributed Dead+Live Load	1255.696	psf
Column Load	125.5696	kip

Dead Loads

	Steel Decking	4	psf	Total Dead	445.2	psf
	Concrete Slab	37.5	psf			
	HVAC	5	psf			
	Ceiling	1	psf			
	Insulation	1.5	psf			
	Green Roof	25	psf			
	Beams	3.8	psf		8	psf
Residential	Girders	1.55	psf	Commercial	2.8	psf
	Columns	1.59	psf		1.32	psf

Live Loads

Roof LL	20	psf	Total Live	864	psf
Occupancy LL	100	psf			

Snow Loads

Snow	50	psf

Dead Loads

	Steel Decking	4	psf			
	Concrete Slab	37.5	psf	Total Dead	423.696	psf
	HVAC	5	psf			
	Ceiling	1	psf			
	Insulation	1.5	psf			
	Green Roof	25	psf			
	Beams	11.8	psf			
Residential	Girders	4.35	psf		8	psf
	Columns	1.59	psf	Commercial	2.8	psf
					1.32	psf

Live Loads

Roof LL	20	psf	Total Live	832	psf
Occupancy LL	100	psf			

Snow Loads

Snow	50	psf

The spreadsheet above was used to design columns for the first floor of the building. Column loads were determined, a K value of 1 was assumed, and the AISC Steel Manual was used to select an appropriate section size.

Residential Floor Column Loads					**Dead Loads**					
					Steel Decking	4	psf	Total Dead	298.512	psf
Typical Interior Column					Concrete Slab	37.5	psf			
	Tributary Area	400	sq. ft.		HVAC	5	psf			
	Distributed Dead+Live Load	970.512	psf		Ceiling	1	psf			
	Column Load	388.2048	kip		Insulation	1.5	psf			
					Green Roof	25	psf			
Typical Exterior Column					Beams	3.8	psf		8	psf
	Tributary Area	200	sq. ft.	Residenti	Girders	1.55	psf	Commercial	2.8	psf
	Distributed Dead+Live Load	970.512	psf		Columns	1.59	psf		1.32	psf
	Column Load	194.1024	kip							
Typical Corner Column					**Live Loads**					
	Tributary Area	100	sq. ft.		Roof LL	20	psf	Total Live	672	psf
	Distributed Dead+Live Load	970.512	psf		Occupancy LL	100	psf			
	Column Load	97.0512	kip							
					Snow Loads					
					Snow	50	psf			

The spreadsheet above was used to design columns for the residential floors of the building. Column loads were determined, a K value of 1 was assumed, and the AISC Steel Manual was used to select an appropriate section size.

Appendix C - Reinforced Concrete Design Spreadsheets

Bay Sizing					**ROOF LOADING**		
L	20	feet					
W	20	feet		Using 1.5" steel decking, 3" concrete slab= 4.5" total slab thickness			
Loading					steel decking =	4	psf
Dead Load	99	psf			concrete slab =	62.5	psf
Live Load	40	psf			HVAC =	5	psf
Snow Load	55	psf	Including Snow Load of 55psf		ceiling =	1	psf
Wind Loading	90	mph			insulation =	1.5	psf
3x LL	120	psf			greenroof =	25	psf
Clear span	9.58	feet					
Tributary Width	10	feet	Use 1 T- Beam				
					Roof LL =	20	psf
Min thick. (end Bay)	5	inches			Snow load =	55	psf
Min thick (middle bay)	4.29	inches			Occupancy LL =	40	psf
Req'd Slab Thickness	5	inches					
					Assume concrete =	150	pcf
					Shear Reduction Factor		
					Φ=	0.75	
Load Combinations					**Tension Reduction Factor**		
Eqn 1	138.6	psf			Φ=	0.9	
Eqn2	210.3	psf			**Concrete Specs**		
Eqn 3	326.8	psf			Fy=	60000	psi
Eqn 4		psf			f'c=	4000	psi
Eqn 5					P=	0.01	
Eqn 6							
Eqn 7							
Max Load Combo	210.3	psf					
					Slab Thickness (h)=	5	in
					Assume 3/4" clear cover and No. 4 bars		
One Way Slab Design					NO. 4 Bars		
LL < 3x DL	True				d=	4	
W=	0.15						
ΦKn=	492.21						
Calculate Mu @ 1st interior support							
In=	9.58	feet					
Mu=	1.93	ft-k					
Calculate Mu @ 2nd Interior Support							
Mu=	1.76	ft-k					
Max Mu=	1.93	ft-k					
Mu=	2.41	ft-k					
b(d^2)=	47.09	in^3					
Try b=	12	inches					
d=	1.98	inches					
As long as d>=(B49), P<=0.01 according to assumed 3/4" clear cover and No. 4 bars							
This is	True						

Check Slab Thickness for shear									
Exterior Face									
Vu=	1158.84063	lb/ft of width							
Intertior Face									
Vu=	1158.84063	lb/ft of width							
ΦVc=	4553.67983	lb/ft of width							
As long as ΦVc is greater than the highest calculated Vu then the member is adequate for shear									
This is	True								
Reinforcement Design									
As=	0.12	in^2/ft					jd(guess)=	3.7	
a=	0.17								
jd=	3.91								
Recalculated As=	0.11	in^2/ft							
As(min)=	0.108	in^2/ft							
As>As(min)	True	No stirrups needed IF TRUE							
Check Reinforcement Spacing									
s=	13.125	in					Cc=	0.75	inches
but only if less than	12	in					fs=	36	
Smaller value Governs->	12	in							
Shrinkage and Temperature Reinforcement									
Max spacing = 5h if less than 1ε	18	inches							
5h=	25	inches							
Max Spacing=	18	inches							
Use #4 bars @	15	inches OC							
slab thickness=	5	inches					Dead Load	99	psf
DL=	1.98	k/ft					Live Load	40	psf
LL=	0.8	k/ft					Snow Load	55	psf
Total Load=	2.78	k/ft					Wind Loading	90	mph
							3x LL	120	psf
Weight of beam between	0.278	and	0.556				Clear span	9.58	feet
Estimate beam weight @	0.45	k/ft					Tributary Width	0	feet
							Span	20	feet
Wu=	4.106	k/ft							
Mu=	205.3	ft-k							

m=	17.65						Φ=	0.9			
Rn=	547.06	psi					p=	0.01			
Mn Req'd=	228.11	ft-k					Fy=	60000	psi	60	ksi
							f'c=	4000	psi	4	ksi
bd^2 req'd	5003.73	in^3									
d/b should be approx. 1.5-2											
assume 1 layer reinforcement											
b	d	h	Area	Ratio							
12	20	22	4800	1.66667							
11	20	22	4400	1.81818							
12	22	24	5808	1.83333							
Try											
b=	12	inches	1	ft							
d=	20	inches	1.66667	ft							
h=	22	inches	1.83333	ft							
Recheck DL											
Beam Weight	0.46	k/ft					Weight of concrete=	0.15	kcf		
Wu=	4.206	k/ft									
Mu=	210.3	ft-k									
dr=	17.5	inches									
As=	2.67	in^2									
As(min)=	0.17	in^2									
As>=As(min)=	True										
Bar Options page 64											
Size (#)	Amount	Area (in^2)									
5	8	2.48									
6	6	2.64		**Use**	4	#7	**bars**				
7	4	2.40			Area=	2.4					
							B=	0.85			
a=	3.53										
c=	4.15	inches									
Et=	0.01145										
If Et > .005 it is OK	True	therefore section is controlled I tension									
Mn=	218.82	ft-k									
ΦMn=	196.94	ft-k									
If Mu < ΦMn, then design (	False										

Design of Continuous T-Beam									
Max Positive Moment (At)	201.88	ft^2			Clear Span Side	105	in	8.75	ft
Reduced LL=	12.10	psf			Clear Span Interior	126	in	10.5	ft
					Clear Span lateral	228	in	19	ft
					B=	12	in		
Max Negative Moment (At)	269.25	ft^2			Bay Size	20	ft		
Reduced LL=	11.58	psf							
Lower of reduced live loac	11.58	psf							
					Φ(tension)=	0.9			
Wu=	107.32	psf			Φ(shear)=	0.75			
Factored Load/ft=	1.14	k/ft			Dead Load	74	psf		
Assume T-Beam stem weight to be .4 k/ft					In clear span=	10.67	feet		
Trial Load/ft=	1.54	k/ft							
Choose Stem Size									
min h=	12.97	inches							
min d calcs	105.96	ft-k							
Rn=	0.99	ksi	988.235	psi	p=	0.02			
bd^2=	1429.55	in^3			m=	17.65			
b should be approx. 2/3d									
Try									
b=	10.00								
d=	12.96								
h=	15.46	15							
10" wide beam by 16 deep that extends 11" below the 5" slab									

Appendix D - Foundation Design Spreadsheets

The spreadsheet below was used to design footing sizes based on bearing capacity and settlement. The bearing capacity and settlement for each footing were obtained using the spreadsheets created by Donald Coduto and are included in this appendix. The spreadsheet was also used to design the structural steel reinforcement of the footings.

FOOTING DESIGN (from Coduto Spreadsheet)

INTERIOR WITH BASEMENT						INTERIOR COLUMN FOOTING			
B=	5	ft				B=	5	ft	
L=	5	ft				L=	5	ft	
Shape	Square					Shape	Square		
min D=	14	ft				min D=	4	ft	
Allowable Load	1413	kip	Terzaghi Method			Allowable Load	592	kip	Terzaghi Method
Allowable Load	2328	kip	Vesic Method			Allowable Load	747	kip	Vesic Method
Allowable>Actual?	TRUE					Allowable>Actual?	TRUE		
Settlement	1.06	inch	Classical Method			Settlement	1.06	inch	Classical Method
Vuc	77.6792	kip				Vuc	74.50463	kip	
ΦVnc	318.6817	kip				ΦVnc	318.6817	kip	
L	21.5					L	21.5	in	
Muc	2017.259	kip-in				Muc	1934.818	kip-in	
As	1.64543	in				As	1.577937	in	
a	0.29037	in				a	0.278459	in	
ΦMn	2018.114	kip-in				ΦMn	1935.638	kip-in	
min # bars	3	spaced 18"				min # bars	3	spaced 18"	
EXTERIOR WITH BASEMENT						EXTERIOR COLUMN FOOTING			
B=	4	ft				B=	4	ft	
L=	4	ft				L=	4	ft	
Shape	Square					Shape	Square		
min D=	14	ft				min D=	4	ft	
Allowable Load	888	kip	Terzaghi Method			Allowable Load	346	kip	Terzaghi Method
Allowable Load	1494	kip	Vesic Method			Allowable Load	470	kip	Vesic Method
Allowable>Actual?	TRUE					Allowable>Actual?	TRUE		
Settlement	0.73	inch	Classical Method			Settlement	0.73	inch	Classical Method
Vuc	23.86563	kip				Vuc	22.89029	kip	
ΦVnc	318.6817	kip				ΦVnc	318.6817	kip	
L	15.5	in				L	15.5	in	
Muc	655.2819	kip-in				Muc	628.502	kip-in	
As	0.533282	in				As	0.511455	in	
a	0.117636	in				a	0.112821	in	
ΦMn	655.5601	kip-in				ΦMn	628.7689	kip-in	
min # bars	3	spaced 18"				min # bars	3	spaced 18"	
CORNER WITH BASEMENT						CORNER WITHOUT BASEMENT			
B=	3	ft				B=	4	ft	
L=	3	ft				L=	4	ft	
Shape	Square					Shape	Square		
min D=	14	ft				min D=	4	ft	
Allowable Load	481	kip	Terzaghi Method			Allowable Load	346	kip	Terzaghi Method
Allowable Load	837	kip	Vesic Method			Allowable Load	470	kip	Vesic Method
Allowable>Actual?	TRUE					Allowable>Actual?	TRUE		
Settlement	0.4	inch	Classical Method			Settlement	0.4	inch	Classical Method
Variables Used						Variables Used			
c'=	0	lb/ft^2				c'=	0	lb/ft^2	
Φ'=	40	degrees				Φ'=	40	degrees	
γ=	125	lb/ft^3				γ=	125	lb/ft^3	
D_{water}=	18	ft				D_{water}=	18	ft	
Factor of Safety=	3					Factor of Safety=	3		
$C_c/(1+e_0)$=	0.03		Table 3.7, pg. 71 Coduto			$C_c/(1+e_0)$=	0.03		
$C_r/(1+e_0)$=	0.006		Table 3.7, pg. 71 Coduto			$C_r/(1+e_0)$=	0.006		
d=	38	in	f'c=	4000	psi				
c=	20	in	fy=	36000	psi				
b0=	39								

BEARING CAPACITY OF SHALLOW FOUNDATIONS
Terzaghi and Vesic Methods

Date	March 1, 2010						
Identification	Example 6.4						
Input			**Results**				
Units of Measurement				Terzaghi		Vesic	
	E	SI or E	Bearing Capacity				
			q ult =	64,926	lb/ft^2	88,083	lb/ft^2
Foundation Information			q a =	21,642	lb/ft^2	29,361	lb/ft^2
Shape	SQ	SQ, CI, CO, or RE					
B =	4	ft	Allowable Column Load				
L =	4	ft	P =	346	k	470	k
D =	4	ft					
Soil Information							
c =	0	lb/ft^2					
phi =	40	deg					
gamma =	125	lb/ft^3					
Dw =	18	ft					
Factor of Safety							
F =	3						

The spreadsheet above was created by Donald Coduto and was used to determine the bearing capacity of footings based on the size and shape, as well as the surrounding soil properties.

The spreadsheet below was also created by Donald Coduto and was used to determine the settlement of each footing using the classical method of settlement analysis. This spreadsheet uses the footing size and shape, as well as surrounding soil properties, to determine the settlement of each footing.

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS
Classical Method

Date	March 1, 2010
Identification	Interior Footing

Input

Units	E	E or SI
Shape	SQ	SQ, CI, CO, or RE
B =	5	ft
L =	5	ft
D =	4	ft
P =	523	k
Dw =	18	ft
r =	0.85	

Results

q =	21520	lb/ft^2
delta =	1.06	in

Depth to Soil Layer Top (ft)	Bottom (ft)	Cc/(1+e)	Cr/(1+e)	sigma m' (lb/ft^2)	gamma (lb/ft^3)	zf (ft)	sigma c' (lb/ft^2)	sigma zo' (lb/ft^2)	delta sigma (lb/ft^2)	sigma zf' (lb/ft^2)	strain (%)	delta (in)
0.0	4.0				125							
4.0	4.5	0.03	0.006	7000	125	0.25	7531	531	21004	21536	1.75	0.105
4.5	5.0	0.03	0.006	7000	125	0.75	7594	594	20639	21233	1.70	0.102
5.0	5.5	0.03	0.006	7000	125	1.25	7656	656	19546	20202	1.62	0.097
5.5	6.0	0.03	0.006	7000	125	1.75	7719	719	17814	18532	1.50	0.090
6.0	6.5	0.03	0.006	7000	125	2.25	7781	781	15772	16553	1.35	0.081
6.5	7.0	0.03	0.006	7000	125	2.75	7844	844	13719	14562	1.18	0.071
7.0	7.5	0.03	0.006	7000	125	3.25	7906	906	11830	12736	1.01	0.060
7.5	8.0	0.03	0.006	7000	125	3.75	7969	969	10177	11146	0.84	0.050
8.0	8.5	0.03	0.006	7000	125	4.25	8031	1031	8768	9800	0.68	0.041
8.5	9.0	0.03	0.006	7000	125	4.75	8094	1094	7583	8677	0.52	0.031
9.0	9.5	0.03	0.006	7000	125	5.25	8156	1156	6591	7747	0.42	0.025
9.5	10.0	0.03	0.006	7000	125	5.75	8219	1219	5761	6980	0.39	0.023
10.0	10.5	0.03	0.006	7000	125	6.25	8281	1281	5065	6346	0.35	0.021
10.5	11.0	0.03	0.006	7000	125	6.75	8344	1344	4478	5822	0.32	0.019
11.0	11.5	0.03	0.006	7000	125	7.25	8406	1406	3981	5387	0.30	0.018
11.5	12.0	0.03	0.006	7000	125	7.75	8469	1469	3558	5027	0.27	0.016
12.0	12.5	0.03	0.006	7000	125	8.25	8531	1531	3196	4727	0.25	0.015
12.5	13.0	0.03	0.006	7000	125	8.75	8594	1594	2884	4477	0.23	0.014
13.0	13.5	0.03	0.006	7000	125	9.25	8656	1656	2613	4270	0.21	0.013
13.5	14.0	0.03	0.006	7000	125	9.75	8719	1719	2378	4097	0.19	0.012
14.0	14.5	0.03	0.006	7000	125	10.25	8781	1781	2172	3954	0.18	0.011
14.5	15.0	0.03	0.006	7000	125	10.75	8844	1844	1991	3835	0.16	0.010
15.0	15.5	0.03	0.006	7000	125	11.25	8906	1906	1831	3738	0.15	0.009
15.5	16.0	0.03	0.006	7000	125	11.75	8969	1969	1690	3658	0.14	0.008
16.0	16.5	0.03	0.006	7000	125	12.25	9031	2031	1563	3595	0.13	0.008
16.5	17.0	0.03	0.006	7000	125	12.75	9094	2094	1450	3544	0.12	0.007
17.0	17.5	0.03	0.006	10100	125	13.25	12256	2156	1349	3505	0.11	0.006
17.5	18.0	0.03	0.006	10100	125	13.75	12319	2219	1258	3476	0.10	0.006
18.0	18.5	0.03	0.006	10100	125	14.25	12366	2266	1175	3441	0.09	0.006
18.5	19.0	0.03	0.006	10100	125	14.75	12397	2297	1101	3397	0.09	0.005
19.0	19.5	0.03	0.006	10100	125	15.25	12428	2328	1033	3361	0.08	0.005
19.5	20.0	0.03	0.006	10100	125	15.75	12460	2360	971	3330	0.08	0.005
20.0	20.5	0.03	0.006	10100	125	16.25	12491	2391	914	3305	0.07	0.004
20.5	21.0	0.03	0.006	10100	125	16.75	12522	2422	862	3284	0.07	0.004
21.0	21.5	0.03	0.006	10100	125	17.25	12553	2453	815	3268	0.06	0.004
21.5	22.0	0.03	0.006	10100	125	17.75	12585	2485	771	3256	0.06	0.004
22.0	22.5	0.03	0.006	10100	125	18.25	12616	2516	730	3247	0.06	0.003
22.5	23.0	0.03	0.006	10100	125	18.75	12647	2547	693	3240	0.05	0.003
23.0	23.5	0.03	0.006	10100	125	19.25	12679	2579	659	3237	0.05	0.003
23.5	24.0	0.03	0.006	10100	125	19.75	12710	2610	627	3236	0.05	0.003
24.0	24.5	0.03	0.006	10100	125	20.25	12741	2641	597	3238	0.05	0.003
24.5	25.0	0.03	0.006	10100	125	20.75	12773	2673	569	3242	0.04	0.003
25.0	25.5	0.03	0.006	10100	125	21.25	12804	2704	543	3247	0.04	0.002
25.5	26.0	0.03	0.006	10100	125	21.75	12835	2735	519	3254	0.04	0.002
26.0	26.5	0.03	0.006	10100	125	22.25	12866	2766	496	3263	0.04	0.002
26.5	27.0	0.03	0.006	10100	125	22.75	12898	2798	475	3273	0.03	0.002
27.0	27.5	0.03	0.006	10100	125	23.25	12929	2829	455	3284	0.03	0.002
27.5	28.0	0.03	0.006	10100	125	23.75	12960	2860	437	3297	0.03	0.002
28.0	28.5	0.03	0.006	10100	125	24.25	12992	2892	419	3311	0.03	0.002

Appendix E - Cost Estimating Spreadsheets Sprinkler Estimate Spreadsheet

Sprinkler Irrigation Systems Typical complete system costs, including PVC pipe, heads, valves, fittings, trenching and backfill. Per SF of area watered. Add 10% for irrigation systems installed in areas subject to freezing hazard. Equipment is a 55 HP pneumatic tired riding type trencher. []

	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
Small areas, 5,000 SF and under, spray heads[]						
Strip, automatic, shrub type	S4@.008	SF	0.26	0.31	0.14	0.71
Commercial type, manual	S4@.007	SF	0.25	0.27	0.13	0.65
Residential type, manual	S4@.007	SF	0.24	0.27	0.13	0.64
Add for automatic system	S4@.001	SF	0.07	0.04	0.02	0.13

Commercial		$62,040.00	$15,510.00	$16,750.80	$8,065.20	**$40,326.00**

SPRINKLER	**TOTALS**	**$40,326.00**

Grading Estimate Spreadsheet

	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
Grading and Compacting. Based on 8" lifts and 3 passes at 5' wide, using a D-8L crawler tractor dozer with universal blade and a 25.5-ton towed vibrating sheepsfoot roller.						
Grade and compact large area with 300 HP dozer	gr@.012	CY	--	0.62	1.5	2.12

Grading and Compacting. Based on 6" lifts and 3 passes at 5' wide, using a D-4H crawler tractor dozer with angle tilt blade.						
Grade and compact small area with 75 HP dozer	gk@.018	CY	--	0.72	0.43	1.15

Roadway grading Using a Cat 12-G motor grader.						
Grade roadway sub base courses	jm@2.10	MSY	--	83.5	39.9	123.4
Finish grade roadway base or leveling courses	jm@2.36	MSY	--	93.9	44.8	138.7

Rough grade for structures and slabs Using a D-6H crawler tractor dozer, power shift with angle tilt blade.						
Push to stockpile with 140 HP dozer	gl@.015	CY	--	0.6	0.68	1.28

D-8L Entire Site	1155.6		$716.10	$1,732.50	$2,448.60
D-6H Structural Grade	4800.0		$2,880.00	$3,264.00	$6,144.00

GRADING	**TOTALS**	**$8,592.60**

Concrete Estimate Spreadsheet

CSI 03-311, Normal weight structural concrete						
CSI 03-311	Craft@Hrs	Unit	Material	Labor	Equip	Total
Based on 3,000 PSI concrete with 3% waste, using a portable 55 KW 120/240 volt generator, two 25" diameter concrete vibrators, a truck-mounted hydraulic crane with 115’ boom and small tools.						
Pile caps to 5 CY (5m3)	bs@.908	CY	$105.00	$37.80	$10.40	$153.20
Pile caps over 5 CY (5m3)	bs@.517	CY	$105.00	$21.50	$5.91	$132.41
Continuous shallow footings	bs@.800	CY	$105.00	$33.30	$9.14	$147.44
Continuous deep footings	bs@.720	CY	$105.00	$30.00	$8.23	$143.23
Spread footings to 5 CY (5m3)	bs@1.60	CY	$105.00	$66.60	$18.30	$189.90
Spread footings over 5 CY (5m3)	bs@.720	CY	$105.00	$30.00	$8.23	$143.23
Mat foundations	bs@.240	CY	$105.00	$9.99	$2.74	$117.73
Grade beams	bs@.600	CY	$105.00	$25.00	$6.86	$136.86
Slabs on grade, under 6" (15 cm)	bs@.664	CY	$105.00	$27.60	$7.59	$140.19
Slabs on grade 6" (15 cm) or more	bs@.504	CY	$105.00	$21.00	$5.76	$131.76
Stairs on grade	bs@3.66	CY	$105.00	$152.00	$41.80	$298.80
Small elevated beams	bs@1.60	CY	$105.00	$66.60	$18.30	$189.90

Large elevated beams	bs@1.11	CY	$105.00	$46.20	$12.70	$163.90
Elevated slabs under 6" (15 cm)	bs@.758	CY	$105.00	$31.50	$8.66	$145.16
Elevated slabs 6" (15 cm) or more	bs@.554	CY	$105.00	$23.10	$6.33	$134.43
12" (31cm) square or round columns	bs@1.84	CY	$105.00	$76.60	$21.00	$202.60
18" (46cm) square or round columns	bs@1.35	CY	$105.00	$56.20	$15.40	$176.60
24" (61cm) square or round columns	bs@1.09	CY	$105.00	$45.40	$12.50	$162.90
36" (91cm) square or round columns	bs@.770	CY	$105.00	$32.00	$8.80	$145.80
8" (21cm) thick building walls	bs@.963	CY	$105.00	$40.10	$11.00	$156.10
12" (31cm) thick building walls	bs@.818	CY	$105.00	$34.00	$9.35	$148.35
15" (38cm) thick building walls	bs@.770	CY	$105.00	$32.00	$8.80	$145.80
Elevated stairs	bs@3.85	CY	$105.00	$160.00	$44.00	$309.00
Deduct for 2,500 PSI concrete	---@---	CY	$(4.41)	--	--	$(4.41)
Add for 3,500 PSI concrete	---@---	CY	$4.41	--	--	$4.41
Add for 4,000 PSI concrete	---@---	CY	$8.65	--	--	$8.65
Add for 4,500 PSI concrete	---@---	CY	$12.90	--	--	$12.90
Add for 5,000 PSI concrete	---@---	CY	$17.30	--	--	$17.30
Add for type V cement concrete	---@---	CY	$21.20	--	--	$21.20
Add for white cement concrete	---@---	CY	$19.60	--	--	$19.60

Spread Footings							
	Interior	7x7	335.7407407	$35,252.78	$22,360.33	$6,144.06	$63,757.17
	Exterior	5x5	157.4074074	$16,527.78	$10,483.33	$2,880.56	$29,891.67
	Corner	4x4	14.22222222	$1,493.33	$947.20	$260.27	$2,700.80
Elevated Slabs (4 Floors)		5" Slab	1333.333333	$140,000.00	$42,000.00	$11,546.67	$53,546.67
Slab on Grade		1' Slab	800	$84,000.00	$16,800.00	$4,608.00	$105,408.00
12" Columns		12"X12"	39	$4,095.00	$2,987.40	$819.00	$7,901.40

CONCRETE	**TOTALS**	**$255,304.30**

Formwork Estimate Spreadsheet

	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
Slab forms						
Using 2" lumber. Includes stakes, oil, stripping and repairs. Based on 4 uses, using miscellaneous power tools and small tools.						
Up to 6" (15 cm) high	av@.053	LF	$0.66	$2.46	$0.04	$3.16
7" to 12" (18cm to 31cm) high	av@.074	LF	$1.30	$3.44	$0.06	$4.80
Over 12" (over 31cm) high	av@.096	SF	$1.74	$4.46	$0.08	$6.28

Column footing forms, spread						
Including plywood, bracing, ties, accessories, oil, erecting, stripping, stacking and repairs for multiple use, using miscellaneous power tools and small tools.						
1 use	av@.105	SF	$3.42	$4.88	$0.08	$8.38
2 uses	av@.084	SF	$2.76	$3.90	$0.07	$6.73
3 uses	av@.078	SF	$2.31	$3.62	$0.06	$5.99
4 uses	av@.074	SF	$1.76	$3.44	$0.06	$5.26

Slab Forms		2880	LF	$3,801.60	$14,169.60	$230.40	$18,201.60
Footing Forms							
	7x7	6993		$12,307.68	$24,055.92	$419.58	$36,783.18
	5x5	4250		$7,480.00	$14,620.00	$255.00	$22,355.00
	4x4	480		$844.80	$1,651.20	$28.80	$2,524.80

FORMWORK	**TOTALS**	**$79,864.58**

Curing Estimate Spreadsheet

CS 03-305 Concrete Curing

Per 100 SF of surface cured, using small tools.

	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
7.5 oz. burlap, 4 uses	sr@.364	CSF	4.43	14.3	0.08	18.81
12 oz. burlap, 4 uses	sr@.364	CSF	6.08	14.3	0.08	20.46
Waterproof paper, 2-ply reinforced	sr@.286	CSF	6.9	11.2	0.07	18.17

Two sets of burlap for slabs based on 4 uses per burlap set						
Concrete Curing (7.50z Burlap)						
Slabs		1080	$2,392.20	$7,722.00	$43.20	$10,157.40
Footings						
	7x7	69.93	$77.45	$250.00	$1.40	$328.85
	5x5	42.5	$47.07	$6.08	$0.03	$53.18
	4x4	4.8	$5.32	$17.16	$0.10	$22.57

CURING	**TOTALS**	**$10,562.00**

Structural Steel Estimate Spreadsheet

Steel

	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
Combination section, W shapes and channels Using a truck-mounted hydraulic crane with 115' boom and small tools.						
To 30 lbs. per LF	qm@21.3	Ton	$3,120.00	$1,140.00	$262.00	$4,522.00
30 to 65 lbs. per LF	qm@7.11	Ton	$2,470.00	$380.00	$87.50	$2,937.50
65 to 100 lbs. per LF	qm@4.00	Ton	$2,200.00	$214.00	$49.20	$2,463.20
100 to 500 lbs. per LF	qm@1.07	Ton	$1,500.00	$57.10	$13.20	$1,570.30

Column base plates, A-36 steel Using small tools.						
Up to 150 lbs. (68 kg) each	qb@.005	LB	$1.40	$0.30	--	$1.70
Over 150 lbs. (68 kg) each	qb@.007	LB	$1.13	$0.42	--	$1.55
Up to 150 lbs. each	qb@10.0	Ton	$2,790.00	$599.00	$5.90	$3,394.90
Over 150 lbs. each	qb@14.0	Ton	$2,270.00	$839.00	$8.26	$3,117.26

Rolled shape steel angles Using small tools.						
To 10 lbs. per LF	qb@20.0	Ton	$4,350.00	$1,200.00	$11.80	$5,561.80
10 to 20 lbs. per LF	qb@6.67	Ton	$2,590.00	$400.00	$3.94	$2,993.94
20 to 58 lbs. per LF	qb@2.50	Ton	$3,660.00	$150.00	$1.48	$3,811.48

W-Shapes

	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
Floors 1-5						
Beams	W10x19	68.4	$213,408.00	$77,976.00	$17,920.80	$309,304.80
Girders	W16x31	176.7	$436,449.00	$67,146.00	$15,461.25	$519,056.25
Columns	W12x53	112.89	$278,838.30	$42,898.20	$9,877.88	$331,614.38
Angles						
Floors 1-5						
Girder-Beam	11.06	PLF				
CF/angle	0.02	7.46	$19,333.95	$2,985.94	$29.41	$22,349.29
# of Angles (2/beam)	1620					
Girder-Column	11.06	PLF				
CF/angle	0.02	12.16	$31,507.17	$4,865.97	$47.93	$36,421.07
# of Angles (4/girder)	2640					
Bolts, Washers, Nuts						
Beam - Girder (7/8" @ 6/conn.)	324	EA	$14,638.32			$14,638.32
Girder - Column (1" @ 15/conn.)	258	EA	$41,796.00			$41,796.00
Install Bolts, Washers, Nuts	BC@.100	Ea	—	$19,942.02		$19,942.02
					TOTAL	$76,376.34
Column Base Plates	lbs/Plate	127.232	$13,537.48	$2,900.89	$-	$16,438.37
PL 1-3/4 x 16 x 16		LBS				

SI 03-210, Concrete reinforcing steel						
CSI 03-210	Craft@Hrs	Unit	Material	Labor	Equip	Total
Using small tools.						
Grade 50 bars, #3 to #6 bars	p6@12.8	Ton	$1,420.00	$704.00	$4.61	$2,128.61
Grade 50 bars, #7 and up bars	p6@11.4	Ton	$1,320.00	$627.00	$4.10	$1,951.10
Grade 60 bars, #3 to #6 bars	p6@12.8	Ton	$1,450.00	$704.00	$4.61	$2,158.61
Grade 60 bars, #7 and up bars	p6@11.4	Ton	$1,350.00	$627.00	$4.10	$1,981.10
Grade 70 bars, #3 to #6 bars	p6@12.8	Ton	$1,430.00	$704.00	$4.61	$2,138.61
Grade 70 bars, #7 and up bars	p6@11.4	Ton	$1,510.00	$627.00	$4.10	$2,141.10

Footing Reinforcement						
7x7	3.210675		$4,334.41	$2,013.09	$13.16	$6,360.67
5x5	1.77021		$2,389.78	$1,109.92	$7.26	$3,506.96
4x4	0.31239		$421.73	$195.87	$1.28	$618.88

Metal decking, non-cellular, composite, galvanized						
Using a 200-amp trailer mounted welder, and two sets of small tools.						
1-1/2" deep x 16 gauge	qd@.010	SF	$1.94	$0.56	$0.02	$2.52
1-1/2" deep x 18 gauge	qd@.010	SF	$1.53	$0.56	$0.02	$2.11
1-1/2" deep x 20 gauge	qd@.010	SF	$1.22	$0.56	$0.02	$1.80
1-1/2" deep x 22 gauge	qd@.009	SF	$1.03	$0.50	$0.01	$1.54
3" deep x 16 gauge	qd@.013	SF	$2.21	$0.73	$0.02	$2.96
3" deep x 18 gauge	qd@.012	SF	$1.71	$0.67	$0.02	$2.40
3" deep x 20 gauge	qd@.012	SF	$1.37	$0.67	$0.02	$2.06
3" deep x 22 gauge	qd@.011	SF	$1.22	$0.61	$0.02	$1.85

Steel Decking	86400	$190,944.00	$63,072.00	$1,728.00	$255,744.00

STEEL	**TOTALS**	**$1,577,791.01**

Stairs Estimate Spreadsheet

	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
Metal stairs, cast iron tread, pipe handrail, steel stringers, stock units						
Cost per riser, using a 200-amp trailer mounted welder and small tools.						
3'6" (1.07m) wide	gc@.711	Ea	235	40.5	2.18	277.68
4'0" (1.2m) wide	gc@.744	Ea	288	42.4	2.28	332.68
5'0" (1.5m) wide	gc@.781	Ea	327	44.5	2.4	373.9

Metal Stairs 5 Floors 120 4.8" Risers 5' Wide	120	Ea	$39,240.00	$5,340.00	$288.00	$44,868.00

STAIRS	**TOTALS**	**$44,868.00**

Conveyors Estimate Spreadsheet

CSI 14-205, Automatic elevators						
CSI 14-205	Craft@Hrs	Unit	Material	Labor	Equip	Total
Baked enamel shaft doors and plastic laminated trimmed cab, based on shaft of 8 stops and 8 openings, using three sets of small tools.						
3000 lbs. x 300 feet per minute	lv@48.0	Ea	$133,000.00	$2,160.00	$34.10	$135,194.10
3500 lbs. x 300 feet per minute	lv@48.0	Ea	$135,000.00	$2,160.00	$34.10	$137,194.10
4000 lbs. x 300 feet per minute	lv@53.0	Ea	$142,000.00	$2,390.00	$37.60	$144,427.60
5000 lbs. x 300 feet per minute	lv@57.0	Ea	$160,000.00	$2,570.00	$40.50	$162,610.50
3000 lbs. x 400 feet per minute	lv@48.0	Ea	$140,000.00	$2,160.00	$34.10	$142,194.10
3500 lbs. x 400 feet per minute	lv@48.0	Ea	$142,000.00	$2,160.00	$34.10	$144,194.10
4000 lbs. x 400 feet per minute	lv@53.0	Ea	$150,000.00	$2,390.00	$37.60	$152,427.60
5000 lbs. x 400 feet per minute	lv@57.0	Ea	$171,000.00	$2,570.00	$40.50	$173,610.50
3000 lbs. x 600 feet per minute	lv@53.0	Ea	$200,000.00	$2,390.00	$37.60	$202,427.60
3500 lbs. x 600 feet per minute	lv@57.0	Ea	$202,000.00	$2,570.00	$40.50	$204,610.50
4000 lbs. x 600 feet per minute	lv@58.0	Ea	$204,000.00	$2,620.00	$41.20	$206,661.20
5000 lbs. x 600 feet per minute	lv@60.0	Ea	$213,000.00	$2,710.00	$42.60	$215,752.60
3000 lbs. x 800 feet per minute	lv@53.0	Ea	$236,000.00	$2,390.00	$37.60	$238,427.60
3500 lbs. x 800 feet per minute	lv@57.0	Ea	$238,000.00	$2,570.00	$40.50	$240,610.50
4000 lbs. x 800 feet per minute	lv@58.0	Ea	$242,000.00	$2,620.00	$41.20	$244,661.20
5000 lbs. x 800 feet per minute	lv@60.0	Ea	$250,000.00	$2,710.00	$42.60	$252,752.60
Add for each additional 100 feet per minute	---@---	Ea	$13,500.00	--	--	$13,500.00
Add for each additional 500 lbs. capacity	---@---	Ea	$6,750.00	--	--	$6,750.00
Add for each additional opening	---@---	Ea	$13,500.00	--	--	$13,500.00
Add for each additional stop	---@---	Ea	$5,890.00	--	--	$5,890.00
Add for bonderized steel doors, per stop	---@---	Ea	$184.00	--	--	$184.00
Add for colored aluminum doors, per stop	---@---	Ea	$1,040.00	--	--	$1,040.00
Add for stainless steel doors, per stop	---@---	Ea	$736.00	--	--	$736.00
Add for cast bronze doors, per stop	---@---	Ea	$736.00	--	--	$736.00
Add for two speed doors, per stop	---@---	Ea	$1,230.00	--	--	$1,230.00
Add for two speed bi-parting doors, per stop	---@---	Ea	$1,230.00	--	--	$1,230.00
Add for custom plastic laminated doors, per stop	---@---	Ea	$1,990.00	--	--	$1,990.00

3,000lbs @300 fpm	2 Elevators	$266,000.00	$4,320.00	$68.20	$270,388.20

CONVEYOR	**TOTALS**	**$270,388.20**

Scaffolding Estimate Spreadsheet

CSI 04-205, Scaffolding, tubular steel						
	Craft@Hrs	Unit	Material	Labor	Equipment	Total[]
Rented, erected and dismantled. Based on 1 use per month, using small tools.						
Exterior building scaffolding, 1 - 5 story	at@1.62	CSF	54.1	74.1	0.71	128.91

Scaffolding for Brick-Laying (3 months)	504		$81,799.20	$112,039.20	$1,073.52	**$194,911.92**

SCAFFOLDING	**TOTALS**	**$194,911.92**

Brick Estimate Spreadsheet

CSI 04-210, Brick masonry						
CSI 04-210	Craft@Hrs	Unit	Material	Labor	Equip	Total
Standard size brick with running bond, including brick at $.30 each and mortar at $6 per CF, N.I. cost of ties, reinforcing and scaffolding, using small tools.						
Veneer (6.4 per SF)	cd@.205	SF	3	9.34	0.07	12.41
Cavity wall (6.4 per SF)	cd@.244	SF	3	11.1	0.08	14.18
9"solid wall (12.7 per SF)	cd@.326	SF	5.96	14.8	0.11	20.87

Cavity Wall	840 ft	50400	$151,200.00	$559,440.00	$4,032.00	**$714,672.00**

BRICK	**TOTALS**	**$714,672.00**

TOTALS PAGE

Structural Steel		
	Columns	**$331,614.38**
	Girders	**$519,056.25**
	Beams	**$309,304.80**
	Angles (for conn.)	**$58,770.37**
	Bolts/Nuts/Washers	**$76,376.34**
	Steel Decking	**$255,744.00**
	Column Base Plates	**$16,438.37**

Rebar		
	Footing Reinforcement	**$10,486.51**

Concrete		
	Footings	**$96,349.63**
	Slabs	**$158,954.67**
Formwork		
	Footings	**$61,662.98**
	Slabs	**$18,201.60**
Curing		
	Footings	**$404.60**
	Slabs	**$10,157.40**

Metal Stairs		
	4 Sets of Stairs	**$44,868.00**

Grading		
	General/Structural	**$8,592.60**

Conveyors		
	2 Conveyors - 5 Floors	**$270,388.20**

Brick		
	Building Exterior	**$714,672.00**
	Scaffolding (3 Months)	**$194,911.92**

TOTAL	**$3,156,954.61**

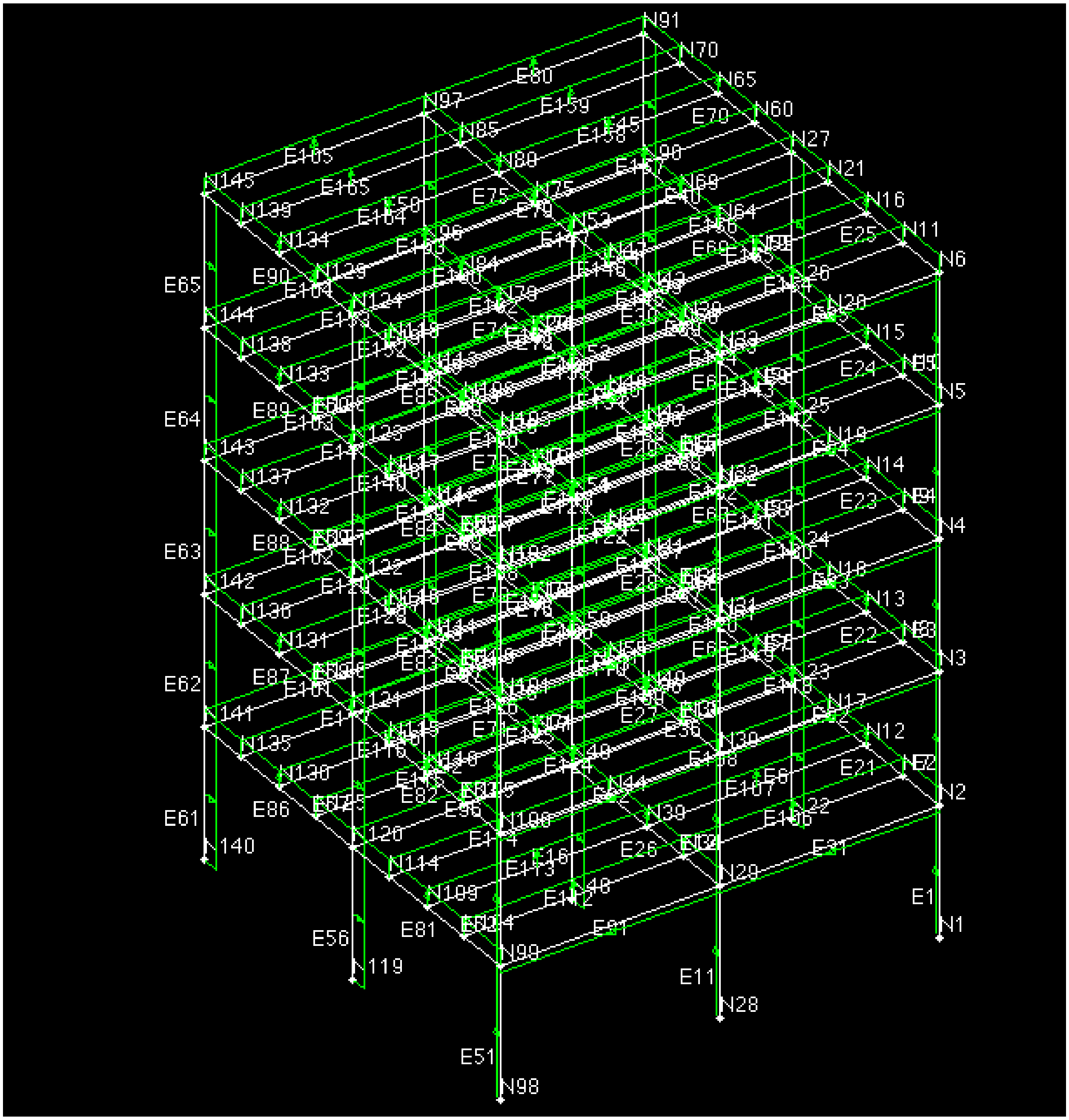
TOTALS PAGE

Structural Steel		
	Columns	**$ 331,614.38**
	Girders	**$ 519,056.25**
	Beams	**$ 309,304.80**
	Angles (for conn.)	**$ 58,770.37**
	Bolts/Nuts/Washers	**$ 76,376.34**
	Steel Decking	**$ 255,744.00**
	Column Base Plates	**$ 16,438.37**
Rebar		
	Footing Reinforcement	**$ 10,486.51**
Concrete		
	Footings	**$ 96,349.63**
	Slabs	**$ 158,954.67**
Formwork		
	Footings	**$ 61,662.98**
	Slabs	**$ 18,201.60**
Curing		
	Footings	**$ 404.60**
	Slabs	**$ 10,157.40**
Metal Stairs		
	4 Sets of Stairs	**$ 44,868.00**
Grading		
	General/Structural	**$ 8,592.60**
Conveyors		
	2 Conveyors - 5 Floors	**$ 270,388.20**
Brick		
	Building Exterior	**$ 714,672.00**
	Scaffolding (3 Months)	**$ 194,911.92**

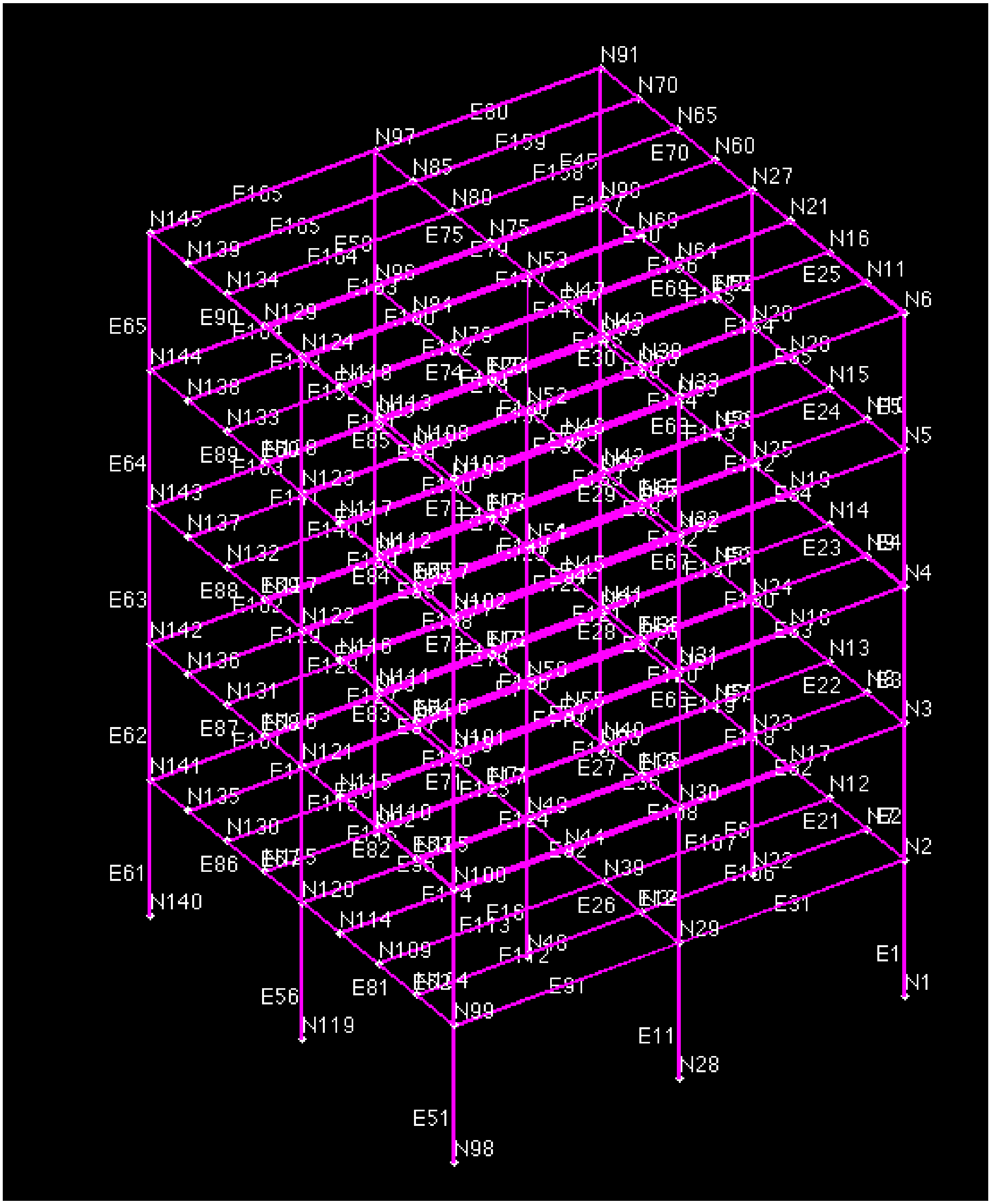
TOTAL	**$ 3,156,954.61**

Appendix F - Structural Software Outputs

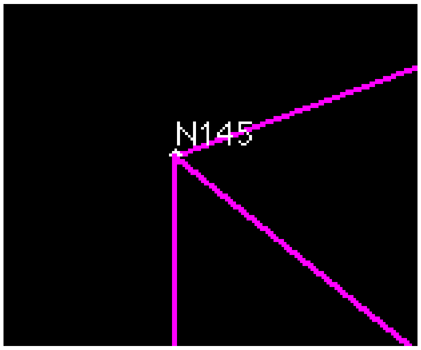
MASTAN FRAME



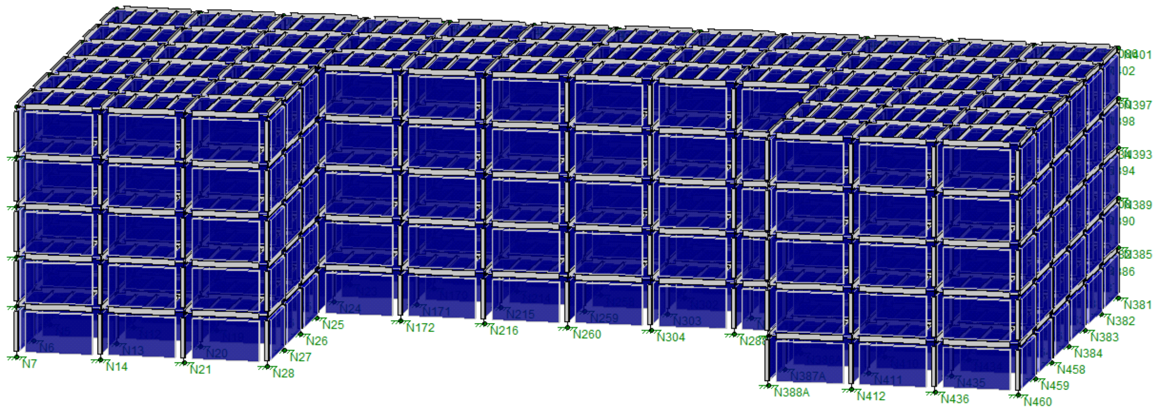
MASTAN FRAME DEFLECTION DIAGRAM



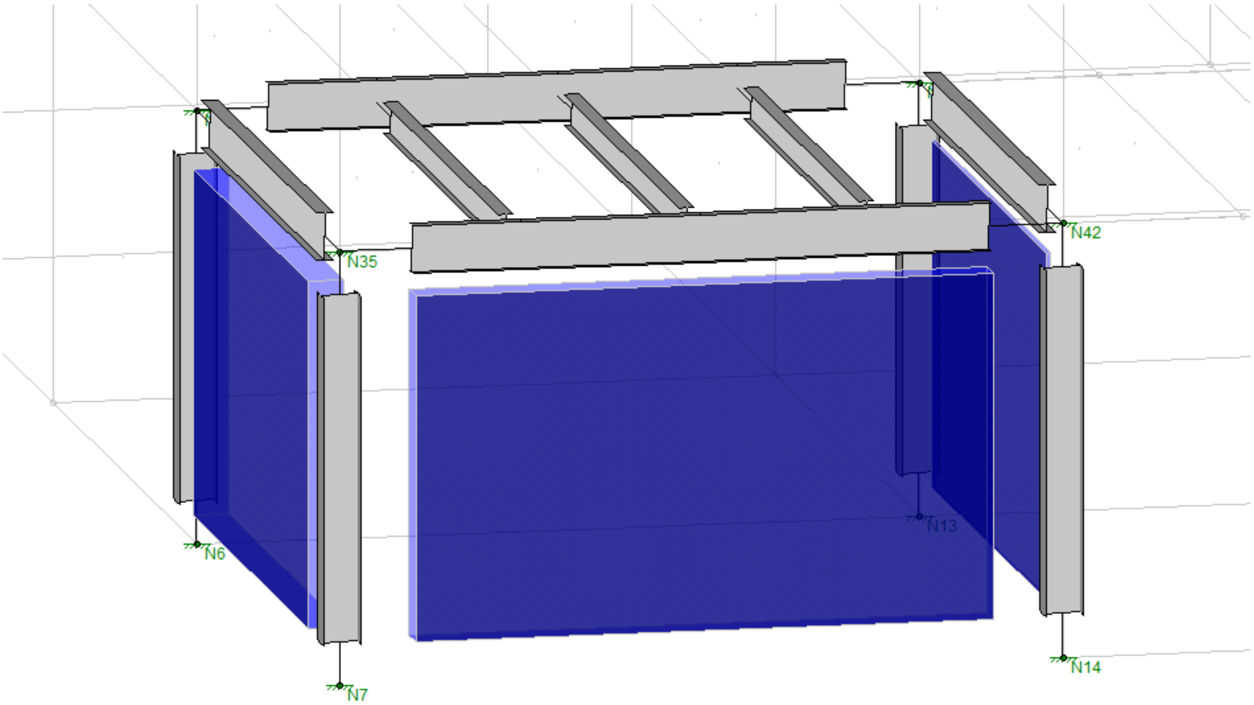
MASTAN FRAME DEFLECTION CLOSE – UP



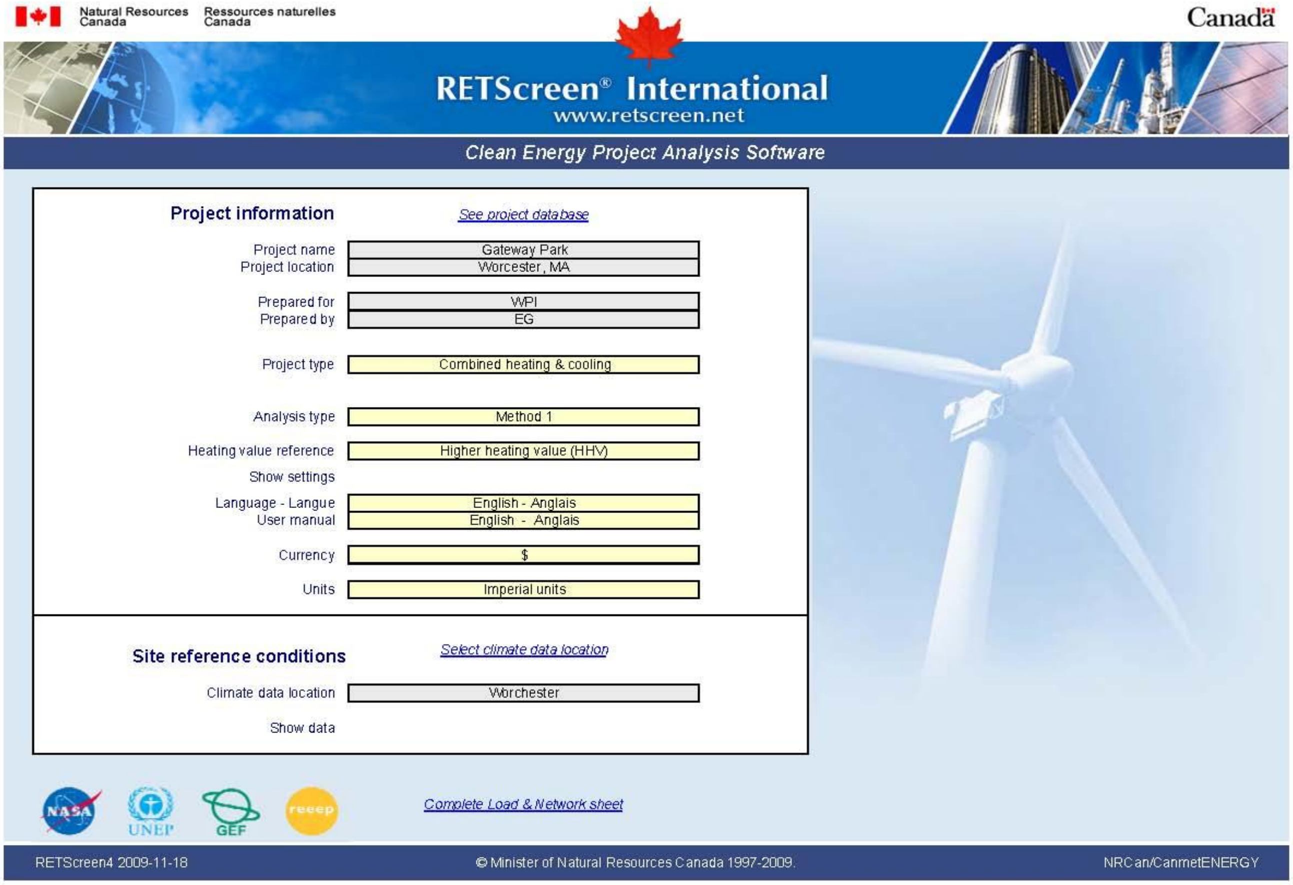
RISA ELEMENTS STRUCTURE



RISA CLOSE-UP



Appendix G - RETScreen Software Output



RETScreen Load & Network Design - Combined heating & cooling project

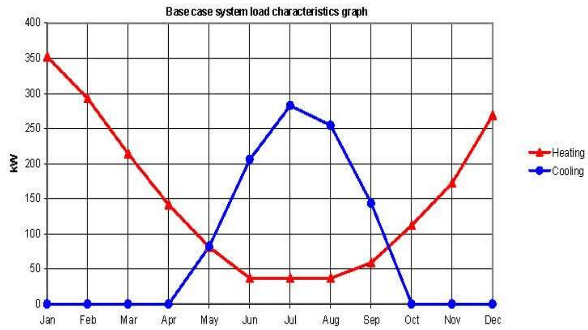
Heating project	Unit	
Base case heating system	Single building - space heating	
Heated floor area for building	ft²	100,000
Fuel type		Electricity
Seasonal efficiency	%	20%
Heating load calculation		
Heating load for building	W/m²	50.0
Domestic hot water heating base demand	%	30%
Total heating	million Btu	4,625
Total peak heating load	million Btu/h	1.6
Fuel consumption - annual	MWh	6,778
Fuel rate	$/kWh	0.080
Fuel cost		$ 542,207
Proposed case energy efficiency measures		
End-use energy efficiency measures	%	0%
Net peak heating load	million Btu/h	1.6
Net heating	million Btu	4,625

Cooling project	Unit	
Base case cooling system	Single building - space cooling	
Cooled floor area for building	ft²	100,000
Fuel type		Electricity
Coefficient of performance - seasonal		3.20
Cooling load calculation		
Cooling load for building	W/m²	50.0
Non-weather dependant cooling	%	0%
Total cooling	RTh	217,887
Total peak cooling load	RT	132.1
Fuel consumption - annual	MWh	239
Fuel rate	$/kWh	0.080
Fuel cost		$ 19,157
Proposed case energy efficiency measures		
End-use energy efficiency measures	%	0%
Net peak cooling load	RT	132.1
Net cooling	RTh	217,887

RETScreen Load & Network Design - Combined heating & cooling project

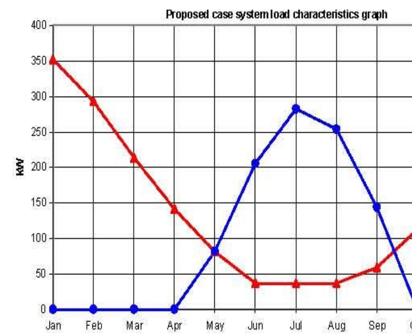
Base case load characteristics

Month	Cooling average load kW	Heating average load kW
January	0	352
February	0	293
March	0	214
April	0	141
May	82	81
June	205	37
July	282	37
August	254	37
September	144	59
October	0	112
November	0	172
December	0	269
Peak load - annual	465	465



Proposed case load characteristics

Month	Cooling system load kW	Heating net average load kW
January	0	352
February	0	293
March	0	214
April	0	141
May	82	81
June	205	37
July	282	37
August	254	37
September	144	59
October	0	112
November	0	172
December	0	269
Peak load - annual	465	465



Proposed case load and energy		Heating
System peak load	million Btu/h	2
System energy	million Btu	4,625

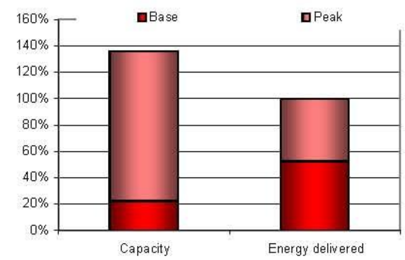
RETScreen Energy Model - Combined heating & cooling project — Show alternative units

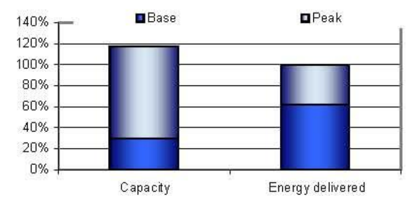
Proposed case cooling system				Incremental initial costs	
Base load cooling system					
Technology		Heat pump			*Show figure*
Fuel type		Electricity			
Fuel rate	$/MWh	80.000			
Capacity	kW	137.0	29.5%		*See product database*
Coefficient of performance - seasonal		4.00			
Manufacturer		Bard			
Model		GSVS301-A	5 unit(s)		
Cooling delivered	RTh	134,855	61.9%		
Peak load cooling system					
Technology		Compressor			
Fuel type		Electricity			
Fuel rate	$/MWh	80.000			
Suggested capacity	RT	93.1			
Capacity	RT	116.0	87.8%		*See product database*
Coefficient of performance - seasonal		3.00			
Manufacturer		York International			
Model		YCAL-0124EB	1 unit(s)		
Cooling delivered	RTh	83,032	38.1%		

Proposed case heating system				Incremental initial costs	
System selection		Base load system			
Base load heating system					
Technology		Heat pump			
Fuel selection method		Single fuel			
Fuel type		Electricity			
Fuel rate	$/MWh	80.000			
Heat pump					
Capacity	kW	102.0	22.0%	$ -	*See product database*
Heating delivered	million Btu	2,409	52.1%		
Manufacturer		Bard			
Model		GSVS301-A	5 unit(s)		
Seasonal efficiency	%	20%			
Fuel required	million Btu/h	1.7			

Proposed case system characteristics	Unit	Estimate	%	Incremental initial costs
Heating				
Base load heating system				
Technology		Heat pump		
Capacity	million Btu/h	0.3	22.0%	
Heating delivered	million Btu	2,409	52.1%	
Peak load heating system				
Technology		Boiler		
Fuel type		Natural gas - m³		
Fuel rate	$/m³	0.250		
Suggested capacity	million Btu/h	1.2		
Capacity	kW	530	114.1%	
Heating delivered	million Btu	2,216.6	47.9%	
Manufacturer		A.O. Smith	*See PDB*	
Model		DW-1810	1 unit(s)	
Seasonal efficiency	%			
Back-up heating system (optional				
Technology				
Capacity	kW			
Cooling				
Base load cooling system				
Technology		Heat pump		
Fuel type		Electricity		
Capacity	RT	39	29.5%	
Cooling delivered	RTh	134,855	61.9%	
Peak load cooling system				
Technology		Compressor		
Fuel type		Electricity		
Capacity	RT	116	87.8%	
Cooling delivered	RTh	83,032	38.1%	
Back-up cooling system (optional				
Technology				
Capacity	kW			

System design graph





Proposed case system summary	Fuel type	Fuel consumption - unit	Fuel consumption	Capacity (kW)	Energy delivered (MWh)
Heating					
Base load	Electricity	MWh	3,529	102	706
Peak load	Natural gas	m³	0	530	650
			Total	632	1,356
Cooling					
Base load	Electricity	MWh	119	137	474
Peak load	Electricity	MWh	97	408	292
			Total	545	766

Emission Analysis

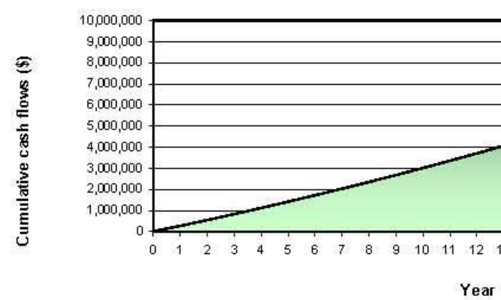
Base case electricity system (Baseline)		GHG emission factor (excl. T&D)	T&D losses	GHG emission factor
Country - region	Fuel type	tCO2/MWh	%	tCO2/MWh
United States of America	All types	0.558		0.558

GHG emission					
Base case	tCO2	3,913.4			
Proposed case	tCO2	2,088.8			
Gross annual GHG emission reduction	tCO2	1,824.6			
GHG credits transaction fee	%				
Net annual GHG emission reduction	tCO2	1,824.6	is equivalent to	334	Cars & light trucks not used
GHG reduction income					
GHG reduction credit rate	$/tCO2				

Financial Analysis

Financial parameters			
Inflation rate	%	2.5%	
Project life	yr	25	
Debt ratio	%	0%	
Initial costs			
Heating system	$	0	
Cooling system	$	0	
Other	$		
Total initial costs	$	0	
Incentives and grants	$		0.0%
Annual costs and debt payments			
O&M (savings) costs	$		
Fuel cost - proposed case	$	299,628	
	$		
Total annual costs	$	299,628	
Annual savings and income			
Fuel cost - base case	$	561,364	
	$		
Total annual savings and income	$	561,364	
Financial viability			
Pre-tax IRR - assets	%	positive	
Simple payback	yr	0.0	
Equity payback	yr	immediate	

Cumulative cash



RETScreen Tools - Combined heating & cooling project

Settings

☐ As fired fuel	☑ Ground heat exchanger	☐ User-defined fuel
☐ Biogas	☐ Heat rate	☐ User-defined fuel
☐ Building envelope properties	☐ Heating value & fuel rate	☐ Water & steam
☐ Appliances & equipment	☐ Hydro formula costing method	☐ Water pumping
☐ Electricity rate - monthly	☐ Landfill gas	☐ Window properties
☐ Electricity rate - time of use	☐ Unit conversion	☐ Custom 1
☐ GHG equivalence	☐ User-defined fuel	☐ Custom 2

Ground heat exchanger

Heat pump	Unit	Heating	Cooling	
Capacity	million Btu/h	0.3	0.5	
Average load	million Btu/h	1.0	132.0	
Manufacturer		Bard		
Model		GSVS301-A		5 unit(s)
Efficiency	High			
Coefficient of performance - design		4.0	5.5	

Site conditions	Unit	Project location	Climate data location
Soil type		Light soil - damp	
Earth temperature	°C	9.2	9.2
Earth temperature amplitude	°C	21.4	21.4
Measured at	m	0.0	0.0

Ground heat exchanger			
Type		Vertical closed-loop	
Design criteria		Heating	
Land area	m²	9,500	2,784
Layout		Compact	
Borehole length	m	26,581	

Specific project costs		Quantity	Unit cost $	Amount $
Circulating pump	kW	2.4		$ -
Circulating fluid	m³	4.70		$ -
Drilling & grouting	m	26,581		$ -
Loop pipe	m	53,162		$ -
Fittings & valves	million Btu/h	0.5		$ -
Total				$ -